[illegible] Strand

HALO SEEN AT PITEÅ IN SWEDEN

Oct$^{r}$ 4 1839.

# A COMPLETE COURSE

OF

# METEOROLOGY,

Ludwig Friedrich

By E. F. KAEMTZ,

PROFESSOR OF PHYSICS AT THE UNIVERSITY OF HALLE.

WITH

NOTES BY CH. MARTINS,

SUPERNUMERARY PROFESSOR OF NATURAL HISTORY TO THE FACULTY OF MEDICINE, PARIS;

AND AN APPENDIX, CONTAINING THE
GRAPHIC REPRESENTATION OF THE NUMERICAL TABLES,
By L. LALANNE, Civil Engineer.

Translated, with Notes and Additions,

BY

C. V. WALKER,

OF THE ELECTRICAL SOCIETY; EDITOR OF THE "ELECTRICAL MAGAZINE," &c. &c.

ILLUSTRATED WITH FIFTEEN PLATES.

---

LONDON:
HIPPOLYTE BAILLIÈRE, PUBLISHER, 219 REGENT ST.
FOREIGN BOOKSELLER TO THE ROYAL COLLEGE OF SURGEONS.
PARIS: J. B. BAILLIÈRE, LIBRAIRE DE L'ACADÉMIE DE MÉDECINE.
LEIPSIG: T. O. WEIGEL.
1845.

LONDON:
PRINTED BY MOYES AND BARCLAY, CASTLE STREET,
LEICESTER SQUARE.

# TABLE OF CONTENTS.

## I.

### CONSIDERATIONS ON THE RANGE OF TEMPERATURE IN GENERAL.

## II.

### ON WINDS.

## III.

## ON AQUEOUS METEORS.

## IV.

## DISTRIBUTION OF TEMPERATURE ON THE SURFACE OF THE GLOBE.

## V.

## WEIGHT OF THE ATMOSPHERE.

## VI.

## ELECTRIC PHENOMENA OF THE ATMOSPHERE.

## VII.

### OPTICAL PHENOMENA OF THE ATMOSPHERE.

## VIII.

### AURORÆ BOREALES.

## IX.

### PROBLEMATIC PHENOMENA.

### NOTES BY M. CH. MARTINS.

# APPENDIX.

## I.

### ON THE PRINCIPLES EMPLOYED FOR THE CONSTRUCTION OF THE FIGURES OF THE APPENDIX.

## II.

### EXPLANATION OF THE FIGURES OF THE APPENDIX.

(*For references to each figure, vide List of the Numerical Tables, on next page.*)

---

## APPENDIX—No. II.

### NOTES BY CHARLES V. WALKER.

# LIST OF THE NUMERICAL TABLES.

# PREFACE

OF

# THE TRANSLATOR.

THE germ of *meteorology* is, as it were, innate in the mind of an Englishman; the weather is proverbially his first thought after every salutation; it comes to him intuitively; and is so a part of him that we can scarcely imagine him to meet his friend without giving utterance to the usual truisms of "fine day!" "rainy weather!" "very cold!" And who of us does not pride himself in the possession of a few weather-axioms, by which we think to foresee the coming changes? Some of these axioms are sound; others are essentially true, but are often misapplied; while a large portion are false. That the latter should be a large class is obvious; because the casual observer is too apt to draw general rules from particular cases, without taking into account, or, perhaps, without being able to take into account, all the accidental circumstances that may be present. The only means we possess of eliminating these sources of error, and arriving at the general laws which govern atmospheric phenomena, is a course of faithful and unwearied observation, followed by sound and accurate deduction. The scientific world have, within the last few years, been awakened to the importance of this course; and very efficient means are in progress, and very plain instructions have been published, toward the attainment of the object in view. In the meantime, we must be reminded that many stumbling-stones have been already removed; and that the path of meteorology has been trodden very effectually to a considerable extent. There does not exist, however, in the English language any complete treatise, from which the ardent student can gather a faithful account of what has been done, and learn what remains yet to be done. It is hoped that the present translation will supply this blank in our scientific literature. M. KAEMTZ, the author of the treatise, was, for several years, professor of this science at the university of Halle, and is now at the university of Dorpat; added to which, he is a skilful and indefatigable observer: he has, for instance, almost unassisted, made at Halle a barometric, thermometric, and psychrometric series of more than ten consecutive years; he has studied atmospheric changes in Germany, on the Rigi, on the Faulhorn, at Deep on the coasts of the Baltic, and at Apenrade in Denmark; and low temperatures and auroræ at Dorpat; to all of which reference will be made in the course of the work. He also published between the years 1831 and 1836 a learned *Treatise on Meteorology*, full of original research, in three volumes 8vo., with the title *Lehrbuch der Meteorologie;* and he afterwards published the *Course*, of which we now present a translation.

Soon after the appearance of the original German edition, a French translation with notes was published (1843) by M. MARTINS, a philosopher, well acquainted with practical meteorology, having taken the observations at Norway and Spitzbergen, in 1838 and 1839, in the voyage of *La Recherche;* as also observations at Paris, on the Faulhorn, and elsewhere. In August of the present year (1844), he reached the summit of Mont Blanc, in conjunction with his friend M. BRAVAIS: to the latter gentleman we are indebted for several notes in the present volume, he having communicated all the results that he had time to reduce from the observations of the Commission of the North, and from those made on the Faulhorn. His notes are indicated throughout the work by the letter B; those of M. MARTINS, by the letter M.

These notes, which are extracted from the most authentic sources, bring up meteorological research to the period of publication, and are of themselves a sufficient explanation of our reason for preferring to present the English reader with a translation of the French rather than one of the original edition. We are thus enabled to furnish him with a vast amount of highly important information, which the original volume does not contain. But we may add to this, that M. MARTINS' translation is enriched by a valuable Appendix, from the hands of M. LALANNE, to which we would specially direct attention, under the conviction that when properly studied, and duly reduced to practice, it will be found a very important auxiliary to the study of the science. The following extract from M. MARTINS' appendix explains the nature of this appendix, and also describes the alteration he has made in the volume:—

"I have been no less powerfully assisted by my friend M. LÉON LALANNE, Civil Engineer. He has given a graphic representation of forty-two numerical tables out of a hundred and thirteen, according to the common system of two rectangular co-ordinates, and according to another system of three co-ordinates, the use of which he was the first to generalise, and the principles of which are explained in the Appendix. These graphic representations are an immense service rendered to meteorology; for they possess the threefold advantage,—of setting before the eye numerical results,—of representing the laws of which they are the expression,—and of shewing, by the irregularity of certain curves, which are they that do not represent natural laws, and that demand a greater number of observations.

"M. LALANNE has, moreover, superintended the long calculations, which were necessary to transform the tables into decimal measures. All these calculations having been made twice, and carefully verified, their accuracy may be depended upon. Thus, then, if this translation possesses any advantage over the original, it is chiefly to my two friends MM. BRAVAIS and LALANNE that I transfer the honour; and I am happy, in this place, to express to them my gratitude for their active co-operation.

"It remains for me to point out the substitutions which I thought it necessary to make in the course of the work, and in the plates which accompany it. The text of the author has been respected throughout; I have only replaced some of the numerical tables by others which were more complete or exact.

"The table of *minima* of temperature observed at different places (p. 168) has been increased by adding the cities of Charlestown, Athens, Washington, Montpellier, Nice, Pisa, Lucca, Florence, Camajore, Bologna, Bangor (U. S.), Turin, Milan, Montreal, Paris, and Bosekop. Into that of *maxima* of temperature (p. 169), I have inserted Catania, Palermo, Naples, Pavia, Pisa, Nice, Cagliari, Lucca, Bologna, Turin, Verona, Milan, and Paris.

"The table of the mean temperatures of a great number of towns given by M. KAEMTZ, contained 141 places; I have substituted for it (p. 177) that of M. MAHLMANN, published by M. DE HUMBOLDT, in the third volume of his work on Central Asia, entitled, *Recherches sur les Chaines de Montagnes et la Climatologie comparée.* This table contains the mean and season temperature, as well as the temperature of the hottest and the coldest months for 305 places in the two hemispheres. I have also supplied the place (p. 228) of the little table of the limit of perpetual snows, at different latitudes, which is given in the German book, by that which M. DE HUMBOLDT has given in the same work.

"M. KAEMTZ's table for the reduction of the barometer to zero extended only from 540 to 778 millimetres; for this I have substituted M. DELCROS', which extends from 400 to 800 millimetres (p. 241), in order that it may be useful to those who apply themselves to the determination of heights by the barometer. At page 243, I have inserted a small paragraph on the correction of the barometer due to capillary action; and I have added the table constructed by M. DELCROS for making this correction, which is of such importance when we desire to know exactly the weight of the atmosphere. The chapter which treats on the height of the barometer at the sea-shore, has been completed (p. 277) by a table, in which MM. SCHOUW and POGGENDORFF have given this height for a great number of places. The paragraph on the influence of the winds on the differences of level calculated by the barometer, has been replaced by that which M. KAEMTZ gave in his preface, as presenting results more conformable to truth. These are the substitutions, which I have taken the liberty of making in the text; they are a necessary consequence of the progress of meteorology. In imitation of the German book, I have printed the names of men in different characters from those of the context. At the end of this book will be found an alphabetical list of these names, which will facilitate the search after facts or theories, of which the most faithful memoir has often retained nothing beyond the name of the author.

" M. LALANNE having graphically represented the greater part of the tables, I have substituted for Plate I. of the German text that of the frontispiece, which represents a halo that I observed in Sweden, with M. BRAVAIS. It appeared to us worthy of being represented; because it presents in one all the circles and arcs which have most frequently been observed, and which theory explains. At page 430 will be found a note, in which this figure is compared with the projection of a complete halo given by M. KAEMTZ, Pl. V. fig. 3.

"Plate II. of the German book was partly occupied by curves; I have replaced them by a general figure, and by the details of FORTIN's barometer as modified by M. DELCROS,—a barometer equally suited to meteorological observations and to levelling.

"Plate III. representing the clouds, left much to be desired in point of execution; I have had it entirely done over again.

"Plates IV. and V. have been faithfully copied.

"Plate VI. of the original work represents the isothermal and the isogeothermal lines of the northern hemisphere, laid down on a MERCATOR's projection. I have preferred giving the isothermal lines only, and on a polar projection, which has the advantage of shewing how the curves become re-entering in the high latitudes, and form the two frigid poles."

In the English translation I have included the additions alluded to by M. MARTINS, in the above extract, and have added a second Appendix of Notes, in which I have endeavoured, as far as practicable, to illustrate certain passages in the text; and to describe some of the new and important registering instruments, which recent necessities have called into existence, and modern science has enabled us to construct: among these, WHEATSTONE's *Electro-Meteorological Register* holds a first rank. I have also given an account of the observatories of Kew and Greenwich; and have described the instruments employed, illustrating the description by printing a fortnight's observations made at Kew. Plates VII. and VIII. of the beautiful auroræ seen by M. LOTTIN; Plate IX. of OSLER's anemometer; and Plates X. and XI. of Mr. WHEATSTONE's Register, have been also added to this edition.

CHARLES V. WALKER.

*London, Nov.* 1844.

# INTRODUCTION.

Meteorology is that part of natural philosophy which treats on the phenomena and the modifications of the atmosphere, in order to analyse them and seek their explanation. Plunged at the bottom of the atmospheric ocean in which the earth is enveloped, we are witnesses of the changes which are incessantly going on in it. Serene or cloudy, cold or hot, calm or agitated, the atmosphere exercises a powerful influence over all organised beings. There does not exist a man who has not asked himself what the cause is of these continual variations. It is not simply the desire of knowledge which urges him to this inquiry; but these questions are often of the highest importance to the husbandman, the sailor, the artisan, and the physician. Our physical and moral well-being depends, in a great measure, on the condition of the atmosphere. When the sky has remained for some weeks covered with dark clouds, the spirits are affected, but the mind becomes serene as soon as the sun appears again: so also, during changeable, damp, and cold weather, the number of invalids is always greater than during fine weather.

From the very remotest antiquity men have been occupied in investigating the causes of these variations. This study even preceded that of natural philosophy, properly so called, because it embraces the most striking phenomena of the inorganic world. In the works of the Greeks and Romans, we find a multitude of observations and laws carefully treasured up. Among all nations, even the least civilised, travellers have met with some notions of Meteorology. It would seem, then, that this science ought to be one among the most advanced, because, for thousands of years, it has been the object of the labours of so many intelligences. Unfortunately it is not so; and a few lines will suffice to give the reason.

The number of observations on the modifications of the atmosphere is doubtless considerable; but they are, at the same time, *observations* in the most restricted sense of that word. We observe the phenomenon presented to us, but we cannot modify and vary it at pleasure; we cannot even reproduce it at will. In a word, we cannot have recourse to *experiment*. Our means and our powers are much too limited to give us the power of producing the least changes in the atmosphere. We are hence compelled to register facts; and, as **W. Herschell** has very well observed, we resemble a man who hears now and then a few fragments of a long history related at distant intervals by a prosy and unmethodical narrator. In recalling to mind what has gone before, he may occasionally connect past with present events; but a host of circumstances omitted or forgotten, and the want of connexion, prevent his obtaining possession of the entire story. Were we allowed to interrupt the narrator, and ask him to explain the apparent contradictions, or to clear up any doubts on obscure points, then might we hope to arrive at a general view. The questions that we would address to nature are the very experiments of which we are deprived in the science of atmospheric modifications.

When reduced to observation, Meteorology cannot possibly advance at a pace equal to that of the other branches of natural philosophy. To attain the power of establishing laws, we are compelled to register a long series of facts similar in appearance, that we may draw from them some general results. These being once obtained, we pass on to the study of isolated variations. We know, for example, that the barometer is ever oscillating, and that it never ascends without its afterwards descending again. We notice a certain connexion between the state of the atmosphere and these variations in atmospheric pressure. In like manner, as the barometer is always in motion, so also the temperature does not rise uniformly from the coldest degree of winter to the hottest moment of summer. Thus cold and hot days, in so far as the season is concerned, interrupt this regular march. Knowing that the weight, and consequently the equilibrium, of the different atmospheric strata, changes with the temperature, we may inquire whether barometric oscillations may not be connected with these changes of temperature. In order to determine whether this relation does exist, the thermometer and barometer are observed for a long period at the same fixed times. We examine how often and how much the two have varied in the space of twenty-four hours: then, grouping separately the observations in which the barometer had ascended or descended, and comparing them with the corresponding thermometric variations, it is found that there is a natural connexion between the two phenomena. When the barometer rises to a certain degree, the thermometer falls proportionately; when the barometer falls, the thermometer rises.

In order to obtain a knowledge of the laws which atmospheric phenomena obey, we must not only possess a large number of observations, but it is further necessary that we should combine them in such a manner that general laws may be separated from all accidental disturbances. It is the latter which excite our curiosity in the greater degree; but they are also very difficult of explanation. Whoever has made observations for any period with meteorological instruments, and has endeavoured to deduce from them any general laws, cannot have failed to find that the result to which he has arrived is in formal contradiction to the best established laws. Thus, in a general way, the thermometer falls when the barometer rises; but how very often is the contrary observed! How are these anomalies to be explained? Must we say that Nature is capricious? Assuredly not; for these anomalies are due to the action of the very causes which give rise to the other phenomena. An isolated observer, however much he may be supposed to be endowed with perseverance and sagacity, could not possibly arrive at a plausible explanation. It is solely by comparing his observations with those that have been made at other points that a satisfactory result can be obtained.

As the meteorologist is obliged to compare observations made at very distant points, we can anticipate how many obstacles are opposed to his researches. Oftentimes these observations do not exist; or, if they have been made, they generally embrace only Europe. Yet, in order to explain certain general disturbances, we should possess observations at a great number of stations in the four quarters of the world, that we may see what the causes are by which these disturbances have been produced. No phenomenon is isolated: as will be seen in the course of this work, it is always connected with those of the entire atmosphere. But what man could flatter himself that he could collect all these observations? and, if he possessed them, would he have time to combine them so as to extract all the results which they contain? Societies, supported by governments, can alone undertake this task; and the very existence of Meteorology depends on association.

Whatever difficulties may have hitherto opposed the developement of this science, it has yet made very notable progress since the end of the last century; and it now advances with a rapid and certain pace. Future ages will erect the edifice, of which we have laid the foundations; and we may already say, with certainty, that the general plan is simple, and that its apparent complexity only arises from the close connexion of the parts with each other,—a connexion so intimate, that it is difficult to circumscribe the limits of the phenomena. These difficulties being once removed, Meteorology satisfies the intellect and excites the curiosity. The object which we have proposed in this work is to present the sum and substance of the best-established laws and facts. Fortunate shall we be, if we can gain some recruits to a science that can only advance by the co-operation of a large number of zealous and persevering observers.

# I.

# CONSIDERATIONS

## ON THE

# RANGE OF TEMPERATURE IN GENERAL.

THE study of Meteorology, however superficial it may be supposed, immediately leads us to recognise that heat plays a very important part in the atmosphere, as in all the rest of nature. As soon as the importance of this agent had been recognised, the science made rapid progress. The ancient philosophers were not ignorant of its influence, but they knew not how to connect it with the entire range of the grand atmospheric phenomena.

The intimate nature of heat is beyond our reach. We know not what modifications occur in bodies whose temperature is raised; however, we have been able to declare, from our experiments, the laws according to which it is propagated and distributed. I will unfold the most important of them in the course of this work, and we shall see the facility with which they explain the great majority of atmospheric disturbances.

**OF THE THERMOMETER.**—Among the instruments by means of which changes of temperature may be studied, the thermometer occupies the first rank. Invented about the end of the sixteenth, or at the beginning of the seventeenth century, by **Galileo,** according to some, or by **Drebbel,** according to others, it is still one of the most important instruments of natural philosophy. It shews that all bodies, on being heated, increase in volume, in a different proportion for each. Scarcely visible in solid bodies, this dilatation is notable in liquids, and considerable in aëriform fluids.

The construction of the thermometer is generally known. A tube of very small diameter is terminated, at one of its extremities, by a spherical or cylindrical reservoir; they both contain a liquid or a gas, generally mercury. It is essential that this liquid be not mixed with air. The condition is fulfilled by boiling it strongly in the thermometer; the air being thus driven out, the extremity of the tube is closed. When the apparatus is cold, the mercurial column possesses a certain length, which varies as the cistern is heated or cooled. In order to obtain the value of these variations, a scale is fixed along the tube, or, which is still better, divisions are engraved on the glass. But, in order that each observer may trace these divisions himself, it was necessary that two fixed points should be found, which should be given by two invariable temperatures. After many attempts it was discovered, on plunging a thermometer repeatedly into pounded ice or melting snow, that the mercurial column stopped sensibly at the same point,* whatever the changes of temperature were to which it had been exposed in the interval between the experiments. The same is the case if it is exposed to the vapour of boiling water, the atmospheric pressure, indicated by the barometer, remaining the same. The two points are marked on the scale, the former by 0, and the latter by 100, in the centigrade, or **Celsius's** thermometer, and by 80 in **Reaumur's**. The interval between them is divided into 100, or into 80 equal parts or *degrees*, according as one or other scale is adopted. If the stem passes these two points, the graduation is prolonged beyond the boiling point, following the natural order of the numbers, 101, 102, 103, 104, &c. Below the zero, they are numbered 1, 2, 3, 4, &c.; but these are termed *negative* degrees, and are always preceded by the sign (—) *minus*, whilst those above the 0 are termed

---

* When thermometers are graduated immediately after their construction, as is the general practice, or when these instruments, although graduated several months after they have been constructed, are subjected to great variations of temperature, the zero is liable to be displaced; that is, the column of the instrument, when plunged anew into melting snow, no longer rests at the point marked zero, where it rested at the time when it was graduated. This correction must, therefore, be known; for it would give rise to a constant error in every degree of the thermometer. The correction is generally negative for temperatures above that of melting ice, and positive for the others; because the column of the thermometer, when plunged into melting snow, generally places itself higher than at the period of graduation. This correction being liable to change with time, careful meteorologists should annually verify the zero of their thermometers.—M.

*positive*, and are either not preceded by any sign, or else they have the sign (+) *plus*. As mathematicians never place the sign + before positive quantities, we think that meteorologists ought to imitate them, in order to avoid a wearisome confusion of signs, when they abstract the contents from extensive meteorological registers.

Throughout this work all the temperatures are marked in the centesimal degrees, or those of **Celsius**. However, the conversion of one scale into the other is a very easy operation. Indeed, 80° R. being equal to 100° of the centesimal scale, or 4° R. an equivalent to 5° C. (designating the degrees of **Reaumur's** scale by the initial R., and those of the centesimal, or **Celsius**, by the initial C.), the indications of **Reaumur's** thermometer are multiplied by 5 and divided by 4, to convert them into centesimal degrees. To perform the converse operation, we multiply by 4 and divide by 5. Thus, then :—

$$14^\circ \text{ R.} = \frac{14 \times 5}{4} = 17^\circ, 5 \text{ C.; and } 14^\circ \text{ C.} = \frac{14 \times 4}{5} = 11^\circ, 5 \text{ R.}$$

There exist a great many other thermometric scales. I shall confine myself to mentioning **Fahrenheit's**, which is still in use among English observers. In this scale the melting point of ice corresponds to the 32d division, and the boiling point to the 212th; and the interval is divided into $212 - 32 = 180$ parts. Below the 32 the reckoning is carried down to zero, below zero the degrees are negative. In order to reduce the indications of this thermometer to those of the centesimal scale, the 32 must first be deducted, so that the zeros may correspond. Then, since 180° F. are equivalent to 100° C., or 9° F. = 5° C., the remainder must be multiplied by 5, and this product divided by 9. Thus :—

$$50^\circ \text{ F.} = (50) - 32) \times \tfrac{5}{9} = 10^\circ \text{ C.}$$

The same formula is employed if the degrees on **Fahrenheit's** thermometer are below 32. Let them, for example, be

$$13^\circ \text{ F.; then } 13^\circ - 32^\circ = -19^\circ \text{; and}$$
$$13^\circ \text{ F.} = -19^\circ \times \tfrac{5}{9} = -10^\circ, 55 \text{ C.}$$

The same process is adopted for converting the negative degrees of **Fahrenheit**. On subtracting, for example, 32° from − 16° F., the result is − 48; and

$$-16^\circ \text{ F.} = -48^\circ \times \tfrac{5}{9} = -26^\circ, 67 \text{ C.}^{1}$$

---

[1] Vide Note *a*, Appendix, No. II.

The thermometers that are employed in meteorological observations are generally those made with mercury; for this metal does not freeze except at very low temperatures, such as are never observed in our climates. But, for a wintering in high latitudes, spirit thermometers must be provided. If the freezing and the boiling points are determined on such an instrument, and the interval is divided into 80 or 100 equal parts, its variation will not be parallel to those of a mercurial thermometer; this is due to the unequal dilatation of the two liquids. Therefore, in comparing a spirit with a mercurial thermometer, a correction must be made through the whole extent of the scale.

It is often essential to know the highest and the lowest degrees marked by the thermometer, in a certain determined interval of time. To effect this we have recourse to *thermometrographs*. Of the different arrangements that have been given, the following is the simplest, and perhaps the best. If a mercurial thermometer is placed horizontally, and a movable index of iron wire or of glass is in contact with the extremity of the mercurial column, this index will be thrust forward as the mercury expands, but will remain at the same place if it contracts under the influence of a reduction of temperature.* The point of the scale where the index is found indicates, therefore, the greatest degree of heat, or the *maximum* to which the instrument has been subjected. An analogous mechanism will give us the lowest degree to which the instrument has fallen. At the extremity of the column of a spirit thermometer a glass index is so placed that it is entirely plunged into the liquid. When the alcohol contracts, it draws with it the index, in consequence of its adhesion to the glass, but, in expanding, it does not displace it; so that the degree, corresponding to the point where the index is found, indicates the *minimum*, or lowest temperature, to which the instrument has been exposed. If, then, we wish to know the *maximum* and the *minimum* of the temperature in the twenty-four hours, the index of iron wire is placed in contact with the mercury, and the upper extremity of the glass index is made to coincide with the extremity of the column of spirit, by inclining the two instruments. The following day the position of the

---

* Indices of glass, and even those of iron wire, in the course of time, are *drowned*, that is, they penetrate into the mercury. To avoid this inconvenience, M. GREINER crowns the thermometric column with a cap of very thin glass, by which the mercury is kept from the index.—M.

two indices will give the *maximum* and the *minimum* of temperature.*

**PROPAGATION OF HEAT.**—A body, when in the neighbourhood of another, the temperature of which is higher or lower, becomes heated or cooled. How does this exchange of heat come about? In two ways, as we have learned from experiments—*conductibility* and *radiation*.

CONDUCTIBILITY.—If cavities are fashioned in a metal bar, and thermometers are introduced into them, it will be found that, at the end of a certain time, all the thermometers will indicate the same temperature; but, if a lamp is brought near to one end of the bar, this end will be heated first, and, in a very short time, the thermometers will rise, and the more so as they are nearer to the source of heat. The propagation of heat takes place because each layer of metal communicates a portion of its heat to the layer with which it is in contact. This property of bodies to transmit their heat thus, by the intervention of their molecules, is termed *conductibility*. Conducting power is different in the various bodies in nature. If bars of the same length and thickness, but composed of different materials, are compared, we discover that they do not conduct heat equally well. Metals transmit it very well, then come rocks, afterwards wood, &c. In general, the more porous a substance is, the less conducting power does it possess. A crowd of phenomena, falling under our daily observation, depend simply on the difference of conducting powers. On a summer's day expose to the sun a mass of metal and a mass of wood, of the same volume, and covered with the same varnish; then touch each of them with the hand: the wood, which is hot on the surface only, will at first give the sensation of a hotter body than the metal; the latter, on the contrary, being deeply penetrated by the heat, will produce a less intense sensation at first, but it will continue much longer, because it will gradually transmit to the hand all the heat that it has absorbed. For the same reason, a piece of metal seems much colder in winter than a piece of wood, because the heat of the hand penetrates much more quickly into the metal than into the

---

* The *minimum* degree is indicated by the upper extremity, the *maximum* by the lower extremity of the index.

SIX's thermometrograph, modified by BELLANI and BUNTEN, is a more convenient instrument, and more exact than RUTHERFORD's, which has just been described (*vide* PECLET, *Traité de Physique*, t. i. p. 542; and POUILLET, *Elémens de Physique*, t. ii. fig. 372). But the indications of this instrument are exact only so long as it has not undergone shocks or pressures, for these displace the index and falsify their results.—M.

wood; the surface alone of the latter becomes heated, and this, too, in a very short space of time. Sand, which is a very bad conductor of heat, is intensely hot on the surface during summer, but, at a few inches deep, this elevated temperature ceases to exist.

Radiation.—Conductibility is not the only means by which bodies interchange temperature. If, in winter, we are at a certain distance from a hot stove, we feel that it transmits heat to us; is this an effect of the conducting power of the air? By no means; for if we place between ourselves and this stove a metal screen, we shall no longer feel the heat, however thin the interposed plate may be; but, as metals are good conductors, the heat ought to traverse the screen. To render this fact perfectly clear, let us place a convex mirror at some distance from the stove, and the bulb of a thermometer in the focus of this mirror. If we place a screen between the mirror and thermometer, the latter will not be affected, but the instant we take away the screen the thermometer rises. Things occur exactly as if the rays of the sun fell on the mirror, and we must admit *calorific rays* for the same reasons that have induced us to conceive *luminous rays*. The mode of transmitting heat is termed *radiation*. Calorific rays easily traverse a certain number of bodies, and especially pure air.

All bodies in nature are incessantly radiating one to another; hence arises a continual interchange of temperature, because some *absorb* what the others lose by radiation. It is principally the surface of bodies that radiates, and, generally, with greater facility the less polished it is. These losses of heat are partially compensated by the heat transmitted from within outward. If, therefore, we surround bodies that are bad conductors but good radiators, such as swan's down, locks of wool, feathers, light sand, glass, snow, &c., with a very cold atmosphere, and compare their cooling with that of bodies which scarcely radiate, but which are good conductors, such as polished metals, we shall perceive that the former become cold much faster than the latter.

**CAPACITY OF BODIES FOR HEAT.**—The thermometer teaches us whether bodies, heated either by direct transmission or by radiation, have the same temperature. To render our explanation more comprehensible, suppose the heat to be something material. It is natural to ask if two bodies of the same temperature always possess the same *quantity* of heat. In other words, is as much heat required to make a temperature of a mass of water rise from 8° to 40° as to raise the temperature of a mass of iron to the same number of degrees? Experiments answer this question in the negative. A different quantity of heat is required to give an equal change of temperature to bodies of a different nature. In order to have a point of comparison, a kilogramme of water at zero is chosen as unity, and we examine how much heat is required to elevate its temperature 1° C. Then this quantity is determined for other bodies by operating, in like manner, upon a kilogramme of the substance. The quantities found are called the *specific heats*, and this property obtains the name of the *calorific capacity* of bodies.

The following experiment shews the truth of what we have said, and explains the method employed to estimate the specific heat of bodies. Pour into a vessel, having thin sides, 500 grammes of water at zero, then add 500 grammes of water at 40°; on making this mixture, we shall have one kilogramme of water at 20°. If the experiment is varied, whatever are the initial temperatures of the two quantities of water, the mixture will always have a temperature equal to half the difference of these initial temperatures.

But if we throw into 500 grammes of water at zero, 500 grammes of iron filings at 40°, the temperature of the mixture will be only 3°,96. Thus, then, the 36°,04 of heat, which the iron has lost, have not been able to elevate the temperature of the water more than 3°,96; and iron requires less heat than water to attain the same degree of temperature in the proportion of 3,°96, 36°,04. The calorific capacity of water being 1, that of iron will, therefore, be 0,11. The difference is analogous to that existing between bodies in respect to their weight. If we fill flasks of the same capacity with different liquids, such as water, alcohol, mercury, &c., we find great differences of weight. Thus the same volume of mercury will be thirteen times heavier than an equal volume of water. Bodies may be regarded as flasks, into which we have poured heat. The thermometer indicates the same temperature, but just as the weights of equal volumes of these liquids are different, so also bodies, in which the thermometer indicates the same temperature, are possessed of very different quantities of heat. Philosophers have given the name of *specific gravity* to this inequality of weight, observed in bodies of the same volume; they have also called the unequal capacity of bodies for heat, *specific heat*.

**INFLUENCE OF THE SUN.**—The study of the laws that regulate the variations of the temperature of the atmosphere prove that the sun is the principal cause. In proportion as this body rises above the horizon, the heat increases; it diminishes as soon as it is set. The differences between summer and winter depend also on the time that it remains below the horizon, and on its distance from the zenith of the observer. Astronomy teaches us, it is true, that the earth was formerly an incandescent globe, which, when launched into space, gradually cooled. In proportion as we descend into the bowels of the earth, we find a greater or less elevation of temperature, which renders the existence of a central fire or incandescent nucleus very probable. But the surface of the earth is composed of bodies that are such bad conductors, that this central heat is very slowly communicated to the atmosphere; and the researches of **Fourier** have shewn that it may be entirely neglected in Meteorology.

The height of the sun above the horizon is one of the most important elements in the study of its calorific action. In fact, a surface is more highly heated by a distant source of heat, as the line drawn from this source to the surface approaches nearer to the perpendicular. Take an open book, and present it to the light of a lamp: on holding it vertically, you will easily be able to read the characters; but, the more you incline it, that is, the smaller the angle is which the incident rays make with the surface of the book, the less will the surface be enlightened, and the more difficult will it be to read the characters; and they will finally become entirely invisible.

Mathematicians have endeavoured to deduce the changes of temperature of days and seasons from the height of the sun; but the action of this body is modified by so many accidental circumstances, that we must have recourse to direct experiment. This is done by means of a thermometer exposed in the open air, on the north side of a building at three or four decimetres from the wall, and at a distance from any white surface likely to reflect the heat. If it becomes wetted by rain, it must be wiped about five minutes before making the observation; for the drops of water, by their evaporation, will lower the temperature of the bulb of the thermometer. Care must be taken, in winter time, that the thermometer is not subjected to a current of hot air coming out from the apartment.

If an instrument thus placed is carefully followed, it will be observed that the temperature changes every moment. It would be an easy matter to turn all these isolated indications to account, in order to compare the temperatures of different months or days in the year. These comparisons would never lead to any satisfactory result, unless we have recourse to *means*. To obtain the mean of any day, the thermometer is observed at short intervals—hourly, for instance; and the sum of the degrees observed is divided by the number of observations that have been made: this is called taking the arithmetical mean of these observations. The mean of a month, of a season, or of a year, is calculated by an analogous process.

**RANGE OF TEMPERATURE DURING THE DAY.**—To observe the thermometer every hour, night and day, would be a task impossible to a single individual, and fatiguing even for several observers. And hence few meteorologists have had this patience; but, fortunately, their results present so much concordance, that we may actually deduce the mean temperature of the day from a very few observations made at suitable hours.

The first horary series is due to **Ciminello** of Padua. For sixteen consecutive months he observed the thermometer every hour from four in the morning till eleven in the evening. During the night he made one more observation at different hours, and he supplied the blank by interpolation. At a later period, at the suggestion of **Brewster,** the artillery officers of the fort of Leith, near Edinburgh, observed the thermometer every hour during the years 1824 and 1825. **Gatterer,** contemporary with **Ciminello,** had observed the thermometer at Göttingen every hour for several years. I have had the opportunity of consulting his manuscript meteorological registers, which M. Anselme **Rotschild** purchased from his heirs, in order to present them to the Society of Physics at Frankfort-on-the-Maine. Numerous daily observations have been made by M. **Neuber,** at Apenrade in Denmark; **Lohrmann,** at Dresden; **Koller,** at Kremsmunster; **Kupfer,** at Petersburg; and since 1835, by the astronomers of the observatory at Milan.*

Latterly, the observations of Captain **Ross,** and those of the Russian officers at Nova Zembla, have furnished valuable materials in regard to the polar regions. I have myself made observations of the thermometer for several years, from six in the morning till ten at night, every hour

---

* To these several series of thermometric observations ought to be added, among others, the hourly observations made at Prague during the years 1839 and 1841. The table of horary means, ranged in monthly order, will be found in the work entitled *Beobachtungen zu Prag*, p. 131.

The first volume of the *Annales de Météorologie*, by M. LAMONT, also contains hourly thermometric observations made at Munich in the course of the year 1841.

or every two hours, in order to determine the progress of temperature at Halle. With regard to night observations, they may easily be derived by means of the very simple formulæ of interpolation, which I have given at page 91, &c. of the first volume of my large treatise on Meteorology. (*Vide* Note A.) The following tables[2] present the summary of the mean temperatures at all hours of the day during the twelve months of the year at Halle, Göttingen, Padua, and the fort of Leith, near Edinburgh.

---

[2] *Vide* Note *b*, Appendix, No. II.

## MEAN TEMPERATURES OF THE DIFFERENT HOURS AT HALLE (*vide* Appendix, *fig.* 1).

| HOURS. | JAN. | FEB. | MARCH. | APRIL. | MAY. | JUNE. | JULY. | AUG. | SEP. | OCT. | NOV. | DEC. | HOURS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Noon | —1°,02 | 1°,91 | 6°,04 | 13°,25 | 16°,26 | 19°,01 | 21°,51 | 21°,11 | 17°,86 | 12°,45 | 5°,69 | 3°,46 | Noon. |
| 1 | —0 ,69 | 2 ,51 | 6 ,45 | 13 ,88 | 16 ,85 | 19 ,56 | 22 ,15 | 21 ,68 | 18 ,35 | 12 ,98 | 6 ,08 | 3 ,69 | 1 |
| 2 | —0 ,59 | 2 ,82 | 6 ,66 | 14 ,18 | 17 ,09 | 19 ,91 | 22 ,53 | 21 ,90 | 18 ,59 | 13 ,16 | 6 ,16 | 3 ,70 | 2 |
| 3 | —0 ,72 | 2 ,63 | 6 ,51 | 14 ,10 | 17 ,14 | 20 ,05 | 22 ,63 | 21 ,95 | 18 ,55 | 12 ,85 | 5 ,90 | 3 ,51 | 3 |
| 4 | —0 ,98 | 2 ,16 | 6 ,21 | 13 ,66 | 16 ,84 | 19 ,76 | 22 ,31 | 21 ,61 | 18 ,19 | 12 ,30 | 5 ,43 | 3 ,26 | 4 |
| 5 | —1 ,39 | 1 ,56 | 5 ,65 | 13 ,02 | 16 ,35 | 19 ,15 | 21 ,65 | 21 ,04 | 17 ,58 | 11 ,66 | 4 ,94 | 2 ,86 | 5 |
| 6 | —1 ,67 | 1 ,04 | 5 ,02 | 12 ,26 | 15 ,73 | 18 ,50 | 20 ,90 | 19 ,95 | 16 ,75 | 10 ,90 | 4 ,50 | 2 ,59 | 6 |
| 7 | —1 ,89 | 0 ,66 | 4 ,53 | 11 ,23 | 14 ,90 | 17 ,59 | 19 ,94 | 19 ,22 | 15 ,86 | 10 ,26 | 4 ,17 | 2 ,38 | 7 |
| 8 | —2 ,05 | 0 ,41 | 3 ,95 | 10 ,46 | 14 ,00 | 16 ,63 | 18 ,89 | 18 ,23 | 14 ,94 | 9 ,66 | 3 ,95 | 2 ,23 | 8 |
| 9 | —2 ,19 | 0 ,14 | 3 ,55 | 9 ,63 | 13 ,05 | 15 ,63 | 17 ,88 | 17 ,30 | 14 ,10 | 9 ,09 | 3 ,74 | 2 ,07 | 9 |
| 10 | —2 ,31 | —0 ,08 | 3 ,14 | 8 ,93 | 12 ,08 | 14 ,59 | 16 ,84 | 16 ,37 | 13 ,37 | 8 ,55 | 3 ,51 | 1 ,91 | 10 |
| 11 | —2 ,44 | —0 ,28 | 2 ,89 | 8 ,37 | 10 ,88 | 13 ,46 | 15 ,86 | 15 ,48 | 12 ,68 | 8 ,00 | 3 ,26 | 1 ,88 | 11 |
| Midnight | —2 ,56 | —0 ,51 | 2 ,65 | 7 ,81 | 9 ,67 | 12 ,36 | 14 ,90 | 14 ,61 | 12 ,09 | 7 ,56 | 3 ,05 | 1 ,84 | Midnight |
| 13 | —2 ,65 | —0 ,74 | 2 ,43 | 7 ,32 | 8 ,64 | 11 ,44 | 14 ,09 | 13 ,92 | 11 ,55 | 7 ,19 | 2 ,89 | 1 ,80 | 13 |
| 14 | —2 ,71 | —0 ,95 | 2 ,18 | 6 ,88 | 7 ,96 | 10 ,83 | 13 ,55 | 13 ,34 | 11 ,09 | 6 ,89 | 2 ,81 | 1 ,76 | 14 |
| 15 | —2 ,75 | —1 ,12 | 1 ,91 | 6 ,45 | 7 ,81 | 10 ,79 | 13 ,42 | 13 ,03 | 10 ,72 | 6 ,62 | 2 ,79 | 1 ,74 | 15 |
| 16 | —2 ,80 | —1 ,27 | 1 ,70 | 6 ,28 | 8 ,21 | 11 ,20 | 13 ,75 | 13 ,04 | 10 ,56 | 6 ,44 | 2 ,74 | 1 ,71 | 16 |
| 17 | —2 ,87 | —1 ,37 | 1 ,60 | 6 ,35 | 9 ,05 | 12 ,03 | 14 ,49 | 13 ,40 | 10 ,69 | 6 ,39 | 2 ,71 | 1 ,67 | 17 |
| 18 | —2 ,95 | —1 ,40 | 1 ,73 | 6 ,76 | 10 ,20 | 13 ,11 | 15 ,52 | 14 ,19 | 11 ,19 | 6 ,59 | 2 ,75 | 1 ,65 | 18 |
| 19 | —2 ,95 | —1 ,33 | 2 ,10 | 7 ,56 | 11 ,31 | 14 ,24 | 16 ,65 | 15 ,11 | 12 ,00 | 7 ,02 | 2 ,85 | 1 ,61 | 19 |
| 20 | —2 ,86 | —1 ,07 | 2 ,70 | 8 ,69 | 12 ,53 | 15 ,41 | 17 ,91 | 16 ,44 | 13 ,23 | 7 ,75 | 3 ,07 | 1 ,65 | 20 |
| 21 | —2 ,50 | —0 ,36 | 3 ,63 | 9 ,99 | 13 ,63 | 16 ,44 | 18 ,91 | 17 ,74 | 14 ,31 | 8 ,99 | 3 ,62 | 1 ,99 | 21 |
| 22 | —2 ,11 | 0 ,40 | 4 ,70 | 11 ,25 | 14 ,61 | 17 ,39 | 19 ,82 | 18 ,99 | 15 ,88 | 10 ,29 | 4 ,39 | 2 ,45 | 22 |
| 23 | —1 ,49 | 1 ,25 | 5 ,36 | 12 ,35 | 15 ,54 | 18 ,23 | 20 ,69 | 20 ,12 | 17 ,00 | 11 ,48 | 5 ,09 | 3 ,01 | 23 |
| Means. | —2°,05 | 0°,30 | 3°,88 | 10°,03 | 12°,93 | 15°,72 | 18°,20 | 17°,49 | 14°,46 | 9°,40 | 4°,00 | 2°,34 | Means. |

## MEAN TEMPERATURES OF THE DIFFERENT HOURS AT GOTTINGEN.

| HOURS. | JAN. | FEB. | MARCH. | APRIL. | MAY. | JUNE. | JULY. | AUG. | SEP. | OCT. | NOV. | DEC. | HOURS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NOON. | 0°,29 | 3°,55 | 7°,96 | 14°,28 | 22°,07 | 26°,39 | 28°,54 | 27°,45 | 23°,00 | 14°,80 | 6°,33 | 3°,33 | NOON. |
| 1 | 0 ,52 | 3 ,74 | 8 ,43 | 14 ,76 | 22 ,72 | 27 ,05 | 28 ,91 | 27 ,83 | 23 ,54 | 15 ,29 | 6 ,49 | 3 ,70 | 1 |
| 2 | 0 ,54 | 3 ,63 | 8 ,73 | 15 ,00 | 22 ,91 | 27 ,44 | 29 ,30 | 28 ,24 | 23 ,79 | 15 ,41 | 6 ,51 | 3 ,53 | 2 |
| 3 | 0 ,18 | 3 ,32 | 8 ,52 | 14 ,90 | 22 ,88 | 27 ,29 | 29 ,19 | 28 ,09 | 23 ,83 | 15 ,23 | 6 ,16 | 3 ,20 | 3 |
| 4 | —0 ,46 | 2 ,53 | 8 ,02 | 14 ,60 | 22 ,53 | 26 ,96 | 28 ,96 | 27 ,69 | 23 ,32 | 14 ,68 | 5 ,63 | 2 ,75 | 4 |
| 5 | —1 ,01 | 1 ,58 | 7 ,16 | 13 ,85 | 21 ,85 | 26 ,26 | 28 ,16 | 26 ,99 | 22 ,46 | 13 ,86 | 5 ,19 | 2 ,38 | 5 |
| 6 | —1 ,59 | 0 ,89 | 6 ,24 | 12 ,88 | 20 ,94 | 25 ,15 | 27 ,19 | 25 ,95 | 21 ,25 | 12 ,85 | 4 ,80 | 2 ,10 | 6 |
| 7 | —1 ,94 | 0 ,45 | 5 ,25 | 11 ,55 | 19 ,74 | 23 ,85 | 25 ,81 | 24 ,41 | 19 ,88 | 12 ,06 | 4 ,50 | 1 ,85 | 7 |
| 8 | —2 ,30 | 0 ,12 | 4 ,49 | 10 ,50 | 18 ,22 | 22 ,59 | 24 ,15 | 22 ,89 | 18 ,73 | 11 ,38 | 4 ,30 | 1 ,68 | 8 |
| 9 | —2 ,50 | —0 ,19 | 3 ,94 | 9 ,59 | 16 ,84 | 21 ,41 | 22 ,83 | 21 ,74 | 17 ,81 | 10 ,79 | 4 ,13 | 1 ,55 | 9 |
| 10 | —2 ,71 | —0 ,33 | 3 ,61 | 8 ,93 | 15 ,95 | 20 ,24 | 21 ,85 | 21 ,03 | 17 ,19 | 10 ,40 | 3 ,99 | 1 ,43 | 10 |
| 11 | —2 ,89 | —0 ,42 | 3 ,30 | 8 ,36 | 15 ,08 | 19 ,04 | 20 ,92 | 20 ,23 | 16 ,65 | 9 ,99 | 3 ,81 | 1 ,38 | 11 |
| Midnight | —3 ,10 | —0 ,50 | 2 ,99 | 7 ,91 | 14 ,79 | 18 ,64 | 20 ,21 | 19 ,39 | 16 ,29 | 9 ,88 | 3 ,73 | 1 ,23 | Midnight |
| 13 | —3 ,13 | —0 ,57 | 2 ,95 | 7 ,75 | 13 ,80 | 18 ,11 | 19 ,74 | 18 ,86 | 15 ,90 | 9 ,70 | 3 ,65 | 1 ,18 | 13 |
| 14 | —3 ,15 | —0 ,59 | 2 ,71 | 7 ,44 | 13 ,31 | 17 ,76 | 19 ,41 | 18 ,43 | 15 ,44 | 9 ,49 | 3 ,58 | 1 ,19 | 14 |
| 15 | —3 ,18 | —0 ,61 | 2 ,41 | 7 ,06 | 13 ,03 | 17 ,74 | 19 ,29 | 18 ,15 | 14 ,75 | 9 ,26 | 3 ,48 | 1 ,21 | 15 |
| 16 | —3 ,24 | —0 ,66 | 2 ,15 | 6 ,75 | 13 ,05 | 17 ,94 | 19 ,45 | 18 ,19 | 14 ,25 | 9 ,06 | 3 ,36 | 1 ,21 | 16 |
| 17 | —3 ,44 | —0 ,74 | 2 ,06 | 6 ,70 | 13 ,50 | 18 ,53 | 19 ,99 | 18 ,65 | 14 ,26 | 8 ,99 | 3 ,26 | 1 ,16 | 17 |
| 18 | —3 ,40 | —0 ,66 | 2 ,30 | 7 ,14 | 14 ,66 | 19 ,63 | 20 ,95 | 19 ,56 | 14 ,41 | 9 ,19 | 3 ,16 | 1 ,10 | 18 |
| 19 | —3 ,41 | —0 ,58 | 2 ,71 | 7 ,75 | 15 ,71 | 20 ,89 | 22 ,44 | 20 ,94 | 15 ,52 | 9 ,70 | 3 ,34 | 1 ,12 | 19 |
| 20 | —3 ,40 | —0 ,16 | 3 ,65 | 9 ,44 | 17 ,00 | 21 ,79 | 23 ,59 | 22 ,35 | 17 ,09 | 10 ,33 | 3 ,85 | 1 ,26 | 20 |
| 21 | —2 ,62 | 0 ,94 | 5 ,10 | 10 ,75 | 18 ,53 | 23 ,09 | 25 ,00 | 23 ,90 | 19 ,07 | 11 ,94 | 4 ,39 | 1 ,56 | 21 |
| 22 | —1 ,54 | 1 ,94 | 6 ,28 | 12 ,20 | 19 ,85 | 24 ,40 | 26 ,96 | 25 ,35 | 20 ,60 | 12 ,71 | 5 ,04 | 1 ,96 | 22 |
| 23 | —0 ,43 | 3 ,06 | 7 ,26 | 13 ,43 | 21 ,18 | 25 ,56 | 27 ,61 | 26 ,59 | 21 ,85 | 13 ,85 | 5 ,75 | 2 ,86 | 23 |
| Means. | 2°,00 | 0°,84 | 4°,92 | 10°,55 | 17°,94 | 22°,40 | 24°,19 | 23°,05 | 18°,79 | 11°,68 | 4°,51 | 1°,93 | Means. |

### MEAN TEMPERATURES OF THE DIFFERENT HOURS AT PADUA.

| HOURS. | JAN. | FEB. | MARCH. | APRIL. | MAY. | JUNE. | JULY. | AUG. | SEP. | OCT. | NOV. | DEC. | HOURS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Noon. | 4°,94 | 6°,44 | 9°,38 | 14°,62 | 23°,39 | 25 ,08 | 30°,01 | 26°,50 | 21°,06 | 16°,68 | 10°,25 | 5°,71 | Noon. |
| 1 | 5 ,44 | 6 ,70 | 9 ,66 | 15 ,13 | 23 ,57 | 25 ,19 | 30 ,47 | 26 ,97 | 21 ,56 | 17 ,10 | 10 ,75 | 6 ,21 | 1 |
| 2 | 5 ,60 | 6 ,91 | 9 ,91 | 15 ,43 | 23 ,65 | 25 ,21 | 30 ,73 | 27 ,45 | 21 ,93 | 17 ,43 | 10 ,92 | 6 ,41 | 2 |
| 3 | 5 ,52 | 6 ,95 | 10 ,10 | 15 ,70 | 23 ,65 | 25 ,17 | 30 ,48 | 27 ,55 | 21 ,97 | 17 ,47 | 10 ,50 | 5 ,94 | 3 |
| 4 | 5 ,19 | 6 ,56 | 9 ,87 | 15 ,65 | 23 ,31 | 24 ,68 | 29 ,59 | 26 ,83 | 21 ,35 | 17 ,34 | 9 ,64 | 5 ,27 | 4 |
| 5 | 4 ,80 | 6 ,11 | 9 ,47 | 15 ,50 | 22 ,57 | 23 ,93 | 29 ,11 | 25 ,90 | 20 ,38 | 16 ,23 | 8 ,64 | 4 ,76 | 5 |
| 6 | 4 ,45 | 5 ,88 | 9 ,01 | 14 ,92 | 21 ,47 | 23 ,18 | 27 ,82 | 24 ,46 | 19 ,42 | 15 ,60 | 7 ,92 | 4 ,25 | 6 |
| 7 | 4 ,11 | 5 ,67 | 8 ,64 | 14 ,43 | 20 ,29 | 22 ,08 | 26 ,64 | 23 ,19 | 18 ,60 | 15 ,09 | 7 ,58 | 4 ,03 | 7 |
| 8 | 3 ,80 | 5 ,42 | 8 ,27 | 13 ,62 | 20 ,14 | 21 ,45 | 24 ,80 | 22 ,17 | 18 ,50 | 14 ,86 | 7 ,32 | 3 ,79 | 8 |
| 9 | 3 ,65 | 5 ,07 | 7 ,86 | 13 ,17 | 18 ,58 | 20 ,21 | 24 ,14 | 21 ,53 | 18 ,09 | 14 ,59 | 7 ,12 | 3 ,52 | 9 |
| 10 | 3 ,49 | 4 ,78 | 7 ,43 | 12 ,69 | 18 ,17 | 19 ,78 | 23 ,97 | 21 ,09 | 17 ,65 | 14 ,27 | 6 ,83 | 3 ,26 | 10 |
| 11 | 3 ,35 | 4 ,50 | 7 ,13 | 12 ,28 | 17 ,78 | 19 ,61 | 23 ,39 | 20 ,57 | 17 ,33 | 14 ,07 | 6 ,66 | 3 ,10 | 11 |
| Midnight | 3 ,25 | 4 ,28 | 6 ,83 | 11 ,97 | 17 ,44 | 19 ,31 | 23 ,02 | 20 ,00 | 16 ,68 | 13 ,94 | 6 ,56 | 2 ,97 | Midnight |
| 13 | 2 ,98 | 4 ,18 | 6 ,63 | 11 ,49 | 16 ,93 | 19 ,17 | 22 ,49 | 19 ,95 | 16 ,39 | 13 ,85 | 6 ,43 | 2 ,80 | 13 |
| 14 | 2 ,98 | 3 ,88 | 6 ,26 | 11 ,17 | 16 ,60 | 18 ,93 | 22 ,06 | 19 ,42 | 16 ,07 | 13 ,63 | 6 ,28 | 2 ,64 | 14 |
| 15 | 2 ,76 | 3 ,68 | 5 ,93 | 10 ,95 | 16 ,22 | 18 ,58 | 21 ,65 | 18 ,98 | 15 ,76 | 13 ,42 | 6 ,15 | 2 ,61 | 15 |
| 16 | 2 ,72 | 3 ,48 | 5 ,67 | 10 ,57 | 16 ,05 | 18 ,54 | 21 ,34 | 18 ,49 | 15 ,46 | 13 ,18 | 6 ,04 | 2 ,53 | 16 |
| 17 | 2 ,38 | 3 ,25 | 5 ,36 | 10 ,20 | 16 ,26 | 18 ,94 | 21 ,89 | 18 ,49 | 15 ,05 | 12 ,94 | 5 ,95 | 2 ,44 | 17 |
| 18 | 2 ,30 | 3 ,06 | 5 ,10 | 10 ,25 | 17 ,52 | 20 ,40 | 23 ,47 | 19 ,13 | 15 ,20 | 13 ,00 | 5 ,87 | 2 ,39 | 18 |
| 19 | 2 ,15 | 2 ,91 | 5 ,41 | 10 ,76 | 19 ,14 | 21 ,83 | 25 ,36 | 20 ,52 | 16 ,15 | 13 ,21 | 5 ,75 | 2 ,30 | 19 |
| 20 | 2 ,37 | 3 ,12 | 6 ,97 | 11 ,74 | 20 ,26 | 22 ,74 | 26 ,37 | 22 ,06 | 17 ,39 | 13 ,91 | 6 ,52 | 2 ,59 | 20 |
| 21 | 2 ,84 | 3 ,86 | 6 ,97 | 12 ,80 | 21 ,31 | 23 ,48 | 28 ,10 | 24 ,85 | 19 ,11 | 14 ,69 | 7 ,70 | 3 ,43 | 21 |
| 22 | 3 ,58 | 4 ,99 | 8 ,72 | 13 ,56 | 22 ,09 | 24 ,00 | 28 ,92 | 25 ,17 | 19 ,67 | 15 ,56 | 8 ,74 | 4 ,16 | 22 |
| 23 | 4 ,43 | 5 ,67 | 8 ,83 | 14 ,09 | 22 ,05 | 24 ,72 | 29 ,52 | 25 ,76 | 20 ,33 | 16 ,16 | 9 ,62 | 5 ,15 | 23 |
| Means. | 3°,71 | 4°,89 | 7°,73 | 13°,03 | 19°,97 | 21°,93 | 26°,02 | 22°,79 | 18°,38 | 14°,92 | 7°,73 | 3°,84 | Means. |

## MEAN TEMPERATURES OF THE DIFFERENT HOURS AT LEITH, NEAR EDINBURGH.

| HOURS. | JAN. | FEB. | MARCH. | APRIL. | MAY. | JUNE. | JULY. | AUG. | SEP. | OCT. | NOV. | DEC. | HOURS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Noon. | 5°,57 | 5°,68 | 6°,29 | 10°,01 | 11°,43 | 14°,81 | 17°,69 | 16°,26 | 15°,28 | 10 ,85 | 6°,16 | 5°,00 | Noon. |
| 1 | 5 ,79 | 5 ,99 | 6 ,49 | 10 ,25 | 11 ,77 | 15 ,01 | 17 ,74 | 16 ,51 | 15 ,72 | 11 ,09 | 6 ,35 | 5 ,10 | 1 |
| 2 | 5 ,88 | 5 ,98 | 6 ,67 | 10 ,45 | 12 ,01 | 15 ,39 | 17 ,96 | 16 ,62 | 15 ,91 | 11 ,12 | 6 ,50 | 5 ,12 | 2 |
| 3 | 5 ,89 | 6 ,00 | 6 ,71 | 10 ,66 | 12 ,05 | 15 ,68 | 18 ,13 | 16 ,62 | 15 ,85 | 10 ,96 | 6 ,53 | 4 ,88 | 3 |
| 4 | 5 ,66 | 5 ,70 | 6 ,69 | 10 ,49 | 12 ,23 | 15 ,45 | 18 ,17 | 16 ,75 | 15 ,52 | 10 ,63 | 6 ,01 | 4 ,72 | 4 |
| 5 | 5 ,38 | 5 ,27 | 6 ,42 | 10 ,19 | 12 ,15 | 15 ,32 | 18 ,24 | 16 ,69 | 15 ,51 | 10 ,27 | 5 ,64 | 4 ,54 | 5 |
| 6 | 5 ,25 | 5 ,00 | 6 ,03 | 9 ,96 | 11 ,86 | 15 ,08 | 18 ,15 | 16 ,52 | 14 ,81 | 9 ,86 | 5 ,44 | 4 ,41 | 6 |
| 7 | 5 ,05 | 4 ,79 | 5 ,49 | 9 ,19 | 11 ,36 | 14 ,66 | 17 ,69 | 15 ,54 | 14 ,08 | 9 ,52 | 5 ,21 | 4 ,16 | 7 |
| 8 | 4 ,93 | 4 ,57 | 5 ,09 | 8 ,28 | 10 ,56 | 13 ,70 | 16 ,42 | 14 ,83 | 13 ,63 | 9 ,22 | 5 ,04 | 4 ,10 | 8 |
| 9 | 4 ,88 | 4 ,40 | 4 ,70 | 7 ,62 | 9 ,73 | 12 ,98 | 15 ,46 | 14 ,27 | 13 ,22 | 9 ,14 | 4 ,90 | 4 ,06 | 9 |
| 10 | 4 ,90 | 4 ,25 | 4 ,41 | 7 ,23 | 9 ,44 | 12 ,21 | 14 ,75 | 13 ,72 | 12 ,85 | 8 ,90 | 4 ,63 | 4 ,03 | 10 |
| 11 | 4 ,83 | 4 ,19 | 4 ,12 | 6 ,62 | 8 ,97 | 12 ,06 | 14 ,30 | 13 ,36 | 12 ,62 | 8 ,65 | 4 ,41 | 3 ,96 | 11 |
| Midnight | 4 ,79 | 4 ,18 | 4 ,04 | 6 ,34 | 8 ,62 | 11 ,77 | 13 ,79 | 13 ,06 | 12 ,28 | 8 ,71 | 4 ,28 | 3 ,93 | Midnight |
| 13 | 4 ,79 | 4 ,26 | 3 ,86 | 6 ,16 | 8 ,22 | 11 ,44 | 13 ,43 | 12 ,96 | 12 ,13 | 8 ,93 | 4 ,37 | 3 ,86 | 13 |
| 14 | 4 ,66 | 4 ,31 | 3 ,74 | 5 ,65 | 7 ,99 | 11 ,25 | 13 ,33 | 12 ,82 | 12 ,00 | 8 ,88 | 4 ,22 | 3 ,90 | 14 |
| 15 | 4 ,62 | 4 ,32 | 3 ,50 | 5 ,29 | 7 ,71 | 11 ,18 | 13 ,11 | 12 ,66 | 11 ,72 | 8 ,82 | 4 ,30 | 3 ,92 | 15 |
| 16 | 4 ,48 | 4 ,22 | 3 ,40 | 4 ,88 | 7 ,46 | 11 ,05 | 12 ,86 | 12 ,54 | 11 ,51 | 8 ,80 | 4 ,26 | 3 ,87 | 16 |
| 17 | 4 ,41 | 4 ,09 | 3 ,31 | 4 ,78 | 7 ,53 | 11 ,07 | 13 ,15 | 12 ,57 | 11 ,44 | 8 ,64 | 4 ,31 | 3 ,84 | 17 |
| 18 | 4 ,41 | 4 ,02 | 3 ,29 | 4 ,85 | 7 ,96 | 11 ,57 | 13 ,73 | 12 ,79 | 11 ,59 | 8 ,41 | 4 ,36 | 3 ,93 | 18 |
| 19 | 4 ,46 | 4 ,05 | 3 ,47 | 5 ,90 | 8 ,44 | 12 ,01 | 14 ,38 | 13 ,35 | 12 ,02 | 8 ,64 | 4 ,48 | 3 ,89 | 19 |
| 20 | 4 ,51 | 4 ,04 | 3 ,84 | 6 ,62 | 9 ,14 | 12 ,65 | 15 ,06 | 14 ,00 | 12 ,73 | 9 ,00 | 4 ,50 | 3 ,96 | 20 |
| 21 | 4 ,66 | 4 ,31 | 4 ,39 | 7 ,98 | 9 ,85 | 13 ,36 | 15 ,83 | 14 ,88 | 13 ,62 | 9 ,37 | 4 ,76 | 4 ,09 | 21 |
| 22 | 4 ,91 | 4 ,78 | 4 ,74 | 8 ,94 | 10 ,50 | 13 ,98 | 16 ,46 | 15 ,30 | 14 ,15 | 10 ,00 | 5 ,26 | 4 ,27 | 22 |
| 23 | 5 ,19 | 5 ,28 | 5 ,51 | 9 ,50 | 11 ,02 | 14 ,53 | 16 ,95 | 15 ,72 | 14 ,77 | 10 ,49 | 5 ,81 | 4 ,73 | 23 |
| Means. | 5°,00 | 4°,74 | 4°,84 | 7°,83 | 9°,91 | 13°,26 | 15°,70 | 14°,60 | 13°,54 | 9°,54 | 5°,07 | 4°,26 | Means. |

These tables shew that there is a *maximum* and a *minimum* of temperature on each day. The *minimum* occurs some little time before the rising of the sun, the *maximum* about two o'clock in the afternoon; a little sooner in winter and a little later in summer. The majority of philosophers admit that the moment of the rising of the sun is that at which the temperature is the lowest; but if we deduce from observations a formula, independent of the trifling errors of reading, which are almost inevitable, we shall find that the *minimum* occurs about half an hour before the rising of the sun, at the time when this body is yet 12° beneath the horizon. This rule, which is only applicable to our climates, varies in different seasons. In autumn and in winter the *minimum* coincides with a depression of 18° below the horizon, and in summer with 6° only.

When the sun is above the horizon, it acts upon the earth and the lower strata of the atmosphere with greater power, as its angular height is greater. One portion of this heat penetrates into the soil, the other is lost by radiation towards the atmosphere and celestial space. Before mid-day the earth receives, in every instant of time, a quantity of heat, exceeding that which it loses by radiation; and its temperature is raised. This effect continues also for some time after the sun has passed the meridian, hence it follows that the maximum takes place some hours after the time of noon.* While the sun is sinking toward the horizon, its

---

* We know that, during the winter at the polar regions, the sun entirely ceases to appear above the horizon for a period of time, which is longer as the observer is nearer the pole. The variations of the thermometer are then due, almost entirely, to the state of the sky and the direction of the wind. We may, therefore, expect to find an almost insensible daily variation. The following are the results which were obtained, during the winter of 1838–9, at Bosekop, in Lapland, under the 70th degree of latitude, by MM. LOTTIN, BRAVAIS, LILLIEHOOK, and SILJESTROEM, members of the Commission of the North. They confined themselves to the mean temperature of the forty days preceding and the forty days succeeding the winter solstice:—

| HOURS. | TEMPER. | HOURS. | TEMPER. |
|---|---|---|---|
| NOON. | −9°,12 | MIDNIGHT. | −9°,09 |
| 2 h. | −9°,05 | 14 h. | −9°,25 |
| 4 h. | −9°,28 | 16 h. | −9°,31 |
| 6 h. | −9°,31 | 18 h. | −9°,30 |
| 8 h. | −9°,22 | 20 h. | −9°,22 |
| 10 h. | −9°,07 | 22 h. | −8°,94 |

(*Vide* Appendix, *fig.* 2).

If entire confidence is to be placed in mere numbers, deduced from the action becomes less powerful, and the loss by radiation exceeds the gain by absorption. The heat diminishes the more rapidly as the sun is nearer setting. As soon as it has disappeared, the calorific source no longer existing, all the acquired heat radiates towards celestial space, the temperature falls, and would fall still lower, if the portion of the heat, which had penetrated into the superficial layers of the soil, did not return to the surface, by virtue of the conducting power of the earth. The lowering of temperature continues until morning announces the return of the sun, which again heats the regions that it illuminates.

These explanations are so simple, that almost all the phenomena of temperature may be deduced from them; and we may also infer from them that the diurnal variation of heat is, probably, the same in all countries. However, in hot climates on the sea-coast, the *maximum* of temperature often occurs before the arrival of the sun at the meridian; because there arises, about mid-day, a fresh breeze from the sea, which lowers the temperature. Daily observations, made in July and August, 1837, on the borders of the Baltic, have shewn me that the *maximum* takes place in the afternoon; although several hours sooner than at Halle, which is in the interior of the Continent.[*]

---

observations made during one winter only, we should be led to admit that the temperature attains its *maximum* about eleven o'clock, A.M., its *minimum* about five o'clock, P.M., and a second *maximum* at eleven o'clock, P.M. But these two oscillations are not sufficiently marked to authorise us as yet in vouching for their constancy. It would, however, be interesting to establish the existence of a daily calorific wave, which should not depend on the *direct* action of the solar rays. The preceding observations shew that its amplitude is not greater than 0°,4. It remains to be proved whether this phenomenon may be explained by a regular diurnal change in the state of the heavens or in the direction of the wind, by the diurnal variation in the pressure of the air, by aurora borealis, or by any other local or general influence.—M.

[*] On the summit of high mountains different causes produce an analogous effect. The hottest period of the day occurs half an hour, or three-quarters of an hour, after the term of the culmination of the sun. M. Kaemtz's observations on the Faulhorn (canton of Berne) at 2683 metres above the level of the sea, in 1832 and 1833; those which I made, with MM. Bravais and Wachsmuth, on the same mountain in 1841; and, finally, those of MM. Peltier and Bravais in 1842, all agree in giving the same result, however various these different series may have been in respect to the meteorological circumstances which accompanied them. The observations on the Great St. Bernard also prove that, in this station, the temperature of mid-day is generally greater than that of three o'clock. If, for these two stations, the period of *maximum* differs, this difference is very probably due to Faulhorn's being an isolated summit, whilst the hospice of St. Bernard is overlooked on all sides by elevated summits. The coldest period coincides with that of the plain,—that is, it happens about half an hour before the rising of the sun.

With respect to the diurnal variation of the thermometer, the climate of the summit of mountains bears a great analogy to *sea-climates*.—M.

**DETERMINATION OF MEAN TEMPERATURE.**—Twice during the day, the degree of the thermometer is equal to the mean temperature. It might, therefore, seem that it would be sufficient for us to take an observation at one of these two periods. But this method is very unworthy of trust. At the moment when it oscillates about the mean, the temperature changes very rapidly; and, if the observation is made a little too soon or a little too late, very notable errors will result.

The surer way is to read it off several times during the day, and at such hours that their arithmetical mean shall approach the true mean as nearly as possible. By taking observations at 4 o'clock and at 10 A.M., and at 4 and 10 o'clock P.M., the fourth of the sum of the temperatures found will give a value that will differ very little from that of the mean. The arithmetical mean of observations at 6 A.M., 2 P.M.. and 10 P.M., also differs very little. M. **Schouw**, in order to facilitate the labour of observers, recommends their confining themselves to three readings,—at 7 A.M., at noon, and at 10 P.M.; the sum of the degrees divided by 3 will give the mean.* At Halle, the mean of June, obtained by this method, is 15°,95; whilst the true mean is 15°,72; consequently 0°,23 lower. If the true mean at Halle were not known, we might arrive at it by determining, by means of observations made in another country, the quantity that must be deducted from the mean deduced from three observations only. Thus, at Padua, the mean found by this latter method is 22°,23; the true mean is 21°,93, the difference = 0°,30. Deduct this difference from the mean deduced at Halle from three observations only, and we have 15°,95 — 0°,30 = 15°,65; a number which is not very far from the true mean, 15°,72. In fine, we must be sure as to whether the arithmetical mean of the three observations is greater or less than the true mean, in the places where the latter is known, and add or deduct this difference from the mean obtained in the place where the observations are being made. For points situate on the Continent, and in the temperate zones, we should take the means of Göttingen, Halle, and Padua, in order to eliminate the little anomalies which might exist in one of these cities taken separately. For England, we should adopt the correction found by the observations made at Leith. Although we do not attain to results that are perfectly accurate, they

---

* In general, the mean of four readings, made at equidistant hours, is not far from the true mean.

will yet be much nearer the truth than those that are not corrected.

The mean being intermediate between the *maximum* and *minimum* of the day, it has often been proposed to deduce it from these two elements, and to consider the half of their sum as the true mean. But the latter is widely different from this empirical mean; and here again we should be obliged to have recourse to a correction which experiment alone can disclose to us. This correction is a constant coefficient, by which the excess of the *maximum* over the *minimum* is to be multiplied; the product is added to the *minimum;* the sum is the true mean sought after. This coefficient varies according to the process by which the *maximum* and *minimum* have been obtained. If a common thermometer is observed at the hours of *maximum* and *minimum*, the readings will differ from the indications of the thermometrograph. In fact, this instrument always indicates the true *maximum* and *minimum ;* whilst the former method does not give them, because the atmospheric accidents of the day may displace the *maximum* and *minimum* by several hours. The mean found by the thermometrograph will, therefore, differ from that deduced from direct observation at the presumed periods of diurnal *maximum* and *minimum ;* because the *maximum* will be always higher, and the *minimum* lower, than those of the thermometrograph.

In many cities, such as Paris, Brussels, and Basle, observations of the thermometrograph and the thermometers have been simultaneously taken several times during the day. We may, therefore, declare, from these comparative observations, a coefficient by means of which we may determine the true mean. With the series of Padua, Halle, Göttingen, and Leith, we have calculated the factor that will enable us to deduce the true mean temperature from the periods of the *maximum* and *minimum*. The following table gives these two coefficients for all the months of the year :—

# TABLE

### OF THE CO-EFFICIENTS BY WHICH THE EXCESS OF THE DIURNAL MAXIMUM OVER THE MINIMUM MUST BE MULTIPLIED; THE SUM OF THE PRODUCT AND OF THE MINIMUM GIVES THE MEAN DIURNAL TEMPERATURE.

| MONTHS. | TEMPERATURES Observed at the presumed instant of *maxima* and *minima*. | EXTREME TEMPERATURES Indicated by the Thermometrograph. |
|---|---|---|
| January . | 0,388 | 0,507 |
| February . | 0,411 | 0,476 |
| March . . | 0,468 | 0,475 |
| April . . | 0,481 | 0,466 |
| May . . . | 0,512 | 0,459 |
| June . . | 0,501 | 0,453 |
| July . . . | 0,488 | 0,462 |
| August . . | 0,500 | 0,451 |
| September . | 0,482 | 0,433 |
| October . . | 0,433 | 0,447 |
| November . | 0,381 | 0,496 |
| December . | 0,357 | 0,521 |

(*Vide* Appendix, *fig*. 3.)

The use of this table is very simple. I will suppose that in March, at the *presumed* times of *maximum* and *minimum*, the reading of the diurnal temperature has been 1°,25 and 8°,32. The difference (8°,32 — 1°,25 =) 7°,07 is to be multiplied by 0·468, the co-efficient of the month of March, and this product is to be added to the *minimum* temperature. The sum will be the true mean in question. Consequently,

*Minimum* . . . . . . . . . = 1°,25
7°,07 × 0,468 . . . . . . . = 3°,31

True Mean . . 4°,56

If, on a day in August, the thermometrograph gave you the extremes 10°,26 and 22°,32, their difference is 12°,06, and the constant coefficient of this month is 0,451. The true mean will therefore be :—

| | |
|---|---|
| *Minimum* . . . . . . . . | = 10°,26 |
| 12°,06 × 0,451 . . . . . . | = 5°,44 |
| True Mean . . | 15°,70 |

We have thus two easy methods of finding the true mean; but meteorologists must endeavour to determine the constant coefficients as rigorously as possible, in order to obtain an accurate knowledge of the daily means. If the Greeks and Romans had invented our instruments and employed these methods, we might now decide the important question respecting the cooling of our planet. Let us then endeavour to collect materials, so that future generations may one day solve this problem.

**RANGE OF TEMPERATURE IN THE COURSE OF THE YEAR.**—The mean temperature of each month having been determined by one of the preceding methods, the annual mean is deduced by dividing the sum of the mensual temperatures by 12. If these mensual temperatures are calculated at the mean of several years, it will be seen that they vary very notably, whilst the annual mean always remains nearly the same. This mean, when deduced from a small number of years, may be considered as the expression of truth, to which it will more nearly approximate as the number of years is greater.

If we now compare the annual and mensual means of the points situated in the temperate zones, we shall find a singular agreement between the results. From the middle of January the temperature rises, at first slowly, then in April and May rapidly; it then increases less rapidly to the end of July, when it attains its *maximum*. It falls at first slowly in August, then rapidly in September and October, and descends to its *minimum* in the middle of January. This march is so constant, that the mensual means of any place may be calculated by means of a very few elements. The justice of this assertion has, moreover, been verified at points situated in Lapland, on the borders of the Persian Gulf, in the new as well as in the old world. If we inquire which are the days when the temperature is equal to the mean, and those when it attains its *maximum* and *minimum*, we find :—

*Minimum* of temperature . January 14.
Mean . . . . . . . . April 24 and Oct. 21.
*Maximum* . . . . . . July 26.[*]

The law of this range of temperature is easily deduced from the position of the sun in relation to our hemisphere. In the month of January, when the days commence lengthening, the sun acts with more force, because its angular height is greater, and it remains longer above the horizon. As the days continue to increase, the earth continues to acquire heat; but the angular height of the sun at first increases slowly, and the heat augments but little; it is only toward the vernal equinox that the temperature rises rapidly. One portion of the heat which the earth receives from the sun during the day is lost by radiation, another portion penetrates to a trifling depth, and another portion serves to warm the atmosphere. By nocturnal radiation, a part of the heat acquired is lost again in space; but, the night being shorter than the day, there is a definite increase of temperature from day to day. Toward the summer solstice, there being little variation in the height of the sun, the increase of temperature increases but slowly.

If the solar influence were the only cause of heat, the *maximum* of temperature would coincide with the longest day of the year. Although the action of the sun is less energetic in proportion as its height decreases, nocturnal radiation is reduced to a mere trifle in summer, on account of the shortness of the nights. Each day, therefore, the sun adds a new quantity of heat to that which the earth already possesses, and the mean of the twenty-four hours still goes on increasing. Therefore it is that the temperature increases even after the summer solstice, so long as the diminution of the days is scarcely sensible, and the *maximum* occurs at the period when the gain of the day compensates

---

[*] In the *Annuaire du Bureau des Longitudes* for 1825, M. Arago has given a list of the days on which *maxima* of heat and cold have been observed at the Observatory of Paris from 1665 to 1823. The days of greatest cold generally fall in the second week of January. Those of greatest heat are irregularly distributed in July and August. At Maestricht (*Mémoires de l'Acad. de Bruxelles*, t. x.) M. CRAHAY found that these days were distributed in the following manner (his period comprehends the years 1818 to 1833): —

| | | | |
|---|---|---|---|
| *Maximum* | July, | 11 times. | Mean Date, July 19. |
| | August, | 3 | |
| | June, | 2 | |
| *Minimum* | January, | 6 times. | Mean Date, January 22. |
| | February, | 5 | |
| | December, | 3 | |
| | March, | 2 | |

M.

for the losses of the night. It is only when the days decrease rapidly, at the time when the sun is approaching the equator, that the temperature falls. This lowering of temperature would be much more sensible if the superficial strata of the earth did not restore to the air a portion of the heat which they had borrowed from it during the summer. This diminution continues for some time, also, after the winter solstice, because the loss during the night always detracts from the gain of the day.

Whatever agreement may be observed in different places in regard to variations in the temperature of the year, we ought not to lose sight of one circumstance, to which we shall return in the sequel with the fullest details: to wit, if we take the difference between the coldest and the hottest months of the year, we find that the difference is very trifling in small islands and on the western shores of continents, but becomes greater as we penetrate into the interior of the continents. So that, in equal latitudes, the coasts and the seas are warmer in winter than the interior of countries.

**SEASONS.**—Astronomic seasons are regulated according to the course of the sun. In Meteorology we seek to divide them according to the march of temperature. Winter being the most rigorous season, we ought to arrange so that the coldest day of the year shall fall nearly in the middle of this season. This day being about the 15th of January, winter will consist of the months of December, January, and February; spring, of March, April, and May, and so on. Few meteorologists have remained attached to astronomical division, which makes winter begin December 21st. A more culpable method still is that which consists in creating artificial seasons for particular spots on the globe, by placing, for example, the commencement of winter at the day when the thermometer marks zero for the first time, and that of spring at the period of the first leaves. Such division cannot but introduce confusion into the science; for, by acting in this manner, we should find an infinite number of distributions of seasons over the surface of the globe.

**INFLUENCE OF LATITUDE OVER TEMPERATURE.**—If we compare spots that differ considerably from each other in latitude, we shall find that their mean temperatures are lower as we proceed further from the equator, and as, consequently, the mean height of the sun is less. Thus, while at the equator the mean temperature varies between 27° and 28°, at Teneriffe it is not more than 21°,7, at Paris 10°,8, and at the North Cape zero. Other circumstances, such as the direction of the winds, the quantity of moisture, &c., have also a notable influence over the mean temperature, which, in equal latitudes, is always more elevated on coasts and in islands than it is in the interior of large continents.

**TEMPERATURE OF THE UPPER STRATA OF THE ATMOSPHERE.**—The mean temperature not only depends on the position of a place with regard to the equator, but also on its elevation above the level of the sea. If the range of the thermometer at the foot and at the summit of a mountain is compared, it will be seen that the mean is lower as the mountain is higher. Aeronauts have made the same observation. On mountains, this diminution of temperature is extremely sensible, because it is almost always accompanied by a very strong wind, which increases the physiological impression of cold. This difference must be attributed to a more active radiation, and to the diminished capacity of the rarified air for heat. In general, it may be admitted that the temperature decreases one degree for every 185 metres; but this number varies with the latitudes, the season, and the hour of the day; for the decrease of temperature is much greater in summer than in winter; in the afternoon it is more sensible than in the morning, and it also depends on the serenity of the sky, on rain, hail, and other hydrometeors.

## II.

## ON WINDS.

**GENERAL CONSIDERATIONS.**—So long as the density of the air is the same every where, the atmosphere remains at rest; but, as soon as this equilibrium is broken by any cause whatever, a motion occurs, which is called *wind*. If, in one part of the atmosphere, the air becomes dense, it passes away to those parts where the density is less, in the same manner as air, compressed in a pair of bellows, escapes by the orifice. This displacement of air is analogous to that of water in rivers; it is a flowing of the aerial ocean from one region towards another.

These currents, the laws of which we are about to study, play a grand part in nature. They favour the fecundation of flowers, by agitating the branches of plants, and transporting the pollen to great distances. They renew the air of cities; and they mitigate the climates of the north by bringing to them the heat of the south. But for them rain would be unknown in the interior of continents, which would be transformed into arid deserts.

**DIRECTION OF THE WINDS.**—To indicate the direction of the winds, the four cardinal points would be insufficient. The horizon is, therefore, divided into eight equal parts, and the wind is designated by giving it the name of the points of the horizon whence it blows. The eight kinds of winds are *north*, *north-east*, *east*, *south-east*, *south*, *south-west*, *west*, and *north-west*.

In meteorological registers, we merely write the initial of these words, that is: N., N.E., E., S.E., S., S.W., W., N.W. Many meteorologists divide the horizon into sixteen equal parts, and designate the points, intermediate between the eight above mentioned, by placing before them the letters N. or S., according as the region whence the wind blows is placed between the meridian and one of the points N.E., N.W., S.E., S.W.; or the letters E. or W., if the region is intermediate between the said points and the line E.W., which is perpendicular to the meridian. Thus, the region situated between the N. and the N.W. is named the N.N.W.; that situated between the N.E. and the E. will be designated by E.N.E. The sixteen points into which the horizon is divided are, therefore, N., N.N.E., N.E., E.N.E., E., E.S.E., S.E., S.S.E., S., S.S.W., S.W., W.S.W., W., W.N.W., N.W., N.N.W. In some particular cases, it is useful to obtain a still further approximation. The region is then described by means of the ordinary divisions of the circle into 360°, starting from the N. or from the S., and pointing out whether the elevation is east or west from the meridian. Thus S. 83° E. indicates a wind coming from a point situated between the E. and the S. at 83° from the meridian; N. 12° W. is a wind which blows from a point situated between the N. and the W., but at 12° distance from the north.

Vanes indicate the general direction of the wind on the surface of the earth. They are commonly placed on elevated buildings, such as steeples, towers, so that small variations, resulting from accidents of the ground, may not have any action on them. Clouds indicate the direction of the upper aerial currents. As it differs very often from the direction of the wind on the surface of the earth, it is well to note both in meteorological registers.

**VELOCITY OF THE WIND.**—The unequal force of the wind is a fact of daily observation. We find every conceivable transition between an almost insensible breeze and hurricanes, which overthrow walls, and root up the largest trees. According to their rapidity, they are divided into gentle wind (slight breeze), moderate wind (brisk breeze), strong wind (fresh breeze), violent wind (strong gale), storm and tempest. The name of hurricane is given to those violent and continued tempests which are observed in the bad season. Within the tropics this word is applied to winds which have nothing in common with our European hurricanes. In mean latitudes, violent storms of the finer season are also designated by this name.

For the most part the force of the wind is estimated by the sensation it produces on our body, and is designated by the figures 1, 2, 3, 4, the wind No. 4 being the most violent of all. But, in order to obtain exact measures, we must have recourse to an *anemometer*. If we suspend a surface vertically, in such a manner that it shall be perpendicular to the direction of the wind, and shall be able to turn around one of its horizontal edges as upon a hinge, the wind will deviate it from the vertical; and, in order to restore it to its former position, a force must be employed, which will be greater as the wind is stronger. If we, therefore, suspend a weight, capable of restoring it to its vertical position, to a lever constituting a continuation of the surface, the force of the wind may be deduced from the weight employed. At first sight this idea appears exceedingly simple; it is, however, very difficult to put in practice. It is better to oppose to the wind a heavy plate, and to measure its angle of deviation from the vertical. One defect is common to all forms of this apparatus; it is, that they can only indicate the force of the wind at the moment of observation; and, in order to obtain the mean velocity of the wind, it is necessary to make continued observations.

**Woltmann's** anemometer appears to me the best contrived of all. Imagine an ordinary vane, furnished, on the side which turns toward the wind, with an horizontal axis, carrying two small windmill sails. The aerial current first places the vane in the proper direction; it then sets these sails in motion. The stronger the wind is, the more rapidly do they turn. The axis carries an endless screw, which corresponds with a toothed wheel, in order to estimate the rotations. If its position is noted at the commencement and at the end of an observation, the number of rotations made in a minute is easily calculated. In order to obtain from this the velocity of the wind, nothing more is necessary than to choose a calm day, and to travel in a carriage or on a railway any known distance in a given time. It is evident that the effect will be the same as if the air were in motion, while the instrument remained at rest. A table is then constructed, which informs us of the velocity of the wind which turns the sails 40, 50, or 60 times in a minute. We might also accurately regulate the instrument, by placing it on an exposed plain, and observing the distance per minute to which the wind carries light bodies, such as small pieces of paper, down, or leaves.

It would undoubtedly be very desirable to have a great number of exact measures of the velocity of the wind; but serious difficulties have, at all times, enfettered this class of researches. Indeed, the instrument ought to be erected on a vast plain, in the open air or on a roof, situations which are very inconvenient for the observer. (*Vide* Note B.)

The velocity of the higher aerial currents is measured by the rapidity with which the shadow of a cloud moves along the surface of the earth.

**MEAN DIRECTION OF THE WIND.**—We will suppose that, in a given place, the force and the direction of the winds have been noted for a certain time; our first inquiry shall be, as to which wind has blown most frequently. We thus obtain eight or sixteen numbers, which do not teach us what we desire to know; but, if we know how often and with what force each of these winds blew, we might arrive at a positive result. Indeed, each wind drives through the place where the observer dwells a mass of air derived from the region whence it comes. The velocities being equal, this mass of air is greater in proportion as the wind has prevailed longer. If the wind is succeeded by another blowing in a diametrically opposite direction, the same mass of air will be brought back. As the velocity of winds is rarely estimated, we are compelled to take account of their frequency only, and to suppose their force equal. Let us suppose then that, in a given place, the north wind has blown thirty times and the south wind twenty times; the former will have brought with it a mass of air, which we may designate by thirty; but the south wind has taken back two-thirds of this mass, or twenty; and the definite result is the same as if the north wind had blown 30—20, or ten times. If the north wind and the east wind had each blown twenty times, the result would have been the same as if the wind had blown from the N.E. By considering the winds in this way, as forces which set the air in motion, we may seek after their resultant according to the laws of mechanics, and we thus obtain the mean direction of the wind. But we have to determine not only the direction, but also the force of this resultant. To arrive at this, let us suppose that the sum of the observed directions amounts to 1000, and let us divide the velocity calculated for the mean direction of the wind by this number. If, then, we find that, at a given place, the mean direction of the wind is S. 63° W., and its force 158, it means that the thousand winds, which have been noted at this spot, have acted in displacing the atmosphere, precisely in the same manner as if the S. 63° W. wind had blown 158 times.[*]

---

[*] This *mean direction* may be easily obtained by a general formula. On a compass card, draw a radius from the centre to the point of the circumference, whence the wind comes, and agree to designate this direction by the angle (azimuth) which this line makes with the meridian, calculating from the north toward the east. The *trigonometric* tangent of this angle will be given by the formula

$$\frac{\text{E.}-\text{W.}+\frac{1}{2}\sqrt{2}\,(\text{N.E.}+\text{S.E.}-\text{N.W.}-\text{S.W.})}{\text{N.}-\text{S.}+\frac{1}{2}\sqrt{2}\,(\text{N.E.}+\text{N.W.}-\text{S.E.}-\text{S.W.}}$$

This is **Lambert's** method. M. **Schouw** seeks the numeric relation between the east (N.E., E., S.E.) and the west winds (N.W., N., S.W.), and that between the north (N.W., N., N.E.) and the south (S.W., S., S.E.) winds. If, at the same place and in a given time, the winds have blown as follows: the N. 84 times; N.E. 98; E. 119; S.E. 87; S. 97; S.W. 185; W. 198; N.W. 131; and we suppose that the total number of winds is 1000; we shall find that the total number of east winds has been

$$98 + 119 + 87 = 304;$$

that of west winds,

$$185 + 198 + 131 = 514;$$

that of north winds,

$$131 + 98 + 84 = 313;$$

and, lastly, that of south winds,

$$87 + 97 + 185 = 369.$$

We find, therefore, for this locality, that the frequency of east winds is to that of west winds as 304 : 514, or as 1 : 1,69; and the frequency of north to that of south winds is as 313 : 369; or as 1 : 1,18. So that the frequency of south and of west winds is superior to that of north and of east winds. The same result is obtained by **Lambert's** method; which, in the preceding example, gives S. 76° W. for the direction, and 177 for the mean force of the wind.

**CAUSES OF WINDS.**—As currents are always produced by a disturbance of equilibrium in the state of the atmosphere, it would seem, at first sight, that they must needs recognise an infinite number of causes. But a more detailed analysis shews that all these causes are deducible to differences of temperature between neighbouring countries. Suppose that two columns of air have the same temperature throughout their entire height, they would be *in equilibrio:* but if the earth, on which they rest, were unequally heated, the equilibrium would be destroyed.

Throwing out of the account the sphericity of the globe, suppose that the air has the same density throughout its

---

where we represent the number of times that each corresponding wind has blown in a total of 1000 times, by N., N.E., E., &c.

When this angle is once obtained, the product of the denominator of the above fraction, by the trigonometric secant of the same angle, will give the general resultant of the wind.

The result of these calculations is not very accurate, as, for want of convenient and exact instruments, fitted to measure the velocity of the wind, we are obliged to suppose that each kind of wind has blown with the same mean velocity.—M.

entire height, and that its upper limit is clearly determined. Let AB (pl. II. fig. 1) represent the surface of the earth, and CD the limit of the atmosphere, parallel to AB. If the whole surface AB were equally heated, the air would expand and remove the limit CD further from the earth. But, if the portion EF is heated, while AE and FB preserve the same temperature, then the column of air EFIL will expand, and its upper limit will be more elevated in GH than in IL for example. But, like as a drop of water, when it falls on a liquid surface, extends equally in all directions, so also the drop of air situated between GH and IL passes away in all directions and produces winds, which, as the upper arrow indicates, blow from the hot towards the colder countries.

Whilst these phenomena are going on in the higher regions of the atmosphere, the equilibrium is also destroyed at the level of the ground; the weight of the columns ACIE and FBLD being increased by the whole weight of air, which has been diffused over their upper surface, this increase of weight is communicated in all directions with a facility bearing proportion to the comparative diminution of the column, which has EF for the base. Like as air compressed in a globe rushes out as soon as an opening is made, so does the air flow away from the colder towards the hotter regions, in the direction of the lower arrows.

If the region EF is considerably cooled, the atmosphere situated above it would contract; and the columns of air AE and FB would pass towards EF, whilst two inverse currents would take place at the surface of the globe. The combination of these facts leads to the following conclusion:—

*If two neighbouring regions are unequally heated, there is produced, in the upper strata, a wind blowing from the hotter to the colder region; and, at the surface of the soil, a contrary current.*

This is the cause of the winds that we observe. The little experiment which follows, and which is due to **Franklin**, very well represents what takes place in the atmosphere. Open in winter a door communicating between a hot and a cold room, there will be two currents: the one above, and directed from the hot to the cold apartment; the other below, and in a contrary direction.

To be convinced of this, it is only necessary to place two tapers by the door, the one high up and the other low down; the flame of the former will be directed from within outwards, that of the latter in the contrary direction. Sometimes these two currents exist above and below a pane of glass when imperfectly puttied in; and we observe, in winter, that a thicker layer of ice is accumulated at its lower part. In a chimney and in a lamp-glass an ascending current is kept up, which feeds the flame; and this current is stronger as the sides of the chimney-funnel or the lamp-glass are more heated.*

Some philosophers have endeavoured to find in the terrestrial globe itself the cause of all the winds. In mountains, say they, the winds are more violent, because they escape more easily from the bosom of the earth. But, although winds may be stronger in mountainous countries, this is merely because the valleys and the summits determine local currents, the velocity of which is added to that of the principal wind. If violent south winds prevail in the middle of Europe, they acquire a violence, of which we can form no idea, in the valleys of the Swiss Alps, where they are known by the name of *foen*.† Water conducts itself in the same manner, when the bed of a river becomes narrow, or studded with rocks; rapid currents rush in all directions among the rocks, even where the water, a few metres higher up, preserves its tranquillity. **De Saussure** has likewise observed on the Alps alternations of calm and very violent gales.

Some philosophers have also laid stress upon a fact well known to miners. During and before violent tempests they have observed very strong ascending currents; but it must not be forgotten that storms are almost always preceded, or accompanied, by a great fall in the barometric column. The atmospheric pressure becoming less, the air in the bowels of the earth expands, and ascends to the surface. This phenomenon reminds one of the experiment which has often been made with the air-pump. Place under the receiver a

---

* The winds produced in this way have been called *winds of aspiration*. The following is a remarkable example. On the 10th of November, 1822, the corvette, Coquille, commanded by Captain Duperrey, was suddenly assailed by a *pampero*, a wind of frequent occurrence at the mouth of the Rio de la Plata, although it was more than 1000 kilometres E.N.E. of this latitude. The circumstance, which serves to characterise this wind coming from the land, as a wind of aspiration, occasioned by a rarefaction of the atmosphere of the sea, is, that at the moment when it was felt there was a rapid fall of the barometer. (*Comptes rendus de l'Académie des Sciences*, t. vii. p. 312.)—M.

† I was at Grindelwald, in the canton of Berne, during the night of the 17th or 18th of July, 1841. In the evening a hot wind began to blow in the valley; it entered by the hollow which separates the Eiger from Mettenberg. Its violence continued increasing during the night, and the following morning nothing was visible on all sides but trees uprooted or broken, and roofs carried away, and transported to great distances. A vast quantity of fragments of ice, detached from the lower glacier of Grindelwald, were stranded in the bed or on the banks of the black Lutschine.—M.

bladder which is well closed, but quite flat, it will swell out as the vacuum is made.

The violent tempests, which frequently accompany volcanic eruptions, are a last argument invoked by some authors. But this coincidence is explained in a very simple manner; to wit, the heat of the volcano determines an ascending current, and the cool air rushes from all sides towards the mountain. The winds, therefore, have a direction the direct opposite to that which they would have if they escaped from the crater of the volcano.

**DIFFERENCES PRESENTED BY THE WINDS IN THE DIFFERENT REGIONS OF THE GLOBE.**—On examining the winds in all parts of the world, we find important differences, which serve to characterise the climates. On the sea-shore, especially within the tropics, a very regular period is observed every day. At certain determinate hours, the wind blows from the sea,—it is a sea-breeze; at other hours the wind comes from the land. In the Atlantic, and the great ocean along the equatorial line, the winds blow almost all the year from the same point of the horizon; those which come from the east are called *trade-winds*. In India and the neighbouring seas, an annual period is observed in the direction of the wind. For six months the wind blows constantly from one point of the horizon, and for the other six months from another point. These variable winds are called *monsoons*. In the higher latitudes, all the winds are variable, and the same wind seldom lasts for several successive days.

**LAND-WINDS AND SEA-BREEZES.**—On coasts, when the weather is calm, no movement is perceived in the air until eight or nine o'clock in the morning, but at that time a sea-breeze gradually rises. It is at first gentle, and is limited to a small space; it gradually increases in force and in extent until three o'clock in the afternoon, then it decreases to give place to the land-wind, which rises soon after sunset, and attains its *maximum* of velocity and extent at the moment when this body rises.

The direction of these two breezes is perpendicular to that of the coast, but if another wind blows at the same time it is modified in various ways. If the east wind blows near an island, the sea-breeze will be stronger on the east coast of the island, and the land-wind will be weak; on the west side, on the contrary, the land-wind will be stronger than the sea-breeze. On the south coast the direction of the breeze will not be normal to that of the coast; the land-wind will blow from the S.E. at the time of its greatest violence, and the sea-breeze from the N.E. In the course of the day the wind will take all the intermediate directions. In the bosom of gulfs the sea-breezes are very weak, on promontories the land-breezes are weak. These breezes exist between the tropics, and some traces of them have even been noticed in Greenland.

The alternation of these winds is explained by the unequal heating of the land and of the sea. About nine o'clock in the morning the temperature is nearly the same on the land and the sea, and the air is in a state of equilibrium. In proportion as the sun rises above the horizon, the earth becomes more heated than the water; and hence there results an upper land-wind, which is recognised by the motion of elevated clouds, and a sea-breeze blowing in the contrary direction. At the time of the *maximum* temperature of the day this breeze acquires its greatest force; but, towards evening, the air on the land becomes cool, and, at sunset, it has the same temperature as the sea air. This causes a few hours of perfect calm. During the night the land becomes colder than the sea, and a land-wind prevails, the *maximum* force of which coincides with the time of the *minimum* temperature of the twenty-four hours, which is likewise that at which the difference of temperature between the earth and the sea is at its extreme.[*]

---

[*] M. Fournet has shewn that there exist in mountains day and night breezes analogous to those of the land and sea. The following is the summary of this memoir, as given by the author himself: —

1st. The asperities of the soil daily determine an atmospheric flux and reflux, which is betrayed by ascending and descending breezes, or winds, known, from time immemorial, in certain localities, under the names of *thalwind*, *pontias*, *vesine*, *solore*, *vauderou*, *rebas*, *vent du Mont Blanc*, *aloup du vent*.

2d. These currents of air obtain the highest degree of developement in the hollows of valleys, without, however, being peculiar to these situations; for they are manifested along the entire slopes, and the current of valleys is nothing more than the result of ascensions, and lateral and partial cascades (valleys of Cogne, Aoste, Quarazza, plain of St. Symphorien, Pilate, Chessy).

3d. The passage from the flux to the reflux and the converse is rapid in narrow gorges, which, after a short passage, tend toward elevated summits (valleys of Anzasca, Sesia, Visbach, Trient, Cogne, Val-Megnier, Martigny, Simplon): it is slower in the general basins, where the flux is usually not fairly established until ten o'clock in the morning, and where the reflux does not commence regularly until about nine in the evening (valleys of Gier, Azergue, Brevanne, Arc, Aoste, Foccia, Upper Rhone). The interval between the ascending and descending tides is occupied by alternate oscillations, or redundances. The hour of this critical moment varies with the seasons, and also with other accidental meteorological circumstances (valleys of Aoste, Maurienne, Nyons, Gier).

4th. The winds of valleys are regular in regular valleys, but present accidents towards their branchings off; these irregularities may be manifested, according to the mode in which the valleys unite, either in the diurnal period (Martigny, Aoste), or in the nocturnal period (Verres, Bannio, St. Jean de Maurienne, Martigny, Firminy).

5th. The configuration of the upper parts of valleys exercises a still

**TRADE-WINDS.**—Few phenomena excited so much astonishment among the early navigators, who, in the fifteenth century, ventured into the Atlantic Ocean, as the east winds, which regularly blew within the tropics. The companions of **Columbus** were struck with terror, when they found themselves driven on by continuous east winds, which seemed to forewarn them that they would never return to their country. For several centuries, the explanation was sought after in vain; at last, **Halley** and **Hadley** proposed the following theory:—

The regions bordering on the equator are the hottest on the earth, because the sun is at no great distance from their zenith; but, setting out from these zones, the temperature goes on diminishing, in proportion as we approach the poles. There is, therefore, formed an upper current from the equator toward the two poles, and a lower one from the poles to the equator. The air from the poles becomes heated in the neighbourhood of the equator; it ascends and

greater influence over these winds according to the hours and seasons: thus they are sometimes more characteristic by day than by night (Maurienne), at other times more by night than by day (*pontias*, *aloup du vent* at Chessy); sometimes winter with its snows is more favourable to the nocturnal winds, at other times summer is to the day-winds. It would be curious to examine, under this relation, the elliptical circuits, which the upper and terminal parts of the Jurassic and subalpine valleys form, compared with the gentle and insensible terminations of the primitive mountains. In the valley of Joux, for example, the alternations from heat to cold are so sudden, that variations of 20° are often experienced there in a few hours, and reapers may be seen in the morning cutting ice with their sickles, whilst a few hours afterwards the thermometer in the sun indicates 38°; it is impossible for such differences as these not to produce extraordinary currents.

6th. The effect of these tides is generally more decided in large valleys, and is weakened in lateral ramifications (Maurienne, Aoste). However, when the basin becomes a true plain, capable of supplying large demands, or absorbing a considerable mass, the effects are reduced: thus the *pontias* rarely reaches the course of the Rhone; and around Geneva the valley breezes of the Arve appear so reduced as not to have excited the attention of the talented philosophers of that city. However, this fact must be verified hereafter.

7th. In comparing the phenomenon of tides about mountains with that of the sea and land-breezes, which are reciprocally produced along the coasts, we perceive that, at the same period when the diurnal sea-winds are driving ships to harbours, the aerial wave is on its part rising about the mountains; and in the night the reverse is the case. It follows, therefore, from this, that the whole of the atmosphere of the Rhone must be daily subject to a motion, which, on the one hand, carries it from the sea to the continent, and from the latter toward the summits of the plain of central France, or of that of the Alps and the Jura; after which it would return, during the night, to its place of departure. But the slowness with which any movement is transmitted in a great mass of an elastic fluid partially nullifies these effects. However, this annihilation is not always complete; and, for the future, I am induced to believe that the light currents which are manifested during the day in the neighbourhood of Lyon, and which may, in some sense, be considered calms, are merely the result of those oscillations, the effects of which I shall develope on another occasion.

8th. The atmospheric tides drive with them bodies that have the power returns anew toward the extremities of the terrestrial axis. On this principle, we ought to find a north wind in the northern hemisphere, and a south wind in the southern; but these two directions combine with the motion of the earth from west to east, and there results a N.E. wind in one hemisphere, and a S.E. wind in the other. Indeed, as the diameter of the parallel circles continues diminishing in proportion as we recede from the equator, and as all the points situated in the same meridian turn round the axis of the earth in twenty-four hours, it follows that they move with a velocity much greater, as they are nearer to the equinoctial line. But the masses of air which flow from the north toward the equator have an acquired velocity less than that of the region toward which they are directed. They, therefore, turn more slowly than do the points situated near the equator, and they oppose to the elevated

of floating. Thus it is that, according to circumstances, smoke, and especially vapour of water, condense during the day around lofty peaks (valleys of Aoste, Maurienne, Ossela, Anzasca, Sesia, vale of Illiers, Col du Géant); whence it follows that the air dries during the night, and becomes moist during the day, on these heights; while the inverse effect takes place at night in hollows (Geneva, Col du Géant, St. Paul). It is easy to see from this that these tides must play an important part in the developement of parasitic clouds, and in the phenomena of the distribution of rains and storms.

9th. The hot air of the plains, ascending during the day, tends to warm the valleys and summits; but this effect is partly counterbalanced by the evaporation which it occasions, so that it may become dry and cold (Marienne): on the other hand, the night breeze tends to cool the valleys, by bringing down the cold of the upper regions; hence the explanation of the sudden coolness occasioned by the *aloup du vent*, the congelations of watery vapour occasioned by the *pontias*, the spring frosts, which, at an equal radiation, affect more particularly the vegetation of the valleys. We might even find in this effect the explanation of some of the anomalies of temperature, which travellers have recognised at different heights on the side of mountains.

10th. The general upper winds might, under certain circumstances, alter the aerial wave or ebb (Maurienne, Aoste, Ossola, Martigny, Mont Cenis), or even complicate them (Cogne); but their effect is not always sufficiently powerful to destroy them entirely (Mont Tharbor, vale of Sesia): sometimes they produce a dead calm (Tarentaise). It follows from this that the prognostics of fine weather, deduced from the regularity in the behaviour of breezes, are often contradicted by experience (valley of Brévenne, Chessy, Bex). However, we may say that the destruction of the currents is generally followed by rain (Maurienne).

11th. Finally, circumstances of local temperature may also nullify mountain breezes; thus it is that the *pontias* ceases to blow when, during the short interval of summer nights, the earth, heated by a burning sun, has not time to become sufficiently cool.

M. FOURNET explains these alternations of ascending diurnal currents, and descending nocturnal currents, by the heating of summits by the rising sun, which determines an ascending current; whilst the heating of the plain, which is greater during the day than that of the mountain, determines a descending current towards evening. I am the more induced to admit this explanation, as it follows, from the experiment made during the summer of 1842, at the summit of the Faulhorn, by M. BRAVAIS, that the *mean* heating of the surface of the soil during the day is sensibly equal to that of the *maximum* of the air (Vide *Annales de Chimie et de Physique*, t. lxxiv. p. 337; 1840).—M.

parts of the surface of the globe a resistance analogous to that of a well-defined N.E. wind. For the same reason the trade-wind of the southern hemisphere blows from the S.E.

On approaching the equator from the parallel of 30°, few changes are observed in the direction of the winds; they vary from N.N.E. to N.E. or E.N.E.; and in the neighbourhood of the equator they are E. It is, in fact, at the equator that the motion by the earth's rotation is most rapid; and there it is that the masses of air remain most behindhand, and oppose the greatest resistance: it is on this line, also, that the trade-winds from both hemispheres meet, and as one comes from the N.E., and the other from the S.E., an east wind is the result; as when one billiard-ball is met by another, it takes a direction intermediate between that of the two balls. The trade-winds of our hemisphere also affect all the directions comprised between E. and N.N.E.

In the upper regions of the atmosphere, there also exist constant currents; in the northern hemisphere the heated air is determined toward the north; and, in proportion as it advances toward the pole, it gets more and more in advance of the earth in its rotatory motion. The combination of this motion from the west toward the east, with the primordial direction from south to north, gives rise to a S.W. wind. For the same reason a N.W. wind is observed in the upper currents of the southern hemisphere.

**TRADE-WINDS OF THE GREAT OCEAN.**—Bounded on one side by the western coast of America, and on the other by the eastern coast of New Holland, sprinkled merely with small groups of islands, this sea presents us with the greatest masses of water on our globe. The N.E. trade-wind blows very regularly at some distance from the earth, between the equator and the northern tropical circle. To the credit of this wind it is that the Spanish galleons always went direct from Acapalco to Manilla, without wandering from their route; and thus they did not discover a multitude of islands which have since been seen. The northern limit of this trade-wind advances, during the summer of our hemisphere, toward the north pole, and retreats during our winter; according as our hemisphere is hotter or colder than the opposite hemisphere. The N.E. trade-wind may be said to prevail between the 2d and the 25th degree of N. latitude; the S.E. trade-wind also blows regularly on the south of the equator; its limits are not so well known, but we shall not be far from the truth in saying that it extends from the 10th to the 21st degree of south latitude.

These winds reign over the whole extent of this sea, as far as the Philippines and New Holland; but they are only found at a certain distance from the American coast. In the belt, from 2° N. to 2° S., which separates the two trade-winds, the air is most highly heated; and it rises with such force, that it neutralises the horizontal motion. So that, in this belt, the dead calm is only disturbed by storms, which the Spaniards and Portuguese term *tornados* or *travados*. We will call this belt the *region of calms;* and we shall see that torrents of rain, and almost daily storms, joined to the causes mentioned, are opposed to the establishment there of regular winds.

**TRADE-WINDS OF THE ATLANTIC OCEAN.**—Navigators who traverse these seas in all directions have fixed their limits with great precision. In the north, the N.E. trade-wind does not prevail beyond the 28th or 30th degree. Its southern limit is at a mean 8° N.; then comes the region of calms, extending to 3° N., whence commences the S.E. trade-wind, which extends onward to 28° of south latitude. The extent of the region of calms also depends on the season; in August it extends from 3° 15′ N. to 13° N.; in February, from 1° 15′ N. to 6° N.

In this sea the S.E. trade-wind always extends to the north of the equator. M. **Prevost** thought of explaining this anomaly by remarking that the southern hemisphere is colder than ours; the region of calms being, in his opinion, limited by two bands, the mean temperature of which ought to be the same, the S.E. trade-wind must pass beyond the equator. This explanation, which was very favourably received at the time, is subject, however, to real difficulties. First, in the Great Ocean the equator forms the limit of the trade-winds; then, if M. **Prevost's** explanation were correct, the following absurd consequence would follow: that the winter of the northern hemisphere must be hotter than the summer of the southern hemisphere, because in this season the S.E. trade-wind always blows to the north of the equator.

The solution of this problem must be sought where M. **de Humboldt** seeks it, in the configuration of the basin of the Atlantic Ocean. The portion of South America, situated to the north of the equator, presents to us the lofty mountains of Columbia, which separate the sea from the Antilles of the Great Ocean. When the sun is at the south of the equator, and, consequently, during the winter of the northern hemisphere, these seas are already hotter than the continent; but the current which flows into the sea of the Antilles, and which is, so to speak, the origin of the Gulf Stream, elevates their temperature still higher. This circumstance would of itself be sufficient to determine a current of air from the south to the north, which, by combining with the east wind, would produce a S.E. wind, that would neutralise the N.E. wind before the latter had reached the equator. Add to this, that the general direction of the coast is from S.E. to N.W. which singularly favours the extension of the south-east wind.

**WEST WIND OF THE HIGHER REGIONS.**—We have already shewn that this wind must constantly prevail in the higher regions of the atmosphere within the tropics. The following proofs are still more conclusive: The inhabitants of Barbadoes, an island situated to the north of the chain of the Antilles, one day to their great astonishment saw volcanic ashes fall from the sky. They came from the volcano of St. Vincent, which is situated to the west of their isle. These ashes, having been launched into the air as high as to the region of the upper current, had been transported by it in the direction from west to east. At the summit of the peak of Teneriffe almost all travellers have found west winds, even while the trade-wind was prevailing at the level of the sea. **Paludan**, a navigator who is well acquainted with these localities, relates that little clouds often float in a reverse direction to the trade-wind; and **Bruce** made the same observations in Abyssinia. A recent fact confirms all the preceding: on the 25th of February, 1835, the ashes emitted from the volcano of Cosiguina, in the state of Guatimala, obscured the light of the sun for five days; they mounted into the region of the upper trade-wind, and fell a short time afterwards in the streets of Kingston in Jamaica, which is situated to the N.E. of Guatimala.

**WINDS IN THE INDIAN OCEAN.**—The winds which prevail in these latitudes, being influenced by the configuration of the lands, present phenomena that are very difficult of analysis. The sea is bounded on the west by Africa, which extends from the S.S.W. to the N.N.E. Every document, after having been subjected to severe criticism by **Ch. Ritter**, tends to shew that this continent is an elevated table-land, of which the first steps only have been explored. On the north are situated Persia and Arabia, which form two slightly elevated table-lands, void of rivers, and covered with nothing but a miserable vegetation. On the south of these deserts of sand, the Indian peninsula advances into the sea in a southerly direction, whilst it is bounded on the north by the Himalaya Mountains, covered with perpetual snow, and by the table-land of Thibet. The coast of Malabar rises abruptly from the bosom of the ocean, whilst that of Coromandel rises gradually above the level. The height of the Indian table-land is every where almost the same; it is lower, however, after passing the north point of the island of Ceylon. At the east of the Bay of Bengal is the Birman Empire, the land extends toward the N.E.; the Chinese Sea is bounded on the north by a chain of mountains, and on the east by the Archipelago of the Philippines. On the south and on the east of the peninsula of Malacca are islands studded with lofty mountains, such as Sumatra, Java, Borneo, and the Celebes. To the south of this group is New Holland, the interior of which is unknown; but the absence of rivers makes it fair to suppose that it presents neither table-land nor elevated chains. The dryness of the winds that blow from the interior enables us to presume, also, that it is not furnished with large lakes or numerous ponds.

This predominance of land, and the differences of temperature constantly existing between it and the sea, disturb the regularity of the trade-winds. Regular winds prevail during the winter and the summer, but their direction is not the same; they are known by the name of *monsoons*, a word derived from the Malay, *moussin*, signifying season.

In January, the temperature of Southern Africa is at its *maximum*, that of Asia at its *minimum*. The northern part of the Indian Ocean is hotter than the continent, but not so hot as the southern part of the same ocean at a similar latitude. In both hemispheres, therefore, we find east winds directed toward the hotter parts. From October to April, the S.E. trade-wind prevails in the southern hemisphere; the N.E. trade-wind blows in the opposite hemisphere, and it obtains the name of *N.E. monsoon;* between the two is the region of calms. When the sun advances toward the north, the temperature of the continent and that of the sea tend to an equilibrium; so that, about the vernal equinox, there cease to be any prevailing winds in the northern hemisphere, but variable winds alternate with dead calms and hurricanes, whilst the *S.E. monsoon* prevails throughout the year in the southern hemisphere. In proportion as the northern declination of the sun increases, the temperature of Asia increases more than that of the sea, whilst it falls in New Holland and in Southern Africa. This difference of temperature attains its *maximum* in July and August, months during which constant sea-breezes are found in the southern part of the Indian Ocean. On examining the relative position of the two continents, whose differences of temperature are most distinctly marked, and reflecting that the masses of air which are distant from the equator must be in advance of the earth's rotation in the easterly direction, we feel convinced that this current must come from the S.W.; this monsoon also prevails from the month of April until October. Thus, whilst in the southern hemisphere the S.E. trade-wind prevails throughout the year, on the north of the equator we find the N.E. monsoon in winter, and the S.W. in summer.

These winds penetrate very far into the neighbouring lands, but their direction is changed by the configuration of these continents. To give an idea of the direction which they affect each month, I here give the results of observations made during eight years by **Hardwicke**, at Dum-dum, near Calcutta. The total number of all the winds in each month is designated by 1.

### RELATIVE FREQUENCY OF THE WINDS, IN THE DIFFERENT MONTHS, AT CALCUTTA.

| MONTHS. | N. | N.E. | E. | S.E. | S. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|---|
| January . | 0,238 | 0,132 | 0,066 | 0,053 | 0,037 | 0,074 | 0,118 | 0,283 |
| February . | 0,103 | 0,122 | 0,154 | 0,075 | 0,075 | 0,117 | 0,159 | 0,196 |
| March . . | 0,046 | 0,075 | 0,079 | 0,176 | 0,197 | 0,281 | 0,079 | 0,067 |
| April . . | 0,009 | 0,033 | 0,029 | 0,163 | 0,326 | 0,284 | 0,117 | 0,038 |
| May . . . | 0,004 | 0,029 | 0,091 | 0,226 | 0,358 | 0,209 | 0,049 | 0,033 |
| June . . | 0 | 0,030 | 0,244 | 0,159 | 0,197 | 0,250 | 0,090 | 0,030 |
| July . . . | 0,008 | 0,020 | 0,177 | 0,258 | 0,198 | 0,230 | 0,089 | 0,020 |
| August . . | 0 | 0,073 | 0,238 | 0,226 | 3,117 | 0,246 | 0,081 | 0,020 |
| September . | 0,021 | 0,091 | 0,207 | 0,266 | 0,091 | 0,232 | 0,071 | 0,021 |
| October . . | 0,113 | 0,113 | 0,064 | 0,081 | 0,073 | 0,165 | 0,097 | 0,294 |
| November . | 0,332 | 0,128 | 0,021 | 0,025 | 0,004 | 0,029 | 0,054 | 0,407 |
| December . | 0,295 | 0,126 | 0,022 | 0,010 | 0 | 0,014 | 0,120 | 0,414 |
| Year . . . | 0,095 | 0,079 | 0,116 | 0,143 | 0,141 | 0,181 | 0,095 | 0,150 |

(*Vide* Appendix, *fig.* 4.)

As a mean for the whole year, the lower strata of air are displaced by 1000 winds blowing at Calcutta, as if 126 winds only had blown from the S. 26° W. with the usual mean force; the other 874 winds being replaced by calm. This direction, however, depends on the seasons; for, if we deduct from these quantities the direction and mutual relation of the winds, we construct the following table:—

DIRECTION, FORCE, AND MEAN RELATIONS OF THE WINDS, IN THE DIFFERENT MONTHS, AT CALCUTTA.

| MONTHS. | DIRECTION. | FORCE. | RELATION OF WEST TO EAST. | RELATION OF SOUTH TO NORTH. |
|---|---|---|---|---|
| January . | N. 23° W. | 0,440 | 1,68 | 0,25 |
| February . | N. 37 W. | 0,146 | 1,34 | 0,63 |
| March . . | S. 10 W. | 0,380 | 1,29 | 3,48 |
| April . . | S. 17 W. | 0,609 | 1,95 | 12,88 |
| May . . | S. 12 E. | 0,633 | 0,84 | 11,11 |
| June . . | S. 11 E. | 0,453 | 0,85 | 10,10 |
| July . . | S. 12 E. | 0,518 | 0,75 | 14,29 |
| August . | S. 25 E. | 0,425 | 0,64 | 6,33 |
| September | S. 31 E. | 0,403 | 0,58 | 4,43 |
| October . | N. 46 W. | 0,306 | 2,16 | 0,42 |
| November | N. 19 W. | 0,708 | 2,82 | 0,07 |
| December | N. 25 W. | 0,726 | 3,47 | 0,03 |

In the winter months, then, we find a marked predominance of N.W. winds; so that, in December, the mean direction is the N.N.W., as if 726 winds out of 1000 blew in this direction. The predominance gradually diminishes: even in March the winds blow more frequently from the south than from the north; the west winds, however, still retaining their superiority over those from the east. This relation ceases, in its turn, in proportion as the meridian altitude of the sun increases; and, at the summer solstice, the wind blows from the S.S.E., a direction diametrically opposed to that of the winter. The winds turn to the west when the declination of the sun is more southerly; and in winter they again settle, without variation, in the west.

The influence of the declination of the sun upon the monsoons is also manifested, on comparing the epochs at which they prevail at different places. The sun arriving later at the zenith of places situated more northerly, the S.W. wind also blows later at those places. At Anjengo (lat. 8° 30′ N.), on the coast of Malabar, it commences as early as April 8; at Bombay (lat. 19° N.), not until May 15, the time at which the sun is seen at the zenith of these two towns. In Arabia, the monsoon appears a month later than on the coast of Africa, fifteen or twenty days later on the coast of Coromandel than in the northern part of the island of Ceylon.

I have very briefly pointed out the general direction of these winds; it is singularly modified in the various localities of the great archipelago, which is on the east of this sea. For the navigator, all these details are of the highest importance; for, by taking advantage of these winds, navigation is rapid and easy. Even in the times of remotest antiquity, they favoured the communications which were then so frequent between India and Egypt. At the fall of the latter empire these relations ceased, and the tradition of these winds was lost; for, had they been known, **Nearcus** would not have made so long and tedious a voyage from the mouths of the Indus to the bottom of the Persian Gulf.

**WINDS OF THE MEDITERRANEAN.**—This succession of regular winds is met with in other countries, although it is nowhere so remarkable as in the Indian Ocean. However, the Mediterranean has its monsoons, which were even known by the ancients, who had indicated their dependence on the seasons by denominating them *etesian** *winds*.

The immense desert of Sahara extends to the south of the basin of the Mediterranean. Deprived of water, and entirely composed of sand and loose flints, it becomes very highly heated, under the influence of an almost vertical sun, whilst the Mediterranean preserves its ordinary temperature. So that, during winter, the air ascends above the desert of Sahara with great rapidity, and, for the most part, passes away towards the north; whilst lower down there are north winds, which extend even as far as Greece and Italy. In the north of Africa, at Cairo, Alexandria, and other places, according to the unanimous testimony of voyagers,

---

* Ἔτος, a year, a season.

none other than north winds are found. All navigators know that, in summer, the passage from Europe to Africa is much quicker than the return; * in winter, on the contrary, when the sand radiates powerfully, the air of the desert is colder than that of the sea; and in Egypt a very cold south wind is felt, which is not nearly so strong as the north winds of summer.

**DESCENT OF THE WEST WIND FROM THE HIGHER STRATA IN MEAN LATITUDES.** — We have already described and pointed out the existence of this counter-current to the trade-winds. In proportion as it arrives at the higher latitudes, it loses its velocity and its heat, and descends at about the 30th parallel. This is the origin of the S.W. winds, which prevail even as far as the pole in the northern hemisphere. At sea, these winds blow with so much regularity, that the voyage from America to Europe is much more easy than the return. Thus, from a mean of six years, the packets calculate on 40 days to go from Liverpool to New York, and only 23 days to return from New York to Liverpool. †

---

* The present frequency of navigation between France and Algiers has, for some years, given us better opportunities of appreciating the normal state of the winds in the western part of the Mediterranean basin. North winds are decidedly those which predominate. This frequency of north winds is gathered from several indications. Thus, if we compare the semi-mean of the outward and homeward trips between Toulon and Algiers, we find that the homeward trip is longer by one-fourth for a sailing vessel, and by one-tenth for a steam-vessel. The effect cannot be attributed to the currents; for they are very feeble. Then all the declivity north of the islands of Majorca and Minorca, and especially of the latter, is brushed with the same wind, which occasions a very sensilbe check in vegetation. These winds prevail at Algiers, Toulon, and Marseilles.

In winter they attain their greatest violence between the coast of Provence and that of Africa.

By the intervention of these north winds the sea-breeze of the coasts of Africa, which results from the thermometric aspiration exercised from the north toward the south by the burning sands of Sahara, is associated with the north winds that prevail in Provence, and in the whole of the basin of the Rhone. We are, therefore, permitted to believe that all these winds have a common origin.

In summer, the prevailing wind of the Mediterranean basin is the N.E. This wind is probably nothing more than the lower trade-wind. The line of *maximum* temperature is divided by the effect of the sun, at about 20° north latitude, and it is not astonishing that the lower trade-wind extends 20° more to the north; but this wind is far from having the regularity of the trade-winds of the two oceans.

The north wind also predominates in the western part of the same basin. So that in Egypt, from the 15th of May to the 15th of October, the winds constantly blow from the north and the north-west. In the winter, their direction is less constant; but the predominance of north winds is still very marked.—M.

† To make these calculations entirely satisfactory, the mean velocity of the *Gulf Stream*, which favours the return to Europe, should be taken into account.

The N.E. trade-wind advances more towards the north in the Atlantic Ocean in summer than in winter. Thus the observations of **Heinecken,** who abode several years at Madeira, teach us that the north winds are predominant throughout the year, especially in summer, when the south winds do not blow at all. The trade-wind is even felt on the coast of Portugal. Meteorological observations continued for four years at Mafra prove that the mean direction of the wind there is N. 3° E., with the same force as if 836 out of 1000 winds blew in this direction, while in winter the south winds are more common.

The region in which the two winds interchange extends more or less towards the north. During the winter, the places in which both blow regularly are separated by a belt, where variable winds alternate with calms and violent gales. If you consult the journals of ships sailing from Europe to the southern hemisphere, you will see that they are almost always assailed by squalls before reaching the region of the trade-winds.

It is almost a general rule, that gales are not felt except in latitudes where regular winds do not prevail; for example, in the region of calms, or even in the Indian Ocean, when the monsoons change. It is the same in our countries. The following confirms this general thesis,—that if two currents run one beside the other, but in an opposite direction, there are found in the limit which separates them either perfectly calm waters, or else whirlpools. Examine the conflux of two rivers in the angle formed by the two currents; the water is in some places perfectly smooth, then agitated, to return immediately to calm. In like manner, when the N.E. wind prevails below, and the S.W. above, violent whirlwinds are formed at their limits, which descend to the surface of the earth, and are often endowed with prodigious force.

**GENERAL DIRECTION OF THE WINDS IN MEAN OR HIGHER LATITUDES.**—The trade-wind, which comes down in our latitudes, is the cause of the frequent occurrence of the lower S.W. winds that prevail in high latitudes. In my *Treatise on Meteorology*, I have pointed out the relative frequency of these winds at a great number of places in Europe and America; I will at present content myself with a few countries. Designating the total number of winds that blow in a given time by 1, the following decimal fractions will indicate their relative frequency. Or, which comes to the same thing, we may designate the total number of winds by 1000; then these decimal fractions become whole numbers.[*]

### RELATIVE FREQUENCY OF THE WINDS IN DIFFERENT COUNTRIES.

| COUNTRIES. | N. | N.E. | E. | S.E. | S. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|---|
| England .. | 0,082 | 0,111 | 0,099 | 0,081 | 0,111 | 0,225 | 0,171 | 0,120 |
| France and the Low Countries | 0,126 | 0,140 | 0,084 | 0,076 | 0,117 | 0,192 | 0,155 | 0,110 |
| Germany.. | 0,084 | 0,098 | 0,119 | 0,087 | 0,097 | 0,185 | 0,198 | 0,131 |
| Denmark.. | 0,065 | 0,098 | 0,100 | 0,129 | 0,092 | 0,198 | 0,161 | 0,156 |
| Sweden.... | 0,102 | 0,104 | 0,080 | 0,110 | 0,128 | 0,210 | 0,159 | 0,106 |
| Russia and Hungary. | 0,099 | 0,191 | 0,081 | 0,130 | 0,098 | 0,143 | 0,166 | 0,192 |
| North America...... | 0,096 | 0,116 | 0,049 | 0,108 | 0,123 | 0,197 | 0,101 | 0,210 |

(*Vide* Appendix, *fig.* 5.)

The mere inspection of the preceding table shews the predominance of S.W. winds; for, in all these countries, the most frequent wind blows from a point in the western semi-circumference of the horizon. If we deduce the mean direction from these indications, as well as the relative force of the mean wind, we construct the following table:—

---

[*] It is not without interest to remark, that the mean direction in France is not every where the same. From the researches of M. FOURNET (*Annales de la Société d'Agriculture de Lyon*), our country, in respect to the distribution of winds, may be divided into three regions: 1st. the Atlantic region, which embraces the centre, the N.E., the N., and the W. of the kingdom, and of which the prevailing wind is the S.W.; 2d. the basin of the Rhone, where the N. wind blows from Dijon to the latitude of Viviers; 3d. the Mediterranean region, the west part of which presents winds directed from the W. to the E., whilst the east part of the same zone (Provence) is under the sway of the N.W. winds. At Paris, according to the list of meteorological observations made by M. BOUVARD, from 1806 to 1826, the relations are as follows: north, 0,127; north-east, 0,106; east, 01,64; south-east, 0,065; south, 0,173; south-west, 0,181; west, 0,190; north-west, 0,094. (*Mém. de l'Institut*, t. vii. p. 332).—M.

## DIRECTION, FORCE, AND MEAN RELATIONS OF THE WINDS IN DIFFERENT COUNTRIES.

| COUNTRIES. | DIRECTION. | FORCE. | RELATION OF WEST TO EAST. | RELATION OF SOUTH TO NORTH. |
|---|---|---|---|---|
| England . | S. 66° W. | 0,198 | 1,77 | 1,33 |
| France . | S. 88 W. | 0,133 | 1,52 | 1,03 |
| Germany . | S. 76 W. | 0,177 | 1,69 | 1,18 |
| Denmark . | S. 62 W. | 0,177 | 1,54 | 1,31 |
| Sweden . | S. 50 W. | 0,200 | 1,61 | 1,44 |
| Russia . | N. 87 W. | 0,167 | 1,66 | 0,97 |
| N. America | S. 86 W. | 0,182 | 1,86 | 1,01 |

Thus, not only are the west winds more prevalent than the east, but their mean direction also comes from a region situate between the south and west. With regard to the final displacement of the air, all these winds may be replaced by any wind which would blow for 175 days from this point of the horizon, the other 825 days being entirely calm; or they might be replaced by a constant wind, the velocity of which would be $\frac{175}{1000}$ of the mean velocity of the winds of the locality. The interior of Russia is the only country where the mean direction is a little to the north of west; but yet the number of observations is not sufficient to enable us to deduce any thing conclusive. Moreover, the mean direction differs but a few degrees from that observed in France. We might imagine that this anomaly occurs from these countries being very far from the Western Ocean; but observations made at Tobolsk, during ten consecutive years, give, for the mean direction of the wind, S. 67° W. This result only differs one degree from that which we have obtained for England. In America, we find analogous laws; so that we are enabled to generalise for all the northern hemisphere the fact of the predominance of westerly winds.*

---

* M. Lartigue, captain of a brig, published in 1840 an important work, entitled *Exposition du Système des Vents.*

The author regards the two polar currents, and the trade-winds which

**FREQUENCY OF NORTH-EAST WINDS.**—Remembering what we have seen respecting the origin of the trade-winds, we might expect to find in our own countries regular winds from the N.E., because their temperature is more elevated than that of the countries situated further to the north. The N.E. winds are neutralised by the S.W. current which comes from the equator; but on approaching the pole the force of this current diminishes, and a great many navigators, and among them **D. R. Forster,** speak of having again met with the N.E. winds in the polar seas.

The S.W. current could not entirely neutralise the N.E. winds, for the air that comes from the equator to the pole must return to the equator, or there would be no atmosphere between the tropics. On examining the table of the relative frequency of winds, we shall see that the numbers go on diminishing from the S.W. to the north; they then increase again and attain a second *maximum* at the N.E.; the figures then again diminish to the south. Thus, in mean latitudes the predominant winds are N.E. and S.W. One of these winds, the S.W. for instance, regularly blows over the two seas, whilst in the interior of the continents it is the N.E., as M. **Dove** has maintained; but this is one of those questions which cannot be decided for want of simultaneous observations. If this supposition were verified, we should know by what route the masses of air that are driven to the pole by the S.W. wind return towards the equator.

**VARIABILITY OF THE WINDS IN OUR COUNTRIES.**—We have just established the two general directions of wind that exist in our hemisphere. However, meteorological registers present to us the indication of a great number of winds which blow from all parts of the horizon. When we compare corresponding observations made in many localities of Europe, we are not slow in recognising that these

result from them, as the base of the system of winds; he names them *primitive winds*. He lays down the variations of the trade-winds according to their distance from the polar currents, the effects which result from their junction, and the formation of the variable winds of the torrid zone. Then he passes on to the history of secondary winds, and shews that the intensity of the variable winds of the torrid zone depends on that of the trade-winds. He then examines the manner in which the winds displace each other. The author attributes to the rotation of the earth very little influence over the direction of the trade-winds; the diurnal motion of the sun, and the configuration of countries, appear to him to have a much greater action. Finally, he gives some very curious details on the circular currents of air which are met with between Malaga and Gibraltar, and near the channels that separate the Antillas. A more detailed analysis of this work would be unintelligible without having before us the large hydrographic chart which accompanies it.—M.

winds involve no other causes than differences of temperature. Suppose, for instance, that a general S.W. wind occupies the upper regions, but that the western part of Europe is very hot, while the eastern regions remain very cold with a clouded sky. This difference of temperature will immediately give rise to an east wind; and when this wind meets that from the S.W., there will be a S.E. wind, which may be transformed into a true south wind. These differences of temperature explain the existence of almost all winds. Now, suppose that a region is unusually heated, and that there is no prevailing wind, then the hot air will flow in on all sides; and, according as the observer is on the north, the east, the south, or the west, he will feel a different wind blowing from the corresponding points of the horizon. However, to put this fact beyond doubt, we need corresponding observations embracing a great number of localities.

M. **Dove**, in a simple and ingenious manner, has deduced the production of other winds from the reigning S.W. and N.E. winds. Suppose, for instance, that the N.E. and the S.W. blow at some distance with great regularity, the one at *a*, the other at *b* (pl. II. fig. 2), they will meet somewhere along the line *cd*, for example. Whirlwinds will necessarily be produced there, in the direction of the arrows drawn in the circumference of the circle, that touches the region of the two winds. If, from the middle of the S.W. current *a*, we direct our course toward *b*, we shall find, at the north, a wind blowing from the S.W., from the west, or from the N.W.; at the south, on the contrary, we shall find winds blowing from the N.E., the east, or the S.E. Let us now imagine at the east of the N.E. current, *b*, a second S.W. current at *e*, we shall also find whirlwinds turning in the opposite direction, that is to say, in the directions N.E., north, and N.W.

Not only does M. **Dove** explain, by this theory, the origin of all winds, but he concludes that they must succeed in a certain order. Indeed, if the limit which separates the two winds is displaced towards the west, the direction of the wind changes in the same place. In mean latitudes, where the S.W. wind is not arrested by inequalities of soil, it blows to the west of an observer placed on the coast of Europe, whilst the N.E. wind reigns in the interior of the continent. If the latter extends, which is almost always the case, since the air must return from the poles to the equator, the limit of the two currents is displaced towards the west; and the observer will see the wind gradually turn from the S.W., the west, and N.W., to the north, and finally to the N.E. Thus the succession of phenomena is the same as if we had travelled from *f* to *g*. But the S.W. wind is gradually re-established in the upper regions of the atmosphere; whirlwinds are produced there; the winds come from the west and the S.W.; whilst, at the surface of the earth, the vanes indicate the N.E. or rather the east. The S.W. wind, as it descends, in the interior of the continent, drives back the N.E.: the wind turns to the south, and finally settles at the S.W. We may conceive that, in these transitions, the winds pass, in a short time, through all the points of the horizon, and blow in very different directions. It may then happen that the wind does not pass regularly from the west to the north, but that it turns in a contrary direction; for the whirlwinds produced by the meeting of the currents are displaced with them, and can rarely be completely observed in the same locality. The displacement of a whirlwind appears to us as a transition, for example, of the winds from the east to the west, if this whirlwind is displaced from the north to the south.

In the regular succession of phenomena, the wind should turn like the sun from the east to the south and to the west. M. **Dove** has collected a large number of observations from all parts of Europe, and has found that, in the northern hemisphere, wind passes more frequently from the east to the west by the south; and, in the southern hemisphere, from the east to the west by the north.

This conflict between the S.W. and the N.E. winds is the more interesting to us, inasmuch as it determines almost all the temporary changes, and as the predominance of one or other characterises seasons and even entire years. In the sequel, we shall frequently return to this subject. Let it suffice to have pointed out the fact, and to draw attention to the difference which exists between these two winds, one of which, the S.W., is hot and moist, whilst the other is cold and dry.

**INFLUENCE OF SEASONS ON THE WINDS.**—Hitherto we have only considered the mean direction of the wind in high latitudes. But, on reflecting that the continent is hotter in summer, and colder in winter, than the sea which is contiguous to it, the sea-winds ought to predominate during the hot season, and the land-winds during the cold. This alternation is, moreover, very sensible on the eastern coast of America. **Franklin** had long ago observed, that in summer the winds are in the south, and in winter, in the north. The latter often blow with great violence in the Gulf of Mexico.

In Europe, we find similar relations. The mean direction of the wind in winter, in Paris, is S. 48° W.; in summer it is N. 88° W. This result is confirmed in a great number of places in Europe. **Schouw**, in summing up all these observations, has established the following laws :—

In *winter*, the direction of the wind is more southerly than during the rest of the year; in January its force attains its *maximum*.

In *spring*, east winds are common; at certain places in March; at others, in April. They diminish the force of the west current, which, in many countries, is at that time weaker than during the rest of the year. The relation of north to south winds is not constant, and varies according to the localities. In some, the direction is more northerly, in others more southerly, than the mean direction of the year.

In *summer*, especially in July, the winds blow chiefly from the west; their predominance over east winds attains its *maximum;* and, at the same time, the north winds become more common; whence it follows that the mean direction of the wind in this season is north of the annual mean.

In *autumn*, the predominance of west winds diminishes; those of the south more frequently blow, especially in October: so that, in many localities, the general direction is more southerly than in all the other months.

**ON THE MODE OF THE PROPAGATION OF WINDS.**—Does a wind first blow in the country whence it comes, or in that whither it goes? Is an east wind, for example, first felt in the eastern countries, or in the western parts of Europe? This is a question that has often been agitated, without our having been able to resolve it in such a manner as will satisfy every individual case. I think that nothing positive can be said on this point; and I should be induced to believe that the wind commences in a point situated in the middle of the region which it occupies, and that it is thence propagated onward in each direction. The land and sea-breezes, the cause of which is well known, confirm what I have advanced. The sea-breeze is first felt on the coast; then, after some hours, in the interior of the land and in the open sea. It will follow, therefore, that an east wind will blow first in Germany, and a little later in Holland and Russia.

Since **Franklin's** time it has been generally admitted, that winds are rather felt in the countries towards which they blow than in those whence they come. He quotes an observation favourable to this theory. One day, a strong N.E. wind arose about seven o'clock in the evening at Philadelphia, and prevented an eclipse of the moon from being observed. This gale was also felt at Boston, situated to the N.E. of Philadelphia, but not until eleven o'clock in the evening. A violent S.W. wind, which ravaged the United States, on the 12th of June, 1829, first blew at Albany, and then at New York, which is situated more to the south. However, there are numerous exceptions to this rule. The terrible hurricane from the S.W., on the 29th November, 1836, passed over London at ten o'clock in the morning; at the Hague, at one o'clock; at Amsterdam, at half-past one; at Embden, at four; at Hamburg, at six; at Lubeck, Bleckede, and Salzwedel, at seven o'clock; and finally, at Stettin, at half-past nine in the evening. It was, therefore, transported in the same direction as that in which it blew; and it took ten hours to traverse the space which separates London from Stettin; consequently, its velocity was 36 metres per second, or 12960 metres per hour.

**PHYSICAL PROPERTIES OF CERTAIN WINDS.**—When winds come from distant countries, they possess a part of the properties by which those countries are characterised. Thus, the west winds, that blow from the sea, are much more moist than the east, which traverse continents. The latter, particularly when they are N.E., are very cold, especially in spring; and they give rise to a great number of rheumatic affections. The very opposite sensations, produced by violent south or north winds, are much more marked in countries whose inhabitants live in the open air. I should not have mentioned these differences had not these winds been characterised by particular denominations.

COLD WINDS.—In the south of Europe the north winds are celebrated for their violence and their severity. The opposition between the elevated temperature of the Mediterranean and the Alps covered with snow gives rise to aerial currents of extreme rapidity. If their effect is added to that of a general north wind, there is produced a *north-east wind*, having a violence of which we can form no idea. In Istria and Dalmatia this wind is known under the name of *bora*, and its force is such that it sometimes overturns horses and ploughs. It is the same up the valley of the Rhone, where a very cold south wind often prevails, which is named *mistral*, and which is not less formidable than the north wind, known in Spain under the name of *gallego*.

HOT WINDS.—Large deserts and plains covered with but little vegetation engender very hot winds, which have given rise to marvellous stories, and still more extraordinary explanations. These winds prevail in the vast deserts of Asia and Africa, where we only find here and there a few oases of vegetation, in narrow valleys, where moisture may be preserved for some time. Nomade tribes travel over these deserts. Along the great rivers, such as the Nile, the Euphrates, and the Tigris, the earth is cultivated, and in those localities may be found commercial centres existing from the remotest antiquity, but which have no mutual communication, except by traversing the desert.

In all ages the Arab of the desert, a poor nomade, has detested the inhabitant of cities, who leads a comfortable and quiet life. Sometimes also he attacks cities to plunder them and lead the inhabitants into slavery, in order to sell them or to require a high ransom. Thus it is that Joseph was sold as a slave, and that the Jews, a nomade people, stole the precious vessels of the Egyptians, who, from the time of Moses, have not ceased to hate these wandering tribes. To the inhabitants of cities, the desert was the theatre of most exaggerated scenes of horror. Every marvellous tale of extraordinary adventures found in them credulous or prejudiced auditors; like as, in our days, the Turks form the most false and ridiculous ideas of Europe. The inhabitants of the desert did not care to eradicate these errors, for they constituted their strength; on the contrary, they supported them every time that they visited the cities. The merchants, who had traversed the desert, alone knew the truth; but they were in small numbers, made great profits in these voyages, and sought to frighten those who might be tempted to imitate them. Thus these opinions spread more and more among the multitude.

The Arabian writers are full of falsehoods on every thing relating to the desert. European travellers have even surpassed them. The Mahometan believes that he is performing a meritorious work in deceiving the infidel and closing to him the entrance to the desert. All those who have gone thither have profited well by these ridiculous stories, the exaggeration of which the Arabs themselves have confessed to them. **L. Burckardt,** of Bâle, is the first who has furnished us with positive information upon the phenomena of the desert, and especially on the winds that prevail there. He has thus reduced to their true value the fantastic accounts of his predecessors, **Beauchamp, Bruce,** and **Niebuhr.**

In Arabia, Persia, and the greater part of the countries of the East, the burning wind of the desert is named *samoun*, *simoum*, *sémoun*, from the Arabic *samma*, which signifies at once hot and poisonous. It is also called *samiel*, from *samm*, poison. In Egypt it is called *chamsin* (fifty), because it blows for fifty days, from the end of April until June, at the commencement of the inundation of the Nile. In the western part of Sahara it is known under the name of *harmattan*. The name *samoun* is most generally employed; but translators have always insisted on the meaning, *poison*, without reflecting that, like children, uncivilised people call every thing poison which is disagreeable or dangerous.

The dry soil of these countries becomes prodigiously heated, but without the heat penetrating deep, because the quartz sand, which covers them, is a bad conductor of heat: so that the thermometer is sometimes seen to attain 50° in the shade of a tent. If the wind rises it must be burning, and must transport sand and dust, which obscure the rays of the sun. The same occurs, if travellers may be believed, in the deserts of Nubia, on the coast of Guinea, and along Senegal. During a period of calm the ascending current of heated air is of itself sufficient to carry up the sand. **Pottinger** observed a phenomenon of this kind in the desert of Beloochistan. The surface of the soil there is uniformly covered with a fine sand, coloured red with iron, which, being the sport of the winds, forms undulated hills from three to six metres high. Towards mid-day these hills seemed to have disappeared, the sand was raised about three decimetres above the general level, and at each step we could fancy we were placing our foot on a plane raised three decimetres above the summit of these hills. This phenomenon was rarely evident in the evening and morning.

A strong wind raises a much more considerable quantity of sand; the troubled appearance of the horizon then announces the arrival of the *samoun;* afterwards the sky becomes obscured and the sun loses its brilliancy, paler than the moon, its light no longer projects a shadow; the green of the trees appears of a dirty blue, the birds are restless, and the affrighted animals wander in all directions.

The rapid evaporation occurring at the surface of the human body dries the skin, inflames the throat, accelerates respiration, and causes a violent thirst. The water contained in the skins evaporates, and the caravan is a prey to all the horrors of thirst. It is thus that, since the expedition of **Cambyses**, more than one caravan has perished in this desert; but we must class among Arab tales those histories of pestilential winds the contact of which causes death, and which, like a cannon-ball, traverse a troop and choose out their victims. When the Arabs cover their face it is that the sand may not penetrate either into the eyes or into the mouth. For the same reason it is that camels turn their head from the side opposed to the wind; they never perform this manœuvre unless sand is in the air. "In June, 1813," says **Burckardt**, "in going from Siout to Esné, I was surprised by the *samoun* in the plain which separates Farschiout from Berdys. When the wind arose I was alone, mounted on my dromedary, and at a distance from every tree and habitation. I endeavoured to protect my face by wrapping it in a handkerchief. Meanwhile, the dromedary, into whose eyes the wind drove the sand, became restless, commenced galloping, and caused me to lose the stirrups. I remained lying on the earth without moving from the spot, for I could not see to a distance of ten metres, and I wrapped myself up in my clothes until the wind had abated. I then went to search after my dromedary, which I found at a very great distance, lying down near a bush that protected his head against the sand raised by the wind." **Burckardt** never experienced any thing particular at the times when he was exposed to the *samoun*. **Malcolm** and **Morier**, who have traversed the deserts of Persia, and **Kerr Porter**, who has visited that which is at the east of the Euphrates, agree with him in this point. In the latter country the inhabitants daub their bodies with wet mud, and those of western Africa anoint themselves with fat, in order to prevent the skin from cracking in consequence of too rapid an evaporation.

The deserts of Asia and Africa are the countries where these hot winds shew themselves in all their force. However, in India, which is covered with a rich vegetation, at Chili, in Louisiana, and in the great plains (*llanos*) of Oronoco, certain winds have a very elevated temperature. All the land-winds, which blow on the coasts of New Holland, are hot and dry. When the N.W. wind prevails for any time at Paramatta, all the plants wither; and the ill success of the attempts at cultivation, undertaken by the English in this country, is due to no other cause. Even in Europe we have the *solano* of Spain, and the *sirocco* of Italy, which throw the majority of individuals into a condition of peculiar languor. These winds probably arise in the plains of Andalusia, or on the arid rocks of Sicily; they are much more violent on the north than on the south coast of the island, and it is useless to seek after their origin as far off as the deserts of Africa.

# III.

# ON AQUEOUS METEORS.

Daily experience proves to us that the hygrometric state of the atmosphere is continually varying. During storms, water is precipitated from the clouds in torrents, or else it is slowly deposited in the state of dew; sometimes the air is so dry that wood is warped, and then water evaporates with great rapidity in open vessels. We designate all these phenomena by the collective name of *hydrometeors*, a word derived from the Greek ὕδωρ, water, and which signifies aqueous meteors.

**GENERAL REMARKS ON GASES AND VAPOURS.**—Water, in passing into the state of an aëriform body, occupies much greater space than that which it filled while it remained in a liquid state. So that water can exist under two different forms, having nothing in common except the extreme mobility of the component molecules, which are separated and move easily one over the other. In solid bodies, on the contrary, a greater or a less effort is necessary to separate the molecules of which they are composed. The particles of water have, however, a tendency to approach and form little spherical masses. In gases, properly so called, this tendency does not exist, and all the molecules are mutually repulsive; hence results an expansive force for the entire gas. It is also almost an impossibility to approximate or to separate the molecules of water while in the liquid state; whilst a volume of gas, however small it may be, will always entirely fill a vessel of any capacity. Place a bell-glass on the plate of an air-pump, and make as perfect a vacuum as possible; there will, nevertheless, be air in every part of the glass. The following experiment proves that the air is actually dilated; to wit, if we place a tied and flattened bladder under the receiver, it will swell out in proportion as the vacuum is made, but will return to its former condition, as soon as the air is allowed to re-enter the glass. There is, indeed, an equilibrium established between the repulsive forces of the molecules of air contained in the bladder, and those which fill the receiver.

We may convince ourselves of the truth, without the use of philosophical apparatus. Take a small quantity of sulphuret of potassium and pour on it sulphuric acid, a gas will be liberated that smells powerfully of rotten eggs; however small may be the volume of the gas, it will not fail to fill a large room. It is the same with a drop of ether, when evaporated; and philosophy shews that this law is applicable to all gases without exception.

If the attraction of the earth did not neutralise this expansive force of the air, it would escape into space, and our globe would have no atmosphere. Attraction here plays the same part, as do the sides of the vessel in the experiment that we have related. Air, when subjected to this force of attraction, becomes a heavy body, like all others on the surface of the globe. So also a balloon, when void of air, is lighter than the same balloon when full.

Although the particles of gases incessantly tend to separate from each other, we may nevertheless easily diminish the volume of a certain mass of air. A bladder becomes smaller when compressed. A piston may be driven into a hollow cylinder of the same diameter, although it is hermetically sealed; but, as soon as we cease pressure on the piston, the air expands and drives it back. Provided the aëriform bodies do not pass into the liquid state, the spaces occupied are inversely proportional to the compressing forces; that is to say, under a double, triple, quadruple, &c. pressure, they occupy one-half, one-third, or one-fourth of the primitive space.

**PHYSICAL COMPOSITION OF THE ATMOSPHERE.**—Each of the molecules of which it is composed, by virtue of its gravity, exercises a pressure on the molecules situated beneath it; this pressure is added to their proper gravity, and contributes, in combination with the action of the terrestrial globe, to retain them around it. In a vertical column of the air, strata of greater density are found near the ground; this density diminishes in proportion as we ascend, because the portion of the atmosphere, placed beneath the observer, does not exercise any pressure on those portions which are placed at a level with him. The barometer, by which this pressure is measured, is lower at the summit than at the foot of a mountain; and so intimate a relation exists between the pressure and this height, that the difference of level of those spots may be deduced from the difference in the length of the barometric columns observed simultaneously at these two stations.

The more the pressure diminishes, the more does the air tend to dilate; so that, at first sight, it would seem that the atmosphere must extend to a very great distance. We might imagine that it is not till the distance of several myriametres that the density could be sufficiently reduced to be entirely neglected. Experience has not taught us what becomes of those particles of air, whose density would be infinitely more feeble than it is at the surface of the earth. If their expansion were indefinite, they would be diffused into celestial space, and each of the bodies moving there would form an atmosphere by attracting them to itself. Astronomical observations do not favour this hypothesis, and it is probable that the atmosphere of the earth is limited. The distance of the limit is not yet well known; we merely know that, at the height of about seven myriametres, the rarity of the air is such that we may consider this as the limit of the atmosphere.*

---

* M. Biot has lately published some learned researches on the physical constitution of the atmosphere; they have led him to a condition, which assigns a higher limit to the terrestrial atmosphere. He has borrowed the elements of his calculations from three series of barometric, thermometric, and hygrometric observations, made at successive stations by MM. Gay-Lussac, Humboldt, and Boussingault.

M. Gay-Lussac ascended in a balloon, in Oct. 1803, to a height of 6977 metres above the observatory at Paris. The number of intermediate observations is twenty-one.

In the month of June, 1802, M. de Humboldt made observations at five successive stations, as he ascended from the plains at the foot of Chimboraço to the top of the mountain. The first station was 2418, the last 5879 metres above the level of the sea.

Finally, in 1827, M. Boussingault made three series of meteorological observations in his ascents up Chimboraço and Antisana, to the heights of 5900 and 5400 metres above the level of the Pacific Ocean. The Chimboraço series comprehends eight elevated stations, commencing at the height of 2700 metres. Each Antisana series comprehends nine, commencing at 2500 metres.

In order to deduce the height of the atmosphere from these observations, M. Biot first reduces the barometric columns of the different stations to zero; then he reduces them all to the lowest weight, by calculating the correction which each requires from the relative elevation of the station. Dividing all these columns thus reduced by the lower column, he obtains the successive pressures, in fractions of the lower pressure taken as unity.

M. Biot then deduces the densities corresponding to these pressures, from the concomitant temperatures of the air, admitting with M. Gay-Lussac, that the air diminishes $\frac{1}{267}$th of its volume for every centigrade degree of cold. He takes account at the same time of the tension of the aqueous vapour. The densities thus obtained are compared with the lower density of their proper unity, in the same way as was done for the pressures.

**DIFFERENCES BETWEEN GASES AND VAPOURS.**—Aëriform bodies are naturally divided into two classes; some always remain in the gaseous or elastic state, and are called *gases* or *aëriform* bodies,[3] others, under the influence of various circumstances, pass into the liquid state, and are termed *vapours*. Among the agents which determine this change, temperature and pressure must occupy the first rank. Bend a common barometric tube, ABC (pl. II. fig. 3), so that the branch BC is parallel to the branch AD, and close it at C; adapt a scale to the branch BC, which shall indicate the number of cubic millimetres contained in CE, or any portion of the tube CB; adapt in like manner a scale divided into millimetres to the branch AD, dry the interior of the tube by placing it in connexion with a vessel containing anhydrous sulphuric acid, then pour mercury into the longer branch so that it shall be in equilibrium at D and E. The quantity of air contained in CE is no longer in communication with the atmosphere, but is subject to a pressure that is indicated by the height of the barometer. If we pour mercury into the long branch until the column is at F, it will only ascend as far as G in the short trough. Draw through the point G the horizontal line GH, and the measure of the pressure will be obtained by adding the length GH to that of the barometric column observed during the time of the experiment. If FH is equal to the length of the barometric

---

We thus obtain the coexistent values of these two elements, for all the points of the aërial column, where the stations have been established. Taking, then, the pressures as abscissæ, and the densities as ordinates, M. BIOT finds that the curve, which passes through all the stations, is sensibly a straight line. He hence concludes that the decrease of temperature goes on incessantly accelerating to the highest stations to which we have been able to attain. Thus, according to M. BIOT, we must not conclude that further on, and in the inaccessible regions of the atmosphere, this decrease begins to be reduced; and, among the hypotheses that may be adopted, the most favourable to a very elevated atmosphere, will then be that of a constant decrease beyond the height of 6977 metres, the upper limit of the aërostatic stations of M. GAY-LUSSAC. At present, beyond that elevation, M. BIOT substitutes for the real atmosphere a fictitious atmosphere, having at this height the same density, the same degree of pressure, the same heat, and the same local decrease of temperature as the true atmosphere; but subject further to the arbitrary condition that the decrease remains constant, and such as M. GAY-LUSSAC has observed it. Such a condition, joined to the laws of equilibrium, completely defines it; and from the physical elements of the stratum, where it commences, its total height joined to that of this stratum, is 47346 metres. Now, in the real atmosphere, the decrease of temperature being further accelerated beyond 6977 metres, he finds that its limit is lower than that of the fictitious atmosphere, or at 47000 metres. The equatorial series of MM. de HUMBOLDT and BOUSSINGAULT, give even 43000 metres for this upper limit. (Vide *Comptes rendus de l'Académie des Sciences*, t. viii. p. 91; and t. ix. p. 174 [1839].—*Additions à la Connaissance des Temps de* 1841.—*Mémoires de l'Académie des Sciences*, t. xvii.—*Astronomie Physique*, t. i. p. 165.)—M.

[3] *Vide* Note *c*, Appendix II.

column, the air contained in GC will be subject to the pressure of two atmospheres; then CG will be equal to the half of CE, and the air will occupy a space one-half less than that which it occupied under the pressure of one atmosphere. By increasing the pressure, we shall succeed in establishing **Mariotte's** law, already announced, p. 59, that the spaces occupied by gases are inversely proportional to the pressures.

Dry air obeys this law under every pressure hitherto tried. If the air is moist, it will follow the law under feeble pressures; but, under high pressures, the spaces will become less than they would have been had the air been perfectly dry; for, under such circumstances, a portion of the vapour of water condenses and passes into the liquid state, and drops of water are even observed within the tube CE.

The difference between gases and vapours may be demonstrated by another experiment. Take three barometers which have been well boiled, and which correspond well. Designate the three instruments by the letters A, B, and C. Divide the barometric chambers of B and C into parts of equal capacity. Send up a bubble of dry air into the vacuum of B. The dilatation of this air will lower the column of B, which will remain lower than that of A. The difference will give the measure of the elasticity of the gas at this temperature. Send up a drop of liquid into the barometric chamber of C, it will be converted into vapour, which will depress the mercury; and the quantity of this depression, compared with A, will give the tension of the vapour of water at that temperature. Plunge the two tubes B and C vertically into a mercury cup, their mercurial columns will always be shorter than that of A; but the difference between A and B will continue increasing in proportion as the air is more compressed—a proof that its elasticity increases, while the difference between A and C remains invariable. The vapour, therefore, of water has always the same elasticity in a filled space, whether this space be great or small; for, as soon as this space is contracted, a part of the vapour of water passes into the liquid state. It is only while the space is not saturated that the vapour acts as a gas, until the space is sufficiently contracted to be saturated.

Temperature produces the same effects as pressure. Suppose the three barometers to be placed in a situation in which the thermometer stands at 20°. Suppose further, that the mercurial column A is $758^{mm}$ long; those of B and C, $740^{mm}$; the elasticity both of the air and the vapour will be equal to $18^{mm}$. Let the instruments be carried to a place where the temperature is at zero; A will not change at first, while B and C will rise, because the reduction of temperature will diminish the elasticity of the air and the tension of the vapour, so that it will no longer depress the mercury to the same amount. Exact measurements will shew that the barometer B will have risen to 741$^{mm}$,13, the barometer C to 752$^{mm}$,32; the elasticity of the air has, therefore, diminished in the ratio of 18 : 16,87, whilst the force of the tension of the vapours has been only 5$^{mm}$,68, and a portion of the vapour has passed into the liquid state. Minute investigations undertaken by philosophers shew that, if *e* represents the temperature of the space occupied by a certain quantity of air at zero; at the temperature *t* this space will become $e \times 0{,}00375\ t$. We shall presently see how the tension of vapour of water, at different temperatures, is measured.*

The passage of the vapour of water into the liquid state, or, in other words, its *precipitation*, gives rise to a multitude of phenomena that are the subjects of daily observation. If in summer a decanter of cold water is brought into a room occupied by several persons, and in which the air is slightly moist, it is instantly covered with dew, for the air in contact with the decanter is cooled down; but as it contains a greater quantity of vapour than would completely saturate it at this temperature, a portion of this vapour passes into the state of liquid: however, this dew does not fail to disappear as soon as the sides of the vessel have become warmed. In winter the same phenomenon is observed on squares of glass. A portion of the vapour of water contained in the chamber is precipitated in the form of dew on the surface of the squares, that have become cold during the night. If the vapour does not find any solid body on which it may be precipitated, it remains suspended in the air under the form of little vesicles, the association of which forms a fog. This fog is very well seen when a vessel filled with water is heated in the open air; the air being unable to dissolve all this vapour, it passes away in a vesicular state.

**CHEMICAL COMPOSITION OF THE ATMOSPHERE.**—When we reflect upon the number of gases and vapours of different kinds that are disengaged at the surface of the globe, we might be induced to believe that we should find them all when we analyse atmospheric air. But their quantity is so small in comparison with the immensity of the aërial ocean that it escapes our means of

---

* According to the more recent researches of MM. RUDBERG, REGNAULT, and MAGNUS, the true value of this coefficient is 0,00366.

investigation. One portion, moreover, serves for the nutrition of animals and plants, or combines with rocks and metals. A very few gases, together with the vapour of water, are all that are found in the atmosphere. Some meteorologists having explained rain and certain other phenomena by chemical reactions, we must here enumerate these component parts.

The analysis of air every where shews us oxygen, nitrogen, vapour of water, and also, almost always, a little carbonic acid. We will presently point out the means by which the quantity of vapour of water may be estimated. Let it suffice to shew how its presence may be rendered evident. Concentrated sulphuric acid, chloride of calcium, and other bodies, have the property of absorbing water with great avidity. If accurately weighed quantities of these different bodies are placed in a watch-glass, it will be seen, after a few hours' exposure to the open air, that their weight has notably increased; and chemical analysis proves that they have absorbed water. To determine the quantity of water contained in a cubic decimetre, for example, of air, we have recourse to the following process: a tin vessel, of the capacity of about six litres, is pierced above and below with two orifices, which may be closed by means of a stop-cock; this vessel is filled with water, and, by means of a cylinder of caoutchouc, an horizontal tube of glass, about three decimetres long, and several millimetres in diameter, is fixed to the upper orifice. This tube contains filaments of asbestos, and fragments of sulphate of lime, or of pumice-stone, moistened with sulphuric acid, and so placed as not to intercept the passage of the air. Before fixing this tube to the apparatus, it is accurately weighed. Both stop-cocks are then opened, and three litres of water are allowed to escape. These three litres of water are replaced by three litres of air, which rush in through the tube, abandoning to the sulphuric acid the vapour of water, with which they are charged. If the tube is again weighed, its weight will be found to have increased, and the increase of weight is equal to the weight of water contained in three litres of air.

Whilst the quantity of the vapour of water varies notably, according to the condition of the atmosphere, the quantities of oxygen and nitrogen remain constant. Oxygen, as we know, supports combustion and animal respiration. This may be proved by procuring oxygen in a state of perfect purity. Close a tube at one of its extremities, then bend it with an obtuse angle, at four or six centimetres from the extremity; introduce within it some red oxide of mercury, or some chlorate of potass. On heating these bodies, the oxygen which they contain is disengaged, and may be collected under a bell-glass filled with water, and inverted in a pneumatic trough. When the glass is filled, an extinguished taper will be rekindled in it, and will burn with greater brilliancy than in the air; and an iron wire twisted into a helix will consume and throw out bright sparks.

When a body burns, oxygen combines with it, and, in consequence of this combination, heat is developed, which when intense become luminous. A new body is the product of this combination. If it is solid and combustible, the oxygen gas entirely disappears. Fill with oxygen a bell-glass inverted over mercury, introduce into it a piece of phosphorus, which can be ignited by means of a lens, all the oxygen will disappear. If, instead of phosphorus, we had introduced under the glass incandescent coals, the oxygen would, in like manner, have disappeared, but would have been replaced by a gas incapable of supporting respiration or combustion. This gas will destroy the transparency of lime-water. These phenomena are easily explained: in the former case, phosphoric acid is formed, which attaches itself to the sides of the vessel in the form of a solid body; in the latter, carbonic acid is produced, which remains in the gaseous state, and does not pass into the solid state until it combines with the lime suspended in the liquid.

In order to measure the quantity of oxygen contained in air, we have merely to enclose in a graduated tube a determinate quantity of air. It is plunged into a mercury bath, and a piece of phosphorus is then introduced into the tube; it is heated, and the phosphorus consumes and absorbs the oxygen, and the difference between the space originally occupied by the air and the volume of gas remaining gives the measure of the quantity of oxygen that it contained. M. **Brunner** has proposed a process analogous to that which is employed in measuring the quantity of vapour of water contained in the air. Fragments of phosphorus are introduced into a tube, it is weighed, and an accurately determined quantity of air is then passed through the tube; the increase of the weight of the tube will be equal to the weight of the oxygen of the air. What remains is nitrogen, a gas that cannot be fixed, and that serves neither for combustion nor for respiration. A little carbonic acid is also found, as well as traces of organic substances.

There also exist other modes of analysis, and all agree in shewing that a volume of atmospheric air is every where composed of oxygen and nitrogen in the following proportions :—

| | |
|---|---|
| Oxygen . . . . . . . | 21 |
| Nitrogen . . . . . . . | 79 |
| | 100 |

Another interesting combination may take place under certain circumstances. If a vessel of known capacity is filled with atmospheric air, and a long series of electric sparks are passed through it, the volume of the air will diminish, and there will be found in the water small quantities of nitric acid, the result of the combination of the nitrogen with the oxygen. Nature often produces this combination on a large scale. M. **Liebig** has shewn that the water of storm-showers always contains a little nitric acid, while the water of ordinary rain does not afford the least trace of it. Thus the changes of weather, and rain in particular, are not a result of chemical combination ; for the nitric acid, which would be precipitated, would have long ago destroyed all life from off the surface of the earth.*

---

* Does not the composition of the air change in the revolution of ages? Is it the same at all heights? MM. Dumas and Boussingault have lately endeavoured to solve these two questions, both of which are equally important in meteorology. Their process of analysis consists in passing perfectly dry air through a tube filled with metallic copper reduced by hydrogen, and furnished with stop-cocks, by aid of which a vacuum can be made. The copper being heated to redness, the stop-cock by which air enters is opened, air rushes into the tube and instantly gives up the oxygen to the metal. After a few minutes the second stop-cock is opened, as is also another belonging to an empty globe, with which it communicates by means of a tube ; the nitrogen is passed into the globe. When this globe is full of nitrogen, or nearly so, all the stop-cocks are closed. The globe and the tube filled with nitrogen are then separately weighed. They are then weighed again, after having been exhausted. The difference of these weights gives the weight of the nitrogen. With regard to the weight of the oxygen, it is furnished by the excess of weight which the tube containing the copper has acquired during the experiment.

The mean of six analyses proves that the composition of the air has not changed since the eudiometric essays were made, thirty-five years ago, by MM. Gay-Lussac and de Humboldt. The difference of 0,01 in the volume of oxygen is due to the comparative imperfection of the means employed at that time. MM. Dumas and Boussingault have also determined again, with the greatest care, the densities of oxygen and nitrogen, in order to be able to convert the weights of these gases into volumes. The composition, therefore, of normal atmospheric air, is as follows :—

| | *In Volume.* | *In Weight.* |
|---|---|---|
| Oxygen . . . . . . . | 20,8 | 23,0 |
| Nitrogen . . . . . . . | 79,2 | 17,0 |
| | 100,0 | 100,0 |

Some time ago, Dr. Dalton had maintained that the proportion of nitrogen must increase as we ascend in the atmosphere; but the analyses made in America by M. Boussingault, at considerable heights, and those

**PENETRATION OF GASES.**—Vapours and gases obey a common law, by which they are entirely separated from liquids properly so called. If we pour into a vessel water, mercury, oil, or other liquids, that do not combine chemically, they arrange themselves according to their specific gravity: the oil will swim at the surface; the water will remain in the middle; and the mercury will occupy the lower part of the vessel. But if we place together, in a vessel, different gases, for example, hydrogen, oxygen, and carbonic acid, the densities of which are in the order in which we have named the gases, we shall not see the carbonic acid descending to the bottom of the vessel, nor the hydrogen mounting to the top, and the oxygen placing itself between them. According to a law discovered by **Berthollet**, and afterwards developed by **Dalton** and **Graham**, gases penetrate mutually in the most intimate manner. A gas which penetrates another conducts itself exactly as if *in vacuo;* and the other gas merely diminishes its expan-

---

of M. Brunner at the summit of the Faulhorn, did not accord with the deductions of MM. Dalton and Babinet.

In order to obtain a definite solution to the question, M. Dumas was desirous of entrusting to me twelve hollow spheres, each of the capacity of eleven litres. A vacuum was made at Paris in each of these spheres to nearly four or five millimetres; the neck of each, having been closed by a stop-cock, was covered with a very thick cap of caoutchouc. At periods which had been previously agreed upon, I collected the air at the summit of the Faulhorn, 2672 metres above the level of the sea, whilst M. Dumas analysed that of Paris, and M. Brunner that of Berne, 540 metres above the sea. Before collecting the air, I examined, with the assistance of M. Bravais, to see that the spheres had preserved the vacuum, by connecting them with a tube plunged into a basin of mercury. The mercury rose under the influence of pressure, and I compared the length of the column with that of a good barometer. These examinations proved that the spheres had retained the vacuum.

M. Dumas, having analysed the air contained in these spheres, found that the composition was sensibly the same as that of the air of Paris and of Berne, for the differences are within the inevitable errors of experiment (for the details, vide *Annales de Chimie et de Physique*, t. lxxviii. p. 257. 1841).

M. Marignac analysed the air of Geneva, and M. Stas that of Brussels, by employing M. Dumas's apparatus. They found its composition identical with that of the air of Paris. But a young Danish chemist, M. Levy, collected the air during a passage from Havre to Copenhagen, as near as possible to the surface of the sea. This air, when compared with that of Copenhagen, and with air collected on the coast of Kronberg with the sea-breeze, and at twelve metres above the level, presented a somewhat less proportion of oxygen, as the following numbers prove:—

| | |
|---|---|
| Mean of the air at Copenhagen . . . . | 2299,8 |
| on the coast . . . . . | 2301,6 |
| in the open sea . . . . | 2257,5 |

So that, for want of any proof to the contrary, we may say that the air has every where the same composition, except at the surface of the sea (vide *Comptes rendus de l'Institut*, t. xiv. p. 360 and 570. 1842).

With regard to traces of carbonic acid, and sulphuretted or carburetted hydrogen, ammonia, and nitric acid, which have been noticed, these are local accidents, that can have no influence over the general mass of meteorological phenomena.—M.

sion. If two spheres of the same capacity are taken, and, after having filled one with carbonic acid gas, which is very heavy, and the other with hydrogen, the lightest of aëriform bodies, and having connected them by means of a very narrow tube, placing the one containing hydrogen uppermost, and the other, containing carbonic acid gas, lowermost, these gases will nevertheless mix, so that each globe will contain an equal quantity of each. The time, necessary for the penetration to take place, depends on the density of the gases. The same law applies to vapours.

The two gases, oxygen and nitrogen, which constitute the atmosphere, are not in a state of chemical combination; but they do not separate so that oxygen shall be below and nitrogen above. They are, on the contrary, continually mixed by the horizontal winds and the ascending currents, which are so visible in mountainous countries. It hence follows that there is no difference in the composition of the atmosphere, when analysed at different heights.*

**TENSION OF THE VAPOUR OF WATER AT DIFFERENT TEMPERATURES.**—We have seen, that at equal temperatures the tension of vapour is the same in a large or in a small space, provided the space is completely saturated. Analogous researches shew that this tension is also the same, whether the space is deprived of air or filled with any gas. The only difference between the two cases is, that a vacuum, containing a sufficient quantity of water, is always in a state of saturation. If, on the contrary, the space is filled with air, a certain time elapses before the vapours spread throughout the entire space.

A very simple process is had recourse to for measuring the tension of vapour at different temperatures. A drop of water is sent up into a barometric chamber, and we notice how much lower the column rests than does that of a good barometer placed at the same level. The difference gives the corresponding tension of the vapour at the temperature simultaneously observed. In order that the results may be exact, tubes of about two centimetres in diameter must be employed, so as to avoid error resulting from capillary depression of the mercury; all the observations must also be reduced to the same temperature of the mercury column. It is the neglect of these precautions that explains the want of agreement between the quantities obtained by different philosophers. I give here two tables; the first constructed by myself, the second by M. **August**:—

---

* *Vide* the preceding note.

# TABLE

## OF THE TENSIONS OF THE VAPOUR OF WATER, IN MILLIMETRES OF MERCURY, FOR EVERY TENTH OF A DEGREE BETWEEN —26° AND 36°, ACCORDING TO **KAEMTZ**.

| Degrees. | TENTHS OF DEGREES. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| —25 | 0,68 | 0,67 | 0,66 | 0,66 | 0,65 | 0,64 | 0,64 | 0,63 | 0,62 | 0,62 |
| —24 | 0,72 | 0,72 | 0,71 | 0,71 | 0,70 | 0,70 | 0,70 | 0,69 | 0,69 | 0,68 |
| —23 | 0,79 | 0,78 | 0,77 | 0,77 | 0,76 | 0,75 | 0,75 | 0,74 | 0,73 | 0,73 |
| —22 | 0,86 | 0,85 | 0,84 | 0,84 | 0,83 | 0,82 | 0,82 | 0,81 | 0,80 | 0,80 |
| —21 | 0,92 | 0,91 | 0,91 | 0,90 | 0,90 | 0,89 | 0,88 | 0,88 | 0,87 | 0,86 |
| —20 | 1,01 | 1,00 | 0,99 | 0,98 | 0,97 | 0,96 | 0,95 | 0,95 | 0,94 | 0,93 |
| —19 | 1,10 | 1,09 | 1,08 | 1,08 | 1,07 | 1,06 | 1,05 | 1,04 | 1,03 | 1,02 |
| —18 | 1,20 | 1,19 | 1,18 | 1,17 | 1,16 | 1,15 | 1,14 | 1,13 | 1,12 | 1,11 |
| —17 | 1,29 | 1,28 | 1,27 | 1,26 | 1,25 | 1,24 | 1,24 | 1,23 | 1,22 | 1,21 |
| —16 | 1,40 | 1,39 | 1,38 | 1,37 | 1,36 | 1,34 | 1,33 | 1,32 | 1,31 | 1,30 |
| —15 | 1,51 | 1,50 | 1,49 | 1,48 | 1,47 | 1,45 | 1,44 | 1,43 | 1,42 | 1,41 |
| —14 | 1,62 | 1,61 | 1,60 | 1,59 | 1,58 | 1,56 | 1,55 | 1,54 | 1,53 | 1,52 |
| —13 | 1,76 | 1,74 | 1,73 | 1,72 | 1,70 | 1,69 | 1,67 | 1,66 | 1,65 | 1,63 |
| —12 | 1,92 | 1,90 | 1,89 | 1,87 | 1,86 | 1,84 | 1,82 | 1,81 | 1,79 | 1,78 |
| —11 | 2,05 | 2,04 | 2,02 | 2,01 | 2,00 | 1,99 | 1,97 | 1,96 | 1,95 | 1,93 |
| —10 | 2,21 | 2,20 | 2,18 | 2,16 | 2,15 | 2,13 | 2,11 | 2,10 | 2,08 | 2,06 |
| — 9 | 2,39 | 2,37 | 2,35 | 2,34 | 2,32 | 2,30 | 2,28 | 2,26 | 2,25 | 2,23 |
| — 8 | 2,57 | 2,55 | 2,53 | 2,51 | 2,49 | 2,47 | 2,45 | 2,43 | 2,42 | 2,41 |
| — 7 | 2,78 | 2,76 | 2,74 | 2,72 | 2,70 | 2,67 | 2,65 | 2,63 | 2,61 | 2,59 |
| — 6 | 2,98 | 2,96 | 2,94 | 2,92 | 2,90 | 2,88 | 2,86 | 2,84 | 2,82 | 2,80 |
| — 5 | 3,20 | 3,18 | 3,16 | 3,13 | 3,11 | 3,09 | 3,07 | 3,05 | 3,02 | 3,00 |
| — 4 | 3,45 | 3,43 | 3,40 | 3,38 | 3,35 | 3,33 | 3,31 | 3,28 | 3,25 | 3,23 |
| — 3 | 3,70 | 3,68 | 3,65 | 3,63 | 3,60 | 3,58 | 3,55 | 3,53 | 3,50 | 3,48 |
| — 2 | 3,97 | 3,94 | 3,92 | 3,89 | 3,86 | 3,83 | 3,81 | 3,78 | 3,75 | 3,73 |
| — 1 | 4,26 | 4,23 | 4,20 | 4,17 | 4,15 | 4,12 | 4,09 | 4,06 | 4,03 | 4,00 |
| — 0 | 4,58 | 4,55 | 4,52 | 4,48 | 4,45 | 4,42 | 4,39 | 4,36 | 4,32 | 4,29 |
| 0 | 4,58 | 4,61 | 4,65 | 4,68 | 4,72 | 4,75 | 4,78 | 4,82 | 4,85 | 4,89 |
| 1 | 4,92 | 4,95 | 4,99 | 5,02 | 5,06 | 5,09 | 5,12 | 5,16 | 5,19 | 5,23 |
| 2 | 5,26 | 5,30 | 5,34 | 5,37 | 5,41 | 5,45 | 5,49 | 5,53 | 5,56 | 5,60 |
| 3 | 5,64 | 5,68 | 5,72 | 5,75 | 5,79 | 5,83 | 5,87 | 5,91 | 5,95 | 5,99 |
| 4 | 6,02 | 6,06 | 6,11 | 6,15 | 6,19 | 6,24 | 6,28 | 6,32 | 6,36 | 6,41 |
| 5 | 6,45 | 6,50 | 6,54 | 6,59 | 6,63 | 6,68 | 6,72 | 6,77 | 6,81 | 6,86 |

**KAEMTZ'S** Table—*continued.*

| Degrees. | TENTHS OF DEGREES. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 6 | 6,90 | 6,95 | 7,00 | 7,04 | 7,09 | 7,14 | 7,19 | 7,24 | 7,28 | 7,33 |
| 7 | 7,38 | 7,43 | 7,48 | 7,53 | 7,58 | 7,64 | 7,69 | 7,74 | 7,79 | 7,84 |
| 8 | 7,89 | 7,94 | 7,99 | 8,05 | 8,10 | 8,15 | 8,20 | 8,25 | 8,31 | 8,36 |
| 9 | 8,41 | 8,47 | 8,53 | 8,59 | 8,64 | 8,70 | 8,76 | 8,82 | 8,88 | 8,94 |
| 10 | 9,00 | 9,06 | 9,12 | 9,17 | 9,23 | 9,29 | 9,35 | 9,41 | 9,46 | 9,52 |
| 11 | 9,58 | 9,65 | 9,71 | 9,78 | 9,84 | 9,91 | 9,98 | 10,04 | 10,11 | 10,17 |
| 12 | 10,24 | 10,31 | 10,38 | 10,44 | 10,51 | 10,58 | 10,64 | 10,71 | 10,78 | 10,84 |
| 13 | 10,91 | 10,98 | 11,05 | 11,12 | 11,19 | 11,27 | 11,34 | 11,41 | 11,48 | 11,55 |
| 14 | 11,62 | 11,70 | 11,77 | 11,85 | 11,93 | 12,01 | 12,08 | 12,16 | 12,24 | 12,31 |
| 15 | 12,38 | 12,46 | 12,54 | 12,62 | 12,70 | 12,78 | 12,85 | 12,93 | 13,01 | 13,09 |
| 16 | 13,17 | 13,26 | 13,34 | 13,43 | 13,51 | 13,60 | 13,69 | 13,77 | 13,86 | 13,94 |
| 17 | 14,03 | 14,12 | 14,21 | 14,30 | 14,39 | 14,48 | 14,57 | 14,66 | 14,75 | 14,84 |
| 18 | 14,93 | 15,02 | 15,12 | 15,21 | 15,30 | 15,40 | 15,49 | 15,58 | 15,67 | 15,77 |
| 19 | 15,86 | 15,96 | 16,06 | 16,16 | 16,26 | 16,37 | 16,47 | 16,57 | 16,67 | 16,77 |
| 20 | 16,87 | 16,97 | 17,08 | 17,18 | 17,29 | 17,39 | 17,49 | 17,60 | 17,71 | 17,81 |
| 21 | 17,91 | 18,02 | 18,14 | 18,25 | 18,36 | 18,48 | 18,59 | 18,70 | 18,81 | 18,93 |
| 22 | 19,04 | 19,16 | 19,27 | 19,39 | 19,51 | 19,63 | 19,74 | 19,86 | 19,98 | 20,09 |
| 23 | 20,21 | 20,33 | 20,45 | 20,58 | 20,70 | 20,82 | 20,94 | 21,06 | 21,19 | 21,31 |
| 24 | 21,43 | 21,56 | 21,69 | 21,82 | 21,95 | 22,09 | 22,22 | 22,35 | 22,48 | 22,61 |
| 25 | 22,74 | 22,88 | 23,02 | 23,17 | 23,30 | 23,44 | 23,59 | 23,73 | 23,98 | 24,12 |
| 26 | 24,16 | 24,30 | 24,44 | 24,58 | 24,72 | 24,86 | 25,00 | 25,14 | 25,28 | 25,42 |
| 27 | 25,56 | 25,71 | 25,86 | 26,01 | 26,16 | 26,32 | 26,47 | 26,62 | 26,77 | 26,83 |
| 28 | 27,07 | 27,23 | 27,39 | 27,55 | 27,71 | 27,87 | 28,03 | 28,19 | 28,35 | 28,51 |
| 29 | 28,67 | 28,84 | 29,01 | 29,18 | 29,35 | 29,52 | 29,68 | 29,85 | 30,02 | 30,19 |
| 30 | 30,36 | 30,54 | 30,72 | 30,90 | 31,08 | 31,26 | 31,44 | 31,62 | 31,80 | 31,98 |
| 31 | 32,17 | 32,35 | 32,53 | 32,70 | 32,88 | 33,06 | 33,24 | 33,42 | 33,59 | 33,77 |
| 32 | 33,95 | 34,15 | 34,35 | 34,55 | 34,75 | 34,95 | 35,15 | 35,35 | 35,55 | 35,75 |
| 33 | 35,95 | 36,17 | 36,39 | 36,61 | 36,83 | 37,05 | 37,27 | 37,49 | 37,71 | 37,93 |
| 34 | 37,99 | 38,21 | 38,42 | 38,64 | 38,85 | 39,07 | 39,29 | 39,50 | 39,72 | 39,93 |
| 35 | 40,15 | 40,38 | 40,61 | 40,84 | 41,07 | 41,30 | 41,53 | 41,76 | 41,99 | 42,22 |

(*Vide* Appendix, *fig.* 6.)

## TABLE

### OF THE TENSIONS OF THE VAPOUR OF WATER IN MILLIMETRES OF MERCURY, CALCULATED BY M. **AUGUST**, AFTER **DALTON'S** EXPERIMENTS.

| Degrees. | TENTHS OF DEGREES. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| —31 | 0,45 | 0,45 | 0,45 | 0,44 | 0,44 | 0,43 | 0,43 | 0,42 | 0,42 | 0,41 |
| —30 | 0,50 | 0,49 | 0,49 | 0,48 | 0,48 | 0,47 | 0,47 | 0,46 | 0,46 | 0,45 |
| —29 | 0,54 | 0,54 | 0,54 | 0,53 | 0,53 | 0,52 | 0,52 | 0,51 | 0,51 | 0,50 |
| —28 | 0,59 | 0,58 | 0,58 | 0,57 | 0,57 | 0,56 | 0,56 | 0,55 | 0,55 | 0,54 |
| —27 | 0,63 | 0,63 | 0,63 | 0,62 | 0,62 | 0,61 | 0,61 | 0,60 | 0,60 | 0,59 |
| —26 | 0,70 | 0,69 | 0,68 | 0,68 | 0,67 | 0,66 | 0,66 | 0,65 | 0,64 | 0,64 |
| —25 | 0,77 | 0,76 | 0,75 | 0,75 | 0,74 | 0,73 | 0,73 | 0,72 | 0,71 | 0,71 |
| —24 | 0,83 | 0,83 | 0,82 | 0,82 | 0,81 | 0,80 | 0,80 | 0,79 | 0,78 | 0,78 |
| —23 | 0,90 | 0,89 | 0,88 | 0,88 | 0,87 | 0,86 | 0,86 | 0,85 | 0,84 | 0,84 |
| —22 | 0,99 | 0,98 | 0,97 | 0,96 | 0,95 | 0,95 | 0,94 | 0,93 | 0,92 | 0,91 |
| —21 | 1,06 | 1,05 | 1,04 | 1,04 | 1,03 | 1,02 | 1,02 | 1,01 | 1,00 | 1,00 |
| —20 | 1,15 | 1,14 | 1,13 | 1,12 | 1,11 | 1,11 | 1,10 | 1,09 | 1,08 | 1,07 |
| —19 | 1,26 | 1,25 | 1,24 | 1,23 | 1,22 | 1,21 | 1,20 | 1,18 | 1,17 | 1,16 |
| —18 | 1,33 | 1,32 | 1,31 | 1,31 | 1,30 | 1,29 | 1,29 | 1,28 | 1,27 | 1,27 |
| —17 | 1,44 | 1,43 | 1,42 | 1,41 | 1,40 | 1,39 | 1,38 | 1,36 | 1,35 | 1,34 |
| —16 | 1,56 | 1,54 | 1,53 | 1,52 | 1,51 | 1,50 | 1,49 | 1,47 | 1,46 | 1,45 |
| —15 | 1,69 | 1,68 | 1,67 | 1,65 | 1,64 | 1,63 | 1,61 | 1,60 | 1,59 | 1,57 |
| —14 | 1,80 | 1,79 | 1,78 | 1,77 | 1,76 | 1,75 | 1,74 | 1,72 | 1,71 | 1,70 |
| —13 | 1,96 | 1,94 | 1,93 | 1,91 | 1,89 | 1,88 | 1,86 | 1,85 | 1,83 | 1,82 |
| —12 | 2,12 | 2,10 | 2,09 | 2,07 | 2,05 | 2,04 | 2,02 | 2,01 | 1,99 | 1,98 |
| —11 | 2,30 | 2,28 | 2,26 | 2,25 | 2,23 | 2,21 | 2,19 | 2,17 | 2,16 | 2,14 |
| —10 | 2,48 | 2,46 | 2,44 | 2,43 | 2,41 | 2,39 | 2,37 | 3,35 | 2,34 | 2,32 |
| — 9 | 2,66 | 2,64 | 2,62 | 2,61 | 2,59 | 2,57 | 2,55 | 2,53 | 2,52 | 2,50 |
| — 8 | 2,86 | 2,84 | 2,82 | 2,80 | 2,78 | 2,76 | 2,74 | 2,72 | 2,70 | 2,68 |
| — 7 | 3,09 | 3,06 | 3,04 | 3,02 | 3,00 | 2,97 | 2,95 | 2,93 | 2,91 | 2,88 |
| — 6 | 3,32 | 3,29 | 3,27 | 3,25 | 3,23 | 3,20 | 3,18 | 3,16 | 3,14 | 3,11 |
| — 5 | 3,56 | 3,56 | 3,54 | 3,51 | 3,48 | 3,46 | 3,43 | 3,40 | 3,37 | 3,35 |
| — 4 | 3,83 | 3,80 | 3,78 | 3,75 | 3,72 | 3,70 | 3,67 | 3,64 | 3,61 | 3,59 |
| — 3 | 4,11 | 4,07 | 4,05 | 4,02 | 3,99 | 3,97 | 3,94 | 3,91 | 3,88 | 3,86 |
| — 2 | 4,40 | 4,37 | 4,34 | 4,32 | 4,29 | 4,26 | 4,23 | 4,20 | 4,17 | 4,14 |
| — 1 | 4,71 | 4,68 | 4,65 | 4,62 | 4,59 | 4,56 | 4,53 | 4,49 | 4,46 | 4,43 |
| — 0 | 5,05 | 5,01 | 4,98 | 4,95 | 4,91 | 4,88 | 4,85 | 4,81 | 4,78 | 4,74 |
| 0 | 5,05 | 5,09 | 5,12 | 5,16 | 5,19 | 5,23 | 5,27 | 5,30 | 5,34 | 5,37 |

**AUGUST'S** Table—*continued.*

| Degrees. | TENTHS OF DEGREES. | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
| 1 | 5,41 | 5,45 | 5,49 | 5,52 | 5,56 | 5,60 | 5,64 | 5,68 | 5,72 | 5,75 |
| 2 | 5,80 | 5,84 | 5,88 | 5,92 | 5,96 | 6,00 | 6,04 | 6,08 | 6,13 | 6,17 |
| 3 | 6,20 | 6,24 | 6,29 | 6,33 | 6,37 | 6,41 | 6,46 | 6,50 | 6,54 | 6,59 |
| 4 | 6,63 | 6,68 | 6,72 | 6,77 | 6,81 | 6,86 | 6,90 | 6,95 | 6,99 | 7,04 |
| 5 | 7,08 | 7,13 | 7,18 | 7,23 | 7,28 | 7,33 | 7,38 | 7,43 | 7,48 | 7,53 |
| 6 | 7,58 | 7,63 | 7,68 | 7,74 | 7,79 | 7,84 | 7,89 | 7,94 | 7,99 | 8,05 |
| 7 | 8,10 | 8,15 | 8,21 | 8,26 | 8,32 | 8,37 | 8,43 | 8,48 | 8,53 | 8,59 |
| 8 | 8,64 | 8,70 | 8,76 | 8,82 | 8,87 | 8,93 | 8,99 | 9,05 | 9,11 | 9,17 |
| 9 | 9,23 | 9,30 | 9,36 | 9,43 | 9,50 | 9,57 | 9,63 | 9,70 | 9,77 | 9,84 |
| 10 | 9,90 | 9,96 | 10,02 | 10,08 | 10,14 | 10,20 | 10,25 | 10,31 | 10,37 | 10,43 |
| 11 | 10,49 | 10,56 | 10,63 | 10,69 | 10,76 | 10,83 | 10,90 | 10,96 | 11,03 | 11,10 |
| 12 | 11,17 | 11,24 | 11,31 | 11,38 | 11,45 | 11,52 | 11,59 | 11,66 | 11,73 | 11,80 |
| 13 | 11,86 | 11,94 | 12,02 | 12,10 | 12,18 | 12,26 | 12,34 | 12,42 | 12,50 | 12,58 |
| 14 | 12,66 | 12,74 | 12,82 | 12,90 | 12,98 | 13,05 | 13,13 | 13,21 | 13,29 | 13,37 |
| 15 | 13,44 | 13,52 | 13,61 | 13,69 | 13,77 | 13,86 | 13,94 | 14,02 | 14,11 | 14,19 |
| 16 | 14,28 | 14,37 | 14,47 | 14,56 | 14,65 | 14,74 | 14,84 | 14,93 | 15,02 | 15,11 |
| 17 | 15,20 | 15,29 | 15,38 | 15,46 | 15,55 | 15,64 | 15,73 | 15,82 | 15,90 | 15,99 |
| 18 | 16,08 | 16,17 | 16,27 | 16,36 | 16,45 | 16,54 | 16,64 | 16,73 | 16,82 | 16,91 |
| 19 | 17,01 | 17,13 | 17,25 | 17,37 | 17,49 | 17,61 | 17,73 | 17,85 | 17,97 | 18,09 |
| 20 | 18,20 | 18,31 | 18,43 | 18,54 | 18,65 | 18,76 | 18,88 | 18,99 | 19,10 | 19,21 |
| 21 | 19,33 | 19,45 | 19,56 | 19,68 | 19,80 | 19,92 | 20,03 | 20,15 | 20,27 | 20,39 |
| 22 | 20,51 | 20,63 | 20,76 | 20,88 | 21,01 | 21,13 | 21,25 | 21,38 | 21,50 | 21,63 |
| 23 | 21,75 | 21,88 | 22,00 | 22,13 | 22,26 | 22,38 | 22,51 | 22,63 | 22,76 | 22,89 |
| 24 | 23,01 | 23,13 | 23,24 | 23,36 | 23,48 | 23,60 | 23,71 | 23,83 | 23,95 | 24,07 |
| 25 | 24,18 | 24,34 | 24,50 | 24,67 | 24,83 | 24,99 | 25,15 | 25,32 | 25,48 | 25,64 |
| 26 | 25,81 | 25,97 | 26,13 | 26,28 | 26,44 | 26,60 | 26,76 | 26,92 | 27,07 | 27,23 |
| 27 | 27,39 | 27,55 | 27 71 | 27,86 | 28,02 | 28,18 | 28,34 | 28,50 | 28,65 | 28,81 |
| 28 | 28,96 | 29,13 | 29,29 | 29,46 | 29,63 | 29,79 | 29,96 | 30,13 | 30,30 | 30,46 |
| 29 | 30,63 | 30,81 | 30,98 | 31,16 | 31,33 | 31,51 | 31,69 | 31,86 | 32,04 | 32,21 |
| 30 | 32,39 | 32,57 | 32,76 | 32,94 | 33,13 | 33,31 | 33,50 | 33,68 | 33,87 | 34,05 |
| 31 | 34,24 | 34,43 | 34,63 | 34,82 | 35,02 | 35,21 | 35,40 | 35,60 | 35,79 | 35,99 |
| 32 | 36,18 | 36,38 | 36,59 | 36,79 | 36,99 | 37,20 | 37,40 | 37,60 | 37,80 | 38,01 |
| 33 | 38,21 | 38,43 | 38,64 | 38,86 | 39,08 | 39,29 | 39,51 | 39,73 | 39,94 | 40,16 |
| 34 | 40,38 | 40,60 | 40,82 | 41,04 | 41,26 | 41,49 | 41,71 | 41,93 | 42,15 | 42,37 |
| 35 | 42,59 | 42,82 | 43,05 | 43,28 | 43,51 | 43,74 | 43,97 | 44,20 | 44,43 | 44,66 |

(*Vide* Appendix, *fig.* 6.)

The use of these tables is very simple. Suppose we desire the tension of the vapour that saturates a space, having a temperature of 20°,4; we look for 20°, in the first vertical column, and for 0°,4, in the first horizontal line, and take the number that is found where these two columns meet. My table gives $17^{mm}$,29, M. **August's** gives $18^{mm}$,65. I cannot say whence this difference arises; but it is greatly to be desired that these experiments be repeated with tubes having very large diameters. M. **August's** results agree very well with those that have been admitted by the generality of philosophers; we shall adopt them throughout this work.

**WEIGHT OF THE VAPOUR OF WATER.**—To ascertain the weight of the vapour of water, a quantity of water of a determinate weight is sent up into the tube of a barometer. On heating the tube, the tension of the vapour increases; at first, the depression of the barometric column is equal to that indicated to us in the two preceding tables. But, on continuing to heat it, a period is attained at which the tension increases very slowly, and according to the law of a gas. The temperature at which the sudden diminution in the rapidity of the increase of the elasticity takes place is the point of saturation. If we know the capacity of the space filled by the vapour, we may deduce, from the known weight of the water introduced, the weight of the vapour contained in a given space. Trials of this kind, from the experiments of M. **August**, give the following as the weights of water saturating a space of a cubic metre at the temperature indicated in the table.*

---

* M. POUILLET, in his *Eléments de Physique*, t. ii. p. 564, has given a table, which presents at one view the tension of the vapour of water, from —20° to 40°, and the corresponding weight in grammes of the vapour contained in a cubic metre of air. The inspection of this table shews, that from 0° to 25°, the elastic force expressed in millimetres, is sensibly equal to the weight of the corresponding quantity expressed in grammes. The differences are in the value of the first decimal. Thus, at the temperature of 6°, the tension of the aqueous vapour is $7^{mm}$,4, the weight of the vapour contained in a cubic metre of air is $7^{gr}$,7; at the temperature of 16°, the tension is $13^{mm}$,6, the weight of the corresponding vapour is $13^{gr}$,7; at 21°, the tension is $18^{mm}$,3, the corresponding weight, $18^{gr}$,1.—M.

## TABLE

### OF THE WEIGHTS OF VAPOUR OF WATER WHICH A CUBIC METRE OF AIR MAY CONTAIN AT DIFFERENT TEMPERATURES.

| DEGREES. | GRAMMES. | DEGREES. | GRAMMES. |
|---|---|---|---|
| —25 | 0,93 | 6 | 8,25 |
| —24 | 1,01 | 7 | 8,79 |
| —23 | 1,10 | 8 | 9,30 |
| —22 | 1,19 | 9 | 9,86 |
| —21 | 1,26 | 10 | 10,57 |
| —20 | 1,38 | 11 | 11,18 |
| —19 | 1,47 | 12 | 11,83 |
| —18 | 1,60 | 13 | 12,57 |
| —17 | 1,74 | 14 | 13,33 |
| —16 | 1,84 | 15 | 14,17 |
| —15 | 2,00 | 16 | 14,97 |
| —14 | 2,14 | 17 | 15,84 |
| —13 | 2,33 | 18 | 16,76 |
| —12 | 2,48 | 19 | 17,75 |
| —11 | 2,63 | 20 | 18,77 |
| —10 | 2,87 | 21 | 19,82 |
| — 9 | 3,08 | 22 | 20,91 |
| — 8 | 3,30 | 23 | 22,09 |
| — 7 | 3,53 | 24 | 23,36 |
| — 6 | 3,80 | 25 | 24,61 |
| — 5 | 4,08 | 26 | 25,96 |
| — 4 | 4,37 | 27 | 27,34 |
| — 3 | 4,70 | 28 | 28,81 |
| — 2 | 5,01 | 29 | 30,35 |
| — 1 | 5,32 | 30 | 31,93 |
| 0 | 5,66 | 31 | 33,65 |
| 1 | 6,00 | 32 | 35,45 |
| 2 | 6,42 | 33 | 37,20 |
| 3 | 6,84 | 34 | 39,12 |
| 4 | 7,32 | 35 | 41,13 |
| 5 | 7,77 | 36 | 43,17 |

If we know the temperature at which a given space is saturated, we may deduce from it the weight or the tension of the vapour contained in a cubic metre of air. Thus, the weight of the quantity of vapour contained in a cubic metre, at the temperature of 10°, will be $10^{gr},57$ ; the tension of the vapour of water, $9^{mm},90$. Each of these numbers is also expressive of the quantity of vapour of water. In Meteorology it is better to give the tension. Thus, if in the vicinity of the ground we find that the air is saturated at a temperature of 10°, and if vapour expands according to the laws of the dilatation of elastic fluids up to the limits of the atmosphere, the weight of this vapour will balance a column of mercury $9^{mm},90$ in length. It is lawful for us, therefore, to consider the corresponding tension of vapour at each temperature as equal to the weight of the entire mass of the vapour of water diffused throughout the atmosphere.

**LATENT HEAT OF THE VAPOUR OF WATER.**—The enormous dilatation of the vapour of water, under the influence of heat, shews us the important part which this agent plays in its production; of this we shall be further convinced if we study the phenomena of evaporation. Pour into an open metal vessel some water at the atmospheric temperature, and heat it by means of a lamp placed beneath the vessel. A thermometer placed in the water will indicate the time of its attaining the point of ebullition; it will then remain stationary, and it will be in vain to increase the fire, the thermometer will not rise above 100°. If the vessel is closed, the temperature of the water will pass the point of ebullition; but, if the vessel is then opened, the vapour will escape violently, and the thermometer will again descend to 100°.

**Black**, a Scotch philosopher, was the first to study the relations existing between the formation of the vapour of water and the boiling point. In the preceding experiment, as soon as the water has attained the boiling point, all the heat that penetrates the vessel does nothing more than accelerate the evaporation; and these vapours take in the excess of temperature without their own temperature surpassing that of boiling water. This is proved by the fall of the thermometer, that takes place as soon as a closed vessel is opened, in which the temperature of the water had been raised above 100°. **Black** applied the term *latent heat*, or *latent caloric*, to this heat, which is taken in by vapours, but which has no influence on the thermometer. The existence of this latent heat is one of the essentials in the formation of vapours.

If this theory be true, the latent heat of vapour ought to become sensible at the moment when the vapour returns to the liquid state. And this actually takes place: some very simple experiments prove it most undeniably. If we mix in a vessel 500 grammes of water at zero with 500 at 100°, we shall have a kilogramme of water at 50°. Whatever be the relation of the quantities of water mixed, the distribution of heat will be made in the same ratio. If we take 10 kilogrammes of water at zero, and add 1 kilogramme of water at 100°, the temperature of the mixture will be

$$\frac{10 \times 0 + 1 \times 100}{11} = 9^\circ{,}1.$$

Let us now pour 1 kilogramme of water at 100°, in a close vessel, and connect it by a tube with a vessel containing 10 kilogrammes of water at zero; if we heat the former vessel, its temperature will constantly remain at 100°; the vapour, in traversing the cold water, passes into the liquid state, and, when the kilogramme of water is entirely evaporated, there will be in the second vessel 11 kilogrammes of water, not at 9°, as in the preceding case, but at 58°. This difference arises from the latent heat which the vapour has given up to the cold water. Experiments of this kind have shewn that boiling water has a latent heat of about 535°, which brings the total heat to 635° from zero. So that the quantity of heat requisite to transform a kilogramme of boiling water into vapour is equal to that which would elevate the temperature of the water to 635°, if it did not pass into the state of vapour.

Experiment proves that water evaporates at all temperatures; for if, in any season, we expose to the air an open vessel filled with water, the water will disappear by evaporation. Even ice sends off vapours. A piece of ice placed in a balance pan, at a low temperature, is found to lose weight. The vapour formed under these circumstances, lowers the temperature of water, as much as if it were in a state of ebullition. We may convince ourselves of this by means of liquids which have the property of boiling at very low temperatures, and which vaporise faster than water. If the bulb of a thermometer is wrapped in cotton moistened with sulphuric ether, this liquid, by evaporating, will take from the bulb that amount of heat which is requisite to it in its passage into a state of vapour; and, in the very height of summer the instrument may be seen to descend to zero, or even lower. Choose two thermometers, as much alike as possible, envelope the bulb of one of them in very fine muslin moistened with water, and suspend them both in the open air in very dry weather; you will see that the moist thermometer remains several degrees lower than the dry one.[4]

A multitude of observations confirm what we have said. Latent heat plays a very important part in the animal economy. When the skin is covered with perspiration, and the latter evaporates, we experience a very marked sensation of cold. This evaporation being much less active in moist than in dry weather, the sensation of cold is much stronger in the latter case. Hence it is that in summer-time we find the heat insupportable when the air is moist, although the thermometer is not very high; but, if the wind removes successively the atmosphere saturated with vapour, with which our body is surrounded, then the evaporation takes place with greater activity. On this account it is that, at equal temperatures, and at the same degree of moisture, we experience a much more marked sensation of cold, if there is a wind, than if the air is perfectly calm.

**HYGROMETERS.** — Our sensations tell us that the quantity of water contained in the air is not always the same; to determine this accurately, we have recourse to hygrometers. The most rigorous process is that of **Brunner**, which we have already mentioned; but it is impracticable in a regular series of meteorological observations, for every experiment occupies about an hour.

**Dalton's** process, perfected by **Daniell**, and then by **Koerner**, is founded on the following principle. If we suppose that a mass of air is gradually cooled, it will, at last, descend to a degree of temperature at which it will be saturated by the quantity of vapour contained in it. This temperature, called the *dew-point*, being once known, all that will be then necessary is, to seek in a table for the quantity of vapour which corresponds to it. Suppose that this temperature is 25°; if the dew-point is 10°,4, the table (p. 72) will give $10^{mm}$,14 of tension for this temperature of the dew-point; which is equivalent to saying, that the pressure of the atmosphere of vapour keeps in equilibrium a column of mercury $10^{mm}$,14 in height. In order to find the dew-point, we take the thermometer whose bulb is free; we first surround it with muslin, and then apply to the lower half of the bulb a thin cap of gilt silver, which exactly fits it; this being done, sulphuric ether is allowed to

---

[4] *Vide* Note *c*, Appendix No. II.

fall drop by drop on the muslin; the ether evaporates, and takes away heat from the bulb, which soon attains the temperature of the dew-point. At this moment, the vapour contained in the air condenses on the gilt cap. The temperature must then be accurately observed at the moment when the gold is dimmed. In order that the result may be rigorous, we must manage that the reduction of temperature takes place as slowly as possible, when close upon the dew-point, so that the apparatus may have the same temperature in all its parts. Hence, in moist weather, very little sulphuric ether is poured on at one time; if, notwithstanding this precaution, the thermometer falls rapidly, the experiment must be recommenced. When the instrument has again become warm, a few more drops are allowed to fall, until the thermometer has almost descended to the dew-point; then just enough more is added to make it descend very little below this point. With a little experience we soon get to supply the quantity of ether necessary to obtain a result.

I shall not stop to describe the apparatus contrived by **Daniell.** For daily observations it offers great inconveniencies. If the air is very dry, the dew-point is not obtained without the greatest difficulty; if it is moist, it becomes very difficult to say at what degree of the thermometer the gold is dimmed. In the light it is impossible to observe this instrument, and its only real use is to compare other hygrometers with each other.[5]

The dew-point merely indicates to us the quantity of vapours of water which the air contains at the moment of observation, but this element is not sufficient to characterise the hygrometric condition of the air. In winter, when it is cold, the air is often very moist, whilst it would be very dry in summer if it contained the same quantity of the vapour of water. The greater the difference between the temperature of the dew-point and that of the air, the drier the air is, for it then may dissolve in still greater quantity of the vapour of water, without there being any probability of the latter's being precipitated in the form of rain. If the dew-point informed us of *the absolute quantity of the vapour of water* contained in the air, the difference between the dew-point and the temperature of the air will indicate to us *the relative quantity of the vapour of water*, or the *humidity* of the air. In order readily to determine the element, let us notice the quantity of vapour which the air would contain at the

[5] *Vide* Note *d*, Appendix No. II.

moment of the observation, if it were saturated, and divide the quantity which it really contains by this number. The quotient, multiplied by 100, will tell us how much per cent of the first quantity is contained in the air. Suppose a temperature of 28°,4; the dew-point at 12°,1; the tension of the absolute quantity of vapour will be $11^{mm},24$; if the air were saturated at 28°4, the tension would be $29^{mm},63$; the quotient,

$$\frac{11^{mm},24 \times 100}{29^{mm},63} = 37,93.$$

So that the air contains, at the moment of the observation, about 38 per cent of the quantity of vapour of water, which it would contain, if it were in a state of saturation.

**Hutton's** method is still more simple. Modified at first by **Leslie**, it has lately been brought back to its primitive simplicity by M. **August**, of Berlin. Two thermometers, as similar as possible, and so divided that a tenth of a degree may be accurately estimated, are placed beside each other. The bulb of one is covered with muslin, kept constantly moist by means of a thread dipping into a capsule full of water. In consequence of evaporation, the temperature of the moistened thermometer is lower as the air is drier, and the barometer lower. We may, therefore, by means of the cold arising from the evaporation, know the quantity of vapour contained in the air; and the instrument has received from its inventor the name of psychrometer (ψυχρὸς, cold). The true indications of the thermometer are observed, as also the corresponding barometric height. Let $t$ be the temperature of the dry thermometer; $t'$ that of the moist one, each having the centesimal division; $b$ the height of the barometer in millimetres; also let $e$ be the tension of the vapour at the temperature $t$, and $e'$ its tension at the temperature $t'$. For the tension E of the vapour contained in the air, we shall have

$$E = e' - 0,000804\ (t - t')\ b.$$

If the temperature of the thermometer falls below zero, and its bulb is covered with a light film of ice, the following formula must be employed:—

$$E = e' - 0,000748\ (t - t')\ b.$$

Let the dry thermometer be at 21°, and the moist one at 12°,5; let $b = 752^{mm},32$; $t - t'$ will be equal to 8°,5, and

$$0,000804\ (t - t')\ b = 0,000804 \times 8,5 \times 752^{mm},32 = 5^{mm},14.$$

Moreover, $e'=11^{mm},52$; wherefore $E=11,52-5,14=6^{mm},38$, which is the absolute quantity of vapour of water. At 21°, $e=19,33$; and

$$\frac{6,38\times 100}{19,33}=33.$$

which is the relative quantity of vapour.*

By this method, from the indications of two thermometers, and the state of the barometer, the hygrometric conditions of the atmosphere may be deduced; but, if a considerable number of observations are in hand, these calculations become very long. It would then be very well, from the mean height of the barometer at the place of observation, to calculate a table, giving the absolute and relative quantities of vapour for each psychrometric difference, and for all temperatures in tenths of degrees. I cannot recommend this method too strongly; but, if we confine ourselves to take the mean psychrometric difference for each month merely, we should expose ourselves to very serious errors.†

The early meteorologists employed in their researches organic bodies as their hygrometers. When exposed to moist air, these substances absorb the vapour of water, and are enlarged or shortened. The instrument of this kind

---

* For the use and construction of the psychrometer, *vide* E. F. AUGUST, *Ueber die Anwendung des Psychrometers zur Hygrometrie*, Berlin, 1828; and *Ueber die Fortschritte der Hygrometrie in der neuesten Zeit*, Berlin, 1830; POUILLET, *Eléments de Physique*, t. ii. p. 570, and pl. 31, fig. 382.

† The application of the process requires the employment of two identical thermometers; and, however perfectly an ordinary thermometer may be constructed, we know how difficult it is to obtain two instruments strictly comparable.

This difficulty might be remedied by employing a single thermometer, with a very long range, so as to give indications at all the temperatures to be observed.

The instrument most eminently adapted to observations of this kind is one of the *metastatic* spirit thermometers, contrived by M. WALFERDIN, the construction of which is such, that it is regulated at pleasure to all temperatures, and that, within the limit of observation necessary to psychrometric determination, it can indicate the hundredth part, and even less, of a centesimal degree; and yet its reservoir does not exceed in volume that of the smallest thermometer employed in Meteorology.

In using the instrument, attention must be paid to keeping the globule of mercury contained in the tube, and which serves as an index, at a temperature slightly above the surrounding temperature which is then being determined; the instrument must then be swung round, after its bulb has been surrounded with moist muslin to cause evaporation; the new indication must be noted; and the two observations thus obtained must be compared, as is evident, with the same instrument.

In this case the metastatic thermometer becomes a most simple and accurate psychrometric instrument. For the description and figure of this instrument, vide *Compte rendu de l'Académie des Sciences de Paris*, t. xiv. p. 63; and *Les Annales de Physique et de Chimie de* POGGENDORFF, t. lvii. p. 549.—M.

which is best known is **De Saussure's** hair hygrometer. A hair is boiled in a weak solution of soda, in order to remove the grease; one end of it is then fixed in a frame, while the other is rolled upon a cylinder, which carries a needle. When placed in air saturated with moisture, the hair elongates, whereas it shortens when placed in dry air. **De Saussure** places the number 100 at the point where the needle rests, when the air is completely saturated, and 0 at that where it remains fixed, when the air is entirely dry. The interval between these two points is divided into 100 equal parts.

This instrument indicates the relative humidity. When it is placed in air containing known quantities of vapour, observation shews that the degrees are not proportional to the quantities. When the instrument points to eighty, the air often contains not eighty, but merely sixty or seventy per cent of the quantity of vapour, which would be necessary to saturate it. On this point we possess the researches of **De Saussure** himself, carefully recalculated by M. **August**.

RELATIVE HUMIDITY CORRESPONDING TO THE DEGREES OF **De Saussure's** HYGROMETER.

| HYGROMETER. | GAY-LUSSAC. | PRINSEP. | MELLONI. | AUGUST. |
|---|---|---|---|---|
| 100 | 100,0 | 100,0 | 100,0 | 100,0 |
| 95 | 89,1 | 88,7 | 90,8 | 94,0 |
| 90 | 79,1 | 78,2 | 83,1 | 86,0 |
| 85 | 69,6 | 68,3 | 76,5 | 79,0 |
| 80 | 61,2 | 59,2 | 68,9 | 71,0 |
| 75 | 53,8 | 50,6 | 62,0 | 64,0 |
| 70 | 47,2 | 43,6 | 55,6 | 56,0 |
| 65 | 41,4 | 37,2 | 49,6 | 48,0 |
| 60 | 36,3 | 31,5 | 44,0 | 41,0 |
| 55 | 31,8 | 26,3 | 39,1 | 36,0 |
| 50 | 27,8 | 21,8 | 34,6 | 31,0 |
| 45 | 24,1 | 17,7 | 29,8 | 27,0 |
| 40 | 20,8 | 14,3 | 27,0 | 23,0 |
| 35 | 17,7 | 11,4 | 23,8 | 19,0 |
| 30 | 14,8 | 9,1 | 19,0 | 16,0 |
| 25 | 12,0 | 7,1 | 16,4 | 13,0 |
| 20 | 9,4 | 4,9 | 11,7 | 10,0 |
| 15 | 7,0 | 3,0 | 8,3 | 7,0 |
| 10 | 4,6 | 1,6 | 5,0 | 4,0 |
| 5 | 2,2 | 0,6 | 2,6 | 2,0 |
| 0 | 0 | 0 | 0 | 0 |

**DIURNAL VARIATIONS IN THE QUANTITY OF VAPOUR OF WATER.** — The theory of aqueous vapour, and that of hygrometers, is a conquest of modern times. It is therefore desirable that observers should direct their attention to this subject. I know of only three series in which the number of daily observations is sufficiently great to be of any utility. One of them was made by **Neuber**, at Apenrade, in Denmark, during a year. He made observations with **Daniell's** hygrometer every two hours, from seven o'clock in the morning until eleven at night. M. **Kopfer** observed the psychrometer at Petersburg, during a year, from eight o'clock in the morning until ten in the evening. Finally, I have myself done the same thing almost every hour at Halle, since 1831; I have also always noted it in my observations near the sea, and on the Alps. My results embrace the longest period: I have collected them in the following table :—

## TENSION OF VAPOUR AT HALLE, IN MILLIMETRES. (*vide* Appendix, *fig.* 7).

| HOURS. | JAN. | FEB. | MARCH. | APRIL. | MAY. | JUNE. | JULY. | AUG. | SEP. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Noon | 4,29 | 4,69 | 5,34 | 6,15 | 7,94 | 10,36 | 11,62 | 10,77 | 9,96 | 8,27 | 5,93 | 5,64 |
| 1 | 4,32 | 4,74 | 5,34 | 6,05 | 7,88 | 10,28 | 11,42 | 10,61 | 9,88 | 8,29 | 5,98 | 5,64 |
| 2 | 4,34 | 4,80 | 5,35 | 6,08 | 7,87 | 10,22 | 11,32 | 10,60 | 9,74 | 8,23 | 5,98 | 5,66 |
| 3 | 4,33 | 4,81 | 5,33 | 6,09 | 7,85 | 10,21 | 11,22 | 10,56 | 9,66 | 8,15 | 5,92 | 5,64 |
| 4 | 4,28 | 4,82 | 5,29 | 6,09 | 7,82 | 10,23 | 11,18 | 10,57 | 9,57 | 8,10 | 5,89 | 5,63 |
| 5 | 4,25 | 4,77 | 5,28 | 6,09 | 7,91 | 10,27 | 11,25 | 10,55 | 9,56 | 8,06 | 5,82 | 5,58 |
| 6 | 4,24 | 4,72 | 5,27 | 6,12 | 7,98 | 10,33 | 11,36 | 10,72 | 9,60 | 8,10 | 5,77 | 5,56 |
| 7 | 4,22 | 4,66 | 5,23 | 6,15 | 8,04 | 10,46 | 11,68 | 10,79 | 9,58 | 8,07 | 5,72 | 5,52 |
| 8 | 4,20 | 4,61 | 5,18 | 6,13 | 8,11 | 10,60 | 11,76 | 10,85 | 9,61 | 7,96 | 5,68 | 5,51 |
| 9 | 4,18 | 4,57 | 5,15 | 6,10 | 8,08 | 10,54 | 11,75 | 10,98 | 9,61 | 7,88 | 5,64 | 5,52 |
| 10 | 4,15 | 4,55 | 5,12 | 6,05 | 8,11 | 10,39 | 11,67 | 10,69 | 9,65 | 7,80 | 5,59 | 5,48 |
| 11 | 4,14 | 4,53 | 5,10 | 6,03 | 8,05 | 10,19 | 11,52 | 10,59 | 9,57 | 7,72 | 5,57 | 5,47 |
| Midnight | 4,11 | 4,52 | 5,08 | 6,02 | 7,95 | 9,96 | 11,33 | 10,45 | 9,47 | 7,66 | 5,56 | 5,45 |
| 13 | 4,09 | 4,50 | 5,06 | 5,99 | 7,81 | 9,76 | 11,15 | 10,31 | 9,33 | 7,59 | 5,55 | 5,45 |
| 14 | 4,09 | 4,48 | 5,03 | 5,93 | 7,69 | 9,65 | 11,05 | 10,22 | 9,16 | 7,52 | 5,54 | 5,44 |
| 15 | 4,08 | 4,45 | 4,99 | 5,88 | 7,61 | 9,65 | 11,07 | 10,22 | 9,03 | 7,43 | 5,53 | 5,44 |
| 16 | 4,08 | 4,40 | 4,96 | 5,84 | 7,61 | 9,81 | 11,21 | 10,33 | 8,99 | 7,36 | 5,52 | 5,42 |
| 17 | 4,07 | 4,36 | 4,94 | 5,87 | 7,70 | 9,99 | 11,44 | 10,55 | 9,05 | 7,34 | 5,51 | 5,40 |
| 18 | 4,06 | 4,33 | 4,94 | 5,96 | 7,83 | 10,16 | 11,68 | 10,79 | 9,21 | 7,44 | 5,50 | 5,40 |
| 19 | 4,06 | 4,33 | 4,98 | 6,08 | 7,78 | 10,45 | 11,96 | 11,07 | 9,44 | 7,49 | 5,52 | 5,38 |
| 20 | 4,05 | 4,34 | 5,06 | 6,25 | 8,17 | 10,43 | 12,11 | 11,33 | 9,76 | 7,75 | 5,56 | 5,35 |
| 21 | 4,07 | 4,41 | 5,15 | 6,34 | 8,19 | 10,48 | 12,05 | 11,33 | 10,00 | 8,06 | 5,65 | 5,37 |
| 22 | 4,12 | 4,50 | 5,24 | 6,35 | 8,11 | 10,41 | 11,89 | 11,15 | 10,04 | 8,23 | 5,77 | 5,48 |
| 23 | 4,21 | 4,62 | 5,29 | 6,28 | 8,06 | 10,32 | 11,72 | 10,97 | 9,97 | 8,28 | 5,86 | 5,58 |
| Means. | 4,17 | 4,56 | 5,15 | 6,08 | 7,93 | 10,21 | 11,52 | 10,70 | 9,56 | 7,87 | 5,69 | 5,50 |

## TABLE OF RELATIVE HUMIDITY AT HALLE, PER HOUR AND PER MONTH

(*vide* Appendix, *fig*. 8).

| HOURS. | JAN. | FEB. | MARCH. | APRIL. | MAY. | JUNE. | JULY. | AUG. | SEP. | OCT. | NOV. | DEC. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Noon | 82,8 | 74,7 | 69,9 | 59,7 | 57,8 | 59,9 | 55,7 | 54,2 | 61,3 | 69,3 | 80,9 | 84,1 |
| 1 | 81,0 | 72,8 | 67,5 | 56,8 | 55,5 | 57,5 | 53,3 | 50,8 | 58,9 | 66,7 | 79,7 | 82,6 |
| 2 | 80,6 | 72,5 | 67,1 | 56,2 | 53,9 | 55,8 | 52,1 | 49,1 | 57,4 | 66,1 | 79,6 | 82,8 |
| 3 | 81,4 | 73,2 | 67,0 | 56,3 | 53,3 | 55,1 | 51,2 | 49,3 | 57,1 | 66,5 | 80,2 | 83,2 |
| 4 | 82,3 | 75,3 | 67,9 | 57,6 | 53,7 | 56,0 | 51,6 | 50,2 | 57,6 | 68,4 | 81,8 | 84,7 |
| 5 | 83,9 | 77,5 | 70,4 | 61,6 | 56,2 | 58,4 | 54,2 | 52,1 | 59,5 | 70,8 | 83,4 | 85,5 |
| 6 | 85,4 | 79,7 | 73,3 | 62,6 | 59,6 | 61,7 | 57,2 | 55,3 | 63,1 | 74,6 | 84,4 | 86,3 |
| 7 | 86,1 | 81,0 | 75,3 | 65,8 | 63,4 | 65,6 | 62,3 | 58,7 | 66,8 | 77,5 | 85,4 | 86,7 |
| 8 | 86,4 | 81,8 | 77,7 | 69,3 | 67,2 | 70,5 | 67,5 | 62,4 | 71,0 | 79,4 | 86,1 | 87,1 |
| 9 | 86,5 | 82,8 | 79,1 | 72,1 | 70,7 | 74,2 | 71,2 | 65,5 | 74,8 | 80,9 | 86,7 | 88,0 |
| 10 | 87,0 | 83,7 | 80,1 | 74,2 | 73,9 | 76,8 | 74,4 | 69,1 | 78,3 | 82,6 | 87,0 | 88,1 |
| 11 | 87,0 | 84,0 | 80,7 | 76,0 | 75,7 | 78,6 | 76,9 | 71,5 | 80,4 | 83,5 | 87,3 | 88,2 |
| Midnight | 87,2 | 84,3 | 81,0 | 77,7 | 77,7 | 80,2 | 78,7 | 73,8 | 81,5 | 84,3 | 87,6 | 88,5 |
| 13 | 87,4 | 84,6 | 81,5 | 79,3 | 79,8 | 81,5 | 80,2 | 76,0 | 82,2 | 85,1 | 87,9 | 88,6 |
| 14 | 87,7 | 84,9 | 82,4 | 81,0 | 82,0 | 82,9 | 81,8 | 78,3 | 83,0 | 85,8 | 88,2 | 88,6 |
| 15 | 88,0 | 85,3 | 83,5 | 82,7 | 83,7 | 84,3 | 83,0 | 80,5 | 84,1 | 86,7 | 88,5 | 88,6 |
| 16 | 88,3 | 85,7 | 84,7 | 84,2 | 84,6 | 85,2 | 84,0 | 82,2 | 85,3 | 87,4 | 88,8 | 88,6 |
| 17 | 88,6 | 86,0 | 85,6 | 85,0 | 84,2 | 84,9 | 83,3 | 82,8 | 86,1 | 87,9 | 89,1 | 88,7 |
| 18 | 88,8 | 86,3 | 85,5 | 84,6 | 82,3 | 82,9 | 82,6 | 81,9 | 85,3 | 87,8 | 89,4 | 88,8 |
| 19 | 88,9 | 86,2 | 84,7 | 82,1 | 78,8 | 79,9 | 79,0 | 78,7 | 83,8 | 86,7 | 89,1 | 88,7 |
| 20 | 88,3 | 84,3 | 82,9 | 78,8 | 73,8 | 74,2 | 74,0 | 74,1 | 80,3 | 84,8 | 88,1 | 88,4 |
| 21 | 86,9 | 82,2 | 76,6 | 73,3 | 66,8 | 69,9 | 68,2 | 68,6 | 74,9 | 81,6 | 87,9 | 87,7 |
| 22 | 85,4 | 79,2 | 75,9 | 68,9 | 64,7 | 65,3 | 63,1 | 62,9 | 69,1 | 77,2 | 84,5 | 86,5 |
| 23 | 83,9 | 76,8 | 72,1 | 04,3 | 61,2 | 61,8 | 58,9 | 57,8 | 64,5 | 72,8 | 82,4 | 85,1 |
| Means. | 85,8 | 81,0 | 77,3 | 71,3 | 69,2 | 71,0 | 68,5 | 66,1 | 72,8 | 78,9 | 85,6 | 86,8 |

The laws which may be deduced from these tables are very simple. At Halle, the quantity of vapour attains its *minimum* throughout the year, in the morning before sunrise. At the same time, on account of the low degree of temperature, the humidity is at its *maximum*. In proportion as the sun rises above the horizon, the evaporation increases, and the air receives every moment a greater quantity of vapour. But, as the air opposes an obstacle to the formation of this vapour, it becomes further and further removed from the point of saturation, and the relative humidity becomes more and more feeble. This rate continues without interruption until the moment when the temperature attains its *maximum*. In winter, the quantity of vapour regularly increases until toward the afternoon; when the thermometer commences falling, the vapour is in part condensed on cold bodies, and the proportion of vapour diminishes until next morning; while, in consequence of this reduction of temperature, the air becomes relatively moister.

In summer, things go on quite differently; in that season, the absolute quantity of vapour increases in the morning also; but, before mid-day, the *maximum* occurs; and in different months it occurs sooner or later. The absolute quantity of vapour then diminishes until the time of the highest temperature of the day, without, however, attaining a *minimum* so low as that of the morning. As the temperature rises during all this space of time, it follows that the air is further and further from the point of saturation. After having attained its *minimum*, the quantity of vapour again increases very regularly until next morning, while the air becomes relatively more and more moist.

Although these monthly results are the means of observations continued for several years, I do not, however, regard them as definitive. It would be interesting to have similar series for a great number of places; for the variations appear to differ on several points of the globe. Thus the *minimum* of the quantity of vapour of water which occurs about mid-day is relatively less marked on the sea-coast. This seems to be proved by the observations which I made at Deep, near Treptow, on the Rega, near the coasts of the Baltic, during the summer of 1837, with the same instrument which I had employed during the series at Halle. The following table presents the mean tensions, and the mean relative humidity of the different hours of the day and night.

### TENSION OF THE VAPOUR OF WATER AND RELATIVE HUMIDITY AT THE DIFFERENT HOURS ON THE COASTS OF THE BALTIC.

| HOURS. | JULY. | | AUGUST. | |
|---|---|---|---|---|
| | TENSION of vapour in millimetres. | HUMIDITY. | TENSION of vapour in millimetres. | HUMIDITY. |
| Noon | 11,38 | 69,3 | 12,44 | 65,6 |
| 1 | 11,38 | 69,0 | 12,36 | 64,9 |
| 2 | 11,41 | 70,3 | 12,20 | 63,9 |
| 3 | 11,23 | 70,1 | 12,54 | 67,5 |
| 4 | 11,11 | 71,0 | 12,37 | 68,8 |
| 5 | 11,06 | 71,9 | 12,37 | 71,2 |
| 6 | 11,00 | 73,0 | 12,35 | 73,9 |
| 7 | 10,93 | 75,6 | 12,22 | 77,6 |
| 8 | 10,74 | 79,4 | 12,17 | 81,2 |
| 9 | 10,64 | 82,1 | 11,98 | 81,5 |
| 10 | 10,58 | 84,0 | 11,83 | 82,9 |
| 11 | 10,46 | 85,2 | 11,64 | 84,5 |
| Midnight | 10,28 | 85,7 | 11,42 | 85,6 |
| 13 | 10,12 | 85,9 | 11,25 | 86,2 |
| 14 | 10,05 | 86,2 | 11,19 | 86,8 |
| 15 | 10,09 | 86,4 | 11,18 | 87,5 |
| 16 | 10,25 | 86,2 | 11,30 | 87,5 |
| 17 | 10,50 | 84,9 | 11,53 | 86,7 |
| 18 | 10,78 | 82,1 | 11,83 | 84,6 |
| 19 | 10,99 | 78,6 | 12,12 | 81,6 |
| 20 | 11,07 | 75,1 | 12,47 | 78,0 |
| 21 | 11,13 | 72,6 | 12,55 | 73,7 |
| 22 | 11,03 | 69,2 | 12,65 | 72,0 |
| 23 | 11,19 | 68,6 | 12,57 | 68,2 |
| Means. | 10,81 | 77,6 | 12,02 | 77,6 |

We see by this table that the rate of relative moisture is the same as at Halle, with the exception, that the difference between the *maximum* and *minimum* is much less. In July, there is a very regular progressive increase in the quantity of vapour of water from the morning until the afternoon; for partial anomalies, such as that at twenty-two hours, would disappear in a larger series. In August, the quantity of vapour diminishes toward mid-day, although much less so than at Halle. We likewise do not observe any increase towards evening. **Neuber's** observations at Apenrade lead to the same results. From the calculations of M. **Dove**, the following numbers are found for the tensions of vapour.

## TENSION OF THE VAPOUR OF WATER PER HOUR AND PER MONTH AT APENRADE.

| HOURS. | JAN. | FEB. | MARCH. | APRIL. | MAY. | JUNE. | JULY. | AUG. | SEP. | OCT. | NOV. | DEC. | MEANS. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| 7 morn. | 5,730 | 4,941 | 4,670 | 6,767 | 8,053 | 11,121 | 12,316 | 11,820 | 11,008 | 8,211 | 6,655 | 6,136 | 8,119 |
| 9 „ | 5,798 | 4,963 | 4,941 | 7,443 | 8,887 | 11,708 | 13,309 | 13,038 | 12,880 | 8,865 | 6,722 | 6,159 | 8,726 |
| 11 „ | 5,911 | 5,324 | 5,234 | 7,849 | 9,249 | 12,478 | 14,031 | 14,144 | 13,489 | 9,609 | 7,196 | 6,340 | 9,238 |
| 12 „ | 6,113 | 5,504 | 5,369 | 8,052 | 9,317 | 12,858 | 14,031 | 14,572 | 13,693 | 9,723 | 7,308 | 6,385 | 9,410 |
| 1 even. | 6,204 | 5,572 | 5,504 | 8,098 | 9,429 | 12,746 | 14,302 | 14,843 | 13,941 | 9,858 | 7,263 | 6,430 | 9,511 |
| 3 „ | 6,069 | 5,527 | 5,436 | 8,121 | 9,226 | 12,701 | 14,347 | 14,550 | 14,144 | 9,768 | 7,128 | 6,430 | 9,456 |
| 5 „ | 5,888 | 5,166 | 5,098 | 7,737 | 9,091 | 12,204 | 13,829 | 14,121 | 13,648 | 9,317 | 6,947 | 6,317 | 9,114 |
| 7 „ | 5,775 | 4,873 | 4,851 | 7,137 | 8,662 | 11,505 | 11,685 | 12,926 | 12,565 | 8,797 | 6,835 | 6,226 | 8,486 |
| 9 „ | 5,775 | 4,851 | 4,806 | 7,038 | 8,053 | 10,557 | 11,753 | 11,980 | 11,798 | 8,640 | 6,767 | 6,159 | 8,165 |
| 11 „ | 5,775 | 4,851 | 4,783 | 6,700 | 7,513 | 9,813 | 11,279 | 11,166 | 11,076 | 8,559 | 6,700 | 6,136 | 7,863 |
| Means. | 5,904 | 5,157 | 5,069 | 7,494 | 8,848 | 11,769 | 13,088 | 13,316 | 12,824 | 9,144 | 6,952 | 6,272 |  |

(*Vide* Appendix, *fig.* 9).

These observations having been made with **Daniell's** hygrometer, we might imagine that the want of coincidence in these values depends on the difference of the instruments employed. To be certain on this point, I made simultaneous observations for several months, during the summer of 1836, with the psychrometer and **Daniell's** hygrometer: their indications agreed very well. We are hence compelled to admit, that their want of coincidence is due to differences of climate; whilst, at Halle, the quantity of vapour goes on diminishing from morning till mid-day during the whole summer, we find no indication of this diminution at Apenrade, where it augments and diminishes with the temperature, and where the differences between the *maxima* and the *minima* are much more considerable than at Halle.

In order to give a value to these differences, we must know the laws that these variations obey; but, the number of observations being too limited, we must confine ourselves to a few general remarks. All these differences are connected, either with the ascending currents or with the resistance that the air opposes to the transference of vapours. When evaporation commences in the morning with the increase of temperature, the vapour, by virtue of the resistance of the air, accumulates at the surface of the soil, as observations made at all parts of the globe shew. This stratum of vapour does not attain a great thickness; but, as soon as the ascending current commences, especially in summer, the vapours are drawn away toward the upper parts of the atmosphere, with a force that continues increasing until mid-day. The evaporation from the soil is then more active on account of the increase in temperature; nevertheless, the ascending current carries away the greater portion, and there is a diminution in the quantity of vapour. Towards evening, when the temperature begins to fall, the ascending current diminishes in force, or even ceases altogether; then, not only does the vapour accumulate in the lower parts, but it even descends from the higher regions; and, on this account, we observe towards evening a second *maximum*, which is not sustained, because, during the night, the vapour precipitating in the form of dew or white-frost, the air necessarily becomes drier.

The justice of these remarks is fully confirmed by observations made on a high mountain. Whilst at a little height, as that of Halle, the quantity of vapour diminishes toward mid-day, we find, on elevated points, a rapid increase in the course of the day, and, in the evening, a no less rapid diminution. These two phenomena are the more marked as the point is more elevated. In June 1832 and 1833, I observed the hygrometer on the Rigi (1810$^{m}$), and during the months of September and October in the same year, on the Faulhorn (2672$^{m}$), while M. Horner did the same at Munich. The following table gives the mean of the observations of the two years.

### TENSION OF THE VAPOUR OF WATER AND RELATIVE HUMIDITY, AT ZURICH, ON THE RIGI, AND ON THE FAULHORN.

| HOURS. | ZURICH. | | RIGI. | | ZURICH. | | FAULHORN. | |
|---|---|---|---|---|---|---|---|---|
| | mm. | | mm. | | mm. | | mm. | |
| Noon. | 10,92 | 58,9 | 7,54 | 80,3 | 10,03 | 64,0 | 4,86 | 73,4 |
| 1 | 10,99 | 58,7 | 7,49 | 78,2 | 9,86 | 60,7 | 5,04 | 75,7 |
| 2 | 11,05 | 58,6 | 7,42 | 78,6 | 9,87 | 59,2 | 5,00 | 77,0 |
| 3 | 10,91 | 60,0 | 7,40 | 79,8 | 9,77 | 57,9 | 5,16 | 80,7 |
| 4 | 10,97 | 60,9 | 7,24 | 81,2 | 9,65 | 58,8 | 4,94 | 80,8 |
| 5 | 11,17 | 63,8 | 7,06 | 82,7 | 9,86 | 63,6 | 4,62 | 80,5 |
| 6 | 11,23 | 66,6 | 6,98 | 85,2 | 9,97 | 69,5 | 4,32 | 78,5 |
| 7 | 11,21 | 71,4 | 6,84 | 85,7 | 9,86 | 74,1 | 4,16 | 77,6 |
| 8 | 11,34 | 76,3 | 6,69 | 86,4 | 9,66 | 76,7 | 4,01 | 76,1 |
| 9 | 11,30 | 79,6 | 6,70 | 87,3 | 9,44 | 78,7 | 3,93 | 75,8 |
| 10 | 11,13 | 81,7 | 6,66 | 87,8 | 9,24 | 80,4 | 3,86 | 75,0 |
| 11 | 11,05 | 83,8 | 6,59 | 87,8 | 9,08 | 81,6 | 3,80 | 74,4 |
| Midnight | 10,85 | 85,3 | 6,53 | 87,7 | 8,94 | 82,4 | 3,73 | 73,7 |
| 13 | 10,83 | 86,7 | 6,48 | 87,7 | 8,78 | 83,1 | 3,66 | 73,0 |
| 14 | 10,71 | 87,7 | 6,43 | 87,6 | 8,79 | 83,8 | 3,59 | 72,6 |
| 15 | 10,61 | 89,0 | 6,36 | 87,5 | 8,45 | 84,8 | 3,53 | 72,3 |
| 16 | 10,56 | 90,0 | 6,31 | 87,5 | 8,32 | 85,7 | 3,50 | 72,1 |
| 17 | 10,57 | 89,7 | 6,27 | 87,0 | 8,30 | 86,4 | 3,50 | 71,9 |
| 18 | 10,69 | 86,9 | 6,42 | 85,7 | 8,37 | 86,8 | 3,40 | 71,9 |
| 19 | 10,88 | 82,4 | 6,56 | 84,6 | 8,47 | 84,5 | 3,63 | 70,6 |
| 20 | 11,13 | 76,9 | 6,76 | 83,4 | 8,87 | 80,6 | 3,79 | 69,8 |
| 21 | 11,06 | 69,9 | 7,02 | 81,2 | 9,39 | 76,2 | 4,06 | 69,7 |
| 22 | 11,08 | 65,1 | 7,27 | 81,1 | 9,53 | 70,4 | 4,27 | 71,3 |
| 23 | 11,05 | 61,7 | 7,43 | 81,5 | 9,77 | 67,1 | 4,62 | 71,8 |
| Means. | 10,97 | 74, 6 | 6,85 | 84,3 | 9,25 | 74,8 | 4,13 | 74,4 |

(*Vide* Appendix, *fig.* 10.)

Let us compare the absolute tension of vapour at Zurich and on the Rigi; the pressure of the atmosphere of vapour is at its *minimum* at sunrise. On the plain, it presents a *maximum* about nine o'clock in the morning; then comes a slight diminution, and we find, about three o'clock a value lower by about $0^{mm},2$ than that of the morning. The quantity of vapour then increases progressively; and, about sunset, attains a second *maximum*, to diminish then with equal regularity until next morning. On the Rigi, situated at a little distance, and elevated about 1402 metres above the lake of Zurich, the mid-day *minimum* is entirely wanting, on account of the vapours, which incessantly rise from the plain; towards evening these vapours fall very rapidly below its summit. The observations at Faulhorn are still more decisive; on this mountain, the greatest tension of vapour does not take place until several hours after noon.*

These notable differences in the range of the absolute quantity of the vapour of water lead to still greater in that of relative moisture. **De Saussure** and **Deluc** had previously pointed them out to observers, notwithstanding the imperfection of their instruments. The ascending current of the morning draws the vapours toward the upper regions;

---

* We as yet possess but a very few series of hygrometric observations made upon high mountains. In 1841, M. Bravais studied with me, and, in 1842, with M. Peltier, day and night, the moisture of the air, by means of the psychrometer, on the summit of the Faulhorn. The mean of thirty days' observations gave us the following results:—

DIURNAL VARIATION OF HUMIDITY ON THE FAULHORN.

| Evening. | Moisture. | | Morning. | Moisture. | |
|---|---|---|---|---|---|
| | Absolute. | Relative. | | Absolute. | Relative. |
| | mm. | | | mm. | |
| Noon. | 5,69 | 0,77 | Midnight. | 4,37 | 0,77 |
| 2 h. | 5,98 | 0,82 | 2 h. | 4,34 | 0,79 |
| 4 h. | 6,07 | 0,89 | 4 h. | 4,32 | 0,79 |
| 6 h. | 5,78 | 0,90 | 6 h. | 4,36 | 0,77 |
| 8 h. | 5,14 | 0,86 | 8 h. | 4,59 | 0,73 |
| 10 h. | 4,43 | 0,77 | 10 h. | 4,99 | 0,73 |

The range of the absolute tension of vapour, and the relative humidity, is almost the same as that given in M. Kaemtz's table. During our observations, the relative humidity was sensibly stationary from ten o'clock in the evening until the hour of sunrise; according to him, the said humidity slowly decreased during the same period. This difference might arise from M. Kaemtz having obtained the relative numbers of the night-period by interpolation. The amplitude of oscillation is a little greater in our observations than in his.

With regard to absolute tension, the hours of *maximum* and *minimum*, as well as the amplitude of variation, are almost identical.—M.

the air becomes relatively drier than it would be, in consequence of the increase of temperature alone; whilst these vapours are rising, the dryness increases less rapidly, especially as we consider that, in the higher strata of the atmosphere, the temperature changes less than in the lower strata. It may even happen that, on very elevated points, the air becomes relatively moister during the course of the day, whilst its dryness increases toward evening, when the vapours descend to the plains. My observations prove the possibility in the most evident manner; for, although the relative moisture at Zurich and on the Rigi follows a rate depending on the hour of the day, the differences are, however, much less sensible on the Rigi. At Zurich, between sixteen hours and two hours, we find a difference of 31,4 per cent; on the Rigi, between sixteen hours and one hour, a difference of only 9,3 per cent. On the Faulhorn, which is 870 metres higher, the rate is almost the reverse; in the morning about eight or nine o'clock, some hours after the *maximum* humidity at Zurich, the air is driest. In like manner in the afternoon, the relative humidity is very great on the Faulhorn, whilst, in the plain, the air attains its greatest degree of dryness. There must, therefore, exist at a certain height a point where the hygrometer is stationary during the twenty-four hours.

I have insisted on these differences, as they serve to explain several interesting phenomena. We may easily deduce from them the causes which operate so that the diurnal rate of relative moisture is different on the coasts and in the interior of continents. We have seen that, on the seacoast, the quantity of vapour goes on increasing regularly from sunrise till about two or three o'clock in the afternoon; this happens, because the sea-breeze rises precisely at the moment when the ascending currents draw the vapour toward the higher regions. This breeze brings vapours from the sea, and the air becomes moister during the afternoon than it is in the middle of the continent.

**ANNUAL VARIATIONS IN THE QUANTITY OF VAPOUR OF WATER.**—Vapour, being the result of the action of heat on water, it is evident that its quantity must vary in different seasons. This fact is even proved by the very few continued series which we possess. Let it at present suffice to give a few results, shewing what the absolute and relative moisture is at Halle, during the different months of the year.

TENSION OF THE VAPOUR OF WATER AND RELATIVE HUMIDITY IN THE DIFFERENT MONTHS, AT HALLE.

| | TENSION of the Vapour of Water. | RELATIVE Humidity. |
|---|---|---|
| | mm. | |
| January . . . | 4,509 | 85,0 |
| February . . . | 4,749 | 79,9 |
| March . . . . | 5,107 | 76,4 |
| April . . . . | 6,247 | 71,4 |
| May . . . . | 7,836 | 69,1 |
| June . . . . | 10,843 | 69,7 |
| July . . . . | 11,626 | 66,5 |
| August . . . | 10,701 | 66,1 |
| September . . | 9,560 | 72,8 |
| October . . . | 7,868 | 78,9 |
| November . . | 5,644 | 85,3 |
| December . . | 5,599 | 86,2 |

In January, the coldest month of the year, the quantity of vapour attains its *minimum;* at the same time, the relative moisture is at its *maximum.* In proportion as the temperature rises, evaporation becomes more active, and the quantity of vapour increases, at first slowly, because the east winds, which commonly blow during this season, bring dry air from the interior of the continent. However, we must not deny, that the numbers for winter and spring differ probably much from means furnished by series embracing a greater number of years; for the latter winters have been warmer and the springs colder than they generally are. So that the numbers corresponding to winter are too high, and those to spring too low. The quantity of vapour attains its *maximum* in July, the month in which the air is driest. At the approach of winter, when the heat diminishes, the quantity of water precipitated in the form of rain, dew, and hoar-frost, greatly exceeds that which passes into the state of vapour. Its quantity, therefore, goes on diminishing, although the humidity is continually increasing, and is greater in November and December than in the month of January. This is the origin of the damp cold which characterises these two last months.

We find an analagous range in all countries in which observations have as yet been made. Even in India, where the rate of temperature differs so greatly from that which we have in Europe, according to the observations of M. **Prinsep**, at Benares, an increase in the quantity of vapour is found toward the month of July, and a diminution in January.

**HYGROMETRIC CONDITIONS OF DIFFERENT PARTS OF THE EARTH.**—For a host of researches, it would be of the highest importance to know numerically the quantity of vapour which exists in different regions of the globe. The life of plants and animals, and the character of the landscape, depend on this element as much as on temperature. The dryness or humidity of the air have the greatest influence over the developement of diseases. At present we have not a sufficient number of observations; and the following remarks are only inductions which may anticipate truths that are as yet concealed from us.

In the first place, it is certain that the quantity of vapour goes on diminishing with the heat, from the equator to the pole. In localities which are similar, but which are situated at an unequal distance from the pole, is the relative humidity regulated in the same manner or differently? It is impossible to say in the present state of our knowledge. In the open sea, in all latitudes, the air appears to be in a state of saturation; for, if we place pure water, saline solutions, dilute acids, &c. under a receiver, the air of the receiver, after a certain time, will be completely saturated. However, at equal temperatures, the quantity of vapour contained in the receiver will not be equal in these different cases. It will be as great as possible with pure water, and less with other liquids. The relation depends on the nature and on the density of the solution. If we take a mixture of water and sulphuric acid, the quantity of vapour will be less, as the proportion of sulphuric acid is greater. If the sulphuric acid is almost pure, the air will remain dry, even though we should introduce into the receiver a great quantity of vapour. Although heat favours the vaporisation of water, sulphuric acid and certain salts have such an affinity for the vapour of water, that they oppose its formation. If they cannot entirely prevent it, they limit it; and there is only formed a quantity of vapour, which is the result of the equilibrium between the production of vapours by heat and their absorption by sulphuric acid. When a greater quantity of vapour than is necessary to saturate the air is introduced into the apparatus, this excess is absorbed by the acid, and converted into water. It is easy to prove these assertions, by placing a hair hygrometer in the receiver containing the solutions; the hygrometer never indicates 100° except when the liquid is pure water; in all other cases the needle indicates some degrees less than 100.

In applying these considerations to the waters of the sea, we remark that they contain more or less salt; whence it follows that they develope less vapour than does distilled water. So that, in making experiments at different temperatures, we find that the water of the ocean sends forth a quantity of vapour equal only to that which would be produced by an equal mass of distilled water, 3°,5 colder. On the ocean, the dew-point is generally below the temperature of the water of the sea; the air of the ocean, therefore, is always completely saturated.

On coasts, the quantity of vapour is, in equal latitudes, the greatest possible; and it diminishes in proportion as we penetrate into the continent. This rule is confirmed in the interior of the United States of America, in the middle of the plains of Oronoco, in the steppes of Siberia, in the deserts of Africa and Asia, as well as in the interior of New Holland, where the air is habitually very dry. In this we see how all meteorological phenomena are reciprocally linked together; the deserts of Africa, being altogether dry, are not the seat of any evaporation. Besides, the extreme heat, still further increased by the reverberation of the sand, opposes the aqueous precipitations, and consequently this country is condemned to eternal sterility.

**HYGROMETRIC CONDITIONS AT DIFFERENT HEIGHTS IN THE ATMOSPHERE.**—Are the upper strata of the atmosphere drier or more moist than the lower? I will endeavour to treat on this question in the present section; it is of high importance toward giving us a knowledge of atmospheric vicissitudes. We must not forget the distinction, which has already been established, between the absolute quantity of vapour, and the relative humidity of the air. With regard to the former, it would be idle to prove that the pressure of the atmosphere of vapour and its density diminish in proportion as we ascend. All experiments prove this. If certain exceptions are cited, they may be traced to extraordinary perturbations analogous to those which a disturbance in the decrease of temperature produces. The subject at present before us is relative moisture; and on this point, the opinions of philosophers are divided.

**De Saussure,** and **Deluc,** who were the first to take hygrometers up high mountains, but who have not always established the distinction on which we have just insisted, have said in general terms, that the air was drier above than below. This fact, having been very generally admitted by philosophers, was confirmed by the experiments which **De Humboldt** made in intertropical America; but, notwithstanding authorities of so high a stamp, I think I may contest the generality of this assertion.

When we follow the range of the hygrometer for any time, on an elevated point of the Alps, a degree of dryness is recognised, of which we have no idea in the plains; it often accompanies that beautiful weather so ardently sought after by travellers. In cases of this kind, I have frequently seen the snow disappear with extreme rapidity, without moistening the earth, because it was immediately transformed into vapours; wood, placed in the sun, very speedily warped. If these phenomena take place at the surface of the soil, where the hygrometer is influenced by direct evaporation from the earth, they must be still more marked when we ascend in a balloon. However, we must not forget that these very dry days succeed days, and even entire weeks, during which the summits of the mountains are veiled in thick fogs, whilst in the plain the hygrometer is far from the point of saturation. If we reflect that the observations of **De Saussure**, and **Deluc**, with the exception of their stay on the Col du Géant, were all made during journeys over mountains, for which they always selected fine weather, we shall not be astonished if their results are far distant from the mean result. In analysing those of M. **de Humboldt**, we must not forget that his lower station was on the sea-coast, whilst his higher station, situated within the country, was exposed to the influence of east winds, which, when they traverse vast continents, are generally very dry. **De Saussure** made a series of observations during his sixteen-days' stay on the Col du Géant, at a height of 3450 metres; whilst simultaneous observations were being made with the instruments at Geneva, and in the valley of Chamouni. Unfortunately, the inventor of the hygrometer excluded from his calculations all the days during which he was surrounded with clouds; and, consequently, the mean which he obtained is very different from the real mean.

Considerations of this kind have induced me, in my *Treatise on Meteorology*, to throw a doubt on the generally received opinion of the greater dryness of the higher regions. While, for a period of nine weeks, the air at Zurich did not contain, at a mean, more than 74,6 per cent of the vapour necessary to its saturation, it contained 84,3 on the Rigi. After eleven weeks of observations during the months of August, September, and October, this quantity was 74,8 at Zurich, and 74,4 on the Faulhorn. Thus, then, we are authorised to conclude that, as a whole, the air of the upper strata is as moist as that of the lower strata.*

My observations have also shewn me the influence of atmospheric vicissitudes on this phenomenon,—an influence much more marked in the region of clouds than on the plain. The weeks, which I passed, in 1832, on the Faulhorn, were remarkable for their great severity. The sky was cloudy for only a few days, and I was rarely enveloped in clouds. The end of the summer of 1833 was, on the contrary, very moist; the sky rarely remained clear for a few hours; and frequent inundations, the result of abundant rains, desolated many parts of Switzerland. So, in 1832, the relative humidity was 74,4 at Zurich; and 63,3 on the Faulhorn. In 1833, it was 75,3 at Zurich, and 85,5 on the Faulhorn. Thus, while, in the former year, the air was much drier above, it was the reverse during the latter; and the difference of the two years is more characteristic on the mountains.

It remains for us to seek for the causes of these differences in relative humidity. Without doubt, continuous observations for several years would be necessary in order to decide these questions in a definite manner; but, since we do not possess them, I must make use of my own. The first idea which presents itself to the mind is to admit that the tension of vapour diminishes faster in dry weather than it does in moist, in the higher regions of the atmosphere. However, the differences that have been observed are not entirely explained by this circumstance; for, in 1832, the tension of vapour on the Faulhorn was $3^{\mathrm{mm}}$,748, and at Zurich, $8^{\mathrm{mm}}$,797. In 1833, I found it $4^{\mathrm{mm}}$,507, for the Faulhorn, and $9^{\mathrm{mm}}$,710, for Zurich. Thus, then, while during the dry summer of 1832, the quantity of vapour on the Faulhorn is 0,43 of that on the plain, it was 0,46 during the wet summer of 1833; and, although the latter figure is higher than the former, it is not sufficiently so to explain

---

* The observations which I made with M. Bravais, at the summit of the same mountain, on the 16th of July, and the 5th of August, 1841, fully confirm the author's results. We found, for the comparative relative humidity:—

| | |
|---|---|
| Faulhorn . . . . . . . . . . . | 75,9 |
| Zurich . . . . . . . . . . . | 72,9 |
| Milan . . . . . . . . . . . | 63,2 |

M.

the observed differences. The influence of temperature is shewn much more powerfully: in 1832, the mean of the series was 12°,67 at Zurich, and 2°,46 on the Faulhorn; in 1833, it was 14°,20 at Zurich, and 0°,51 on the Faulhorn. During the former year it was necessary to ascend 230 metres, in order to obtain a decrease of 1°; during the latter, a difference of level of 164 metres was sufficient to obtain the same decrease. It is then very probable, that the decrease of temperature is much less rapid during serene than during cloudy weather; and it is this circumstance, which is due to the direction of the wind, and other causes, that reacts in its turn on the state of the weather, either determining or preventing the condensation of vapours.

All these considerations explain to us why observers have always complained of the inaccuracy of hygrometric indications. Thus, the sky is cloudy, or it even rains, and yet the hygrometer is dry; at another time, the weather is fine, and the hygrometer indicates a very high degree of humidity. So that the recriminations of those who regard these instruments as prognosticators of weather, are very legitimate. But philosophers ought not to forget that the thermometer and the hygrometer simply indicate the condition of the air of the place in which they are situated. At fifty or sixty metres above the head of the observer, conditions are changed. Suppose, for example, that the quantity of vapour of water diminishes regularly with the height, but that the decrease is more rapid than usual; we shall then have a clouded sky with a dry hygrometer. If the reverse takes place, and the air is unusually hot above, the hygrometer may be moist with a clear sky.

Thus, therefore, predictions based on the state of the hygrometer will be very often at fault. In the sequel, we shall find that we must combine them with another element, namely, the pressure of the atmosphere.

**INFLUENCE OF WINDS ON THE HYGROMETRIC CONDITIONS OF THE ATMOSPHERE.**—Daily experience has long taught us that the air is not equally moist with every wind. When the farmer wishes to dry his corn or his hay, or the housewife spreads out her wet linen, their wishes are soon satisfied if the wind blows continuously; but a much longer time is required with a west wind. Certain operations in dyeing do not succeed unless during east winds. However instructive these observations may be, they can never lead to rigorous laws.

To obtain these, we must ransack a long series of meteorological journals, in order that partial anomalies may disappear in the means. We associate all the hygrometric indications which correspond to each wind, we take their arithmetical mean, and in this manner obtain the hygrometric card of the winds of the locality in question. To obtain an exact result, certain precautions are indispensable. The hygrometric conditions varying, as we have seen, according to the hour of the day and the season of the year, it would be very irrational innocently to sum up all the numbers found: for, let us suppose that the north wind has blown ten times in winter and thirty times in summer, as the air contains more vapour of water in summer than in winter, the mean quantity of vapour corresponding to this wind would be higher if we contented ourselves with taking the mean of our forty observations. I prefer the following method:—

Being in possession of a considerable number of daily observations made at Halle, I sought the mean direction of the wind for each day, and I applied to it the hygrometric mean. In the cases when there were sudden changes of wind during the day, as from the S.W. to the N.E. for example, I applied the hygrometric mean equally to both winds. If each wind had blown the same number of times in each month, I could have separately added the tensions of vapour observed for each month, and have divided their sum by the number of times that the wind had blown. But each wind does not blow the same number of times, either during a month, or even during a year; we cannot, therefore, adopt this process: but two methods present themselves, by which this difficulty may be solved: 1st, To take the mean for each hour of the month, and then to deduct from it, first the monthly mean, and afterwards the annual mean. But this will be only an approximation; for any given wind blows more frequently in one month than in another; and it will follow, that the same degree of confidence will be given to a mean deduced from a small number of figures as to that which shall be the result of a long series of observations. 2d, Suppose that I have, for instance, taken, for the north wind, the monthly mean of several years; I compare it with the general mean, and look for their difference; I then multiply the latter by the number of observations; I afterwards add these products quarterly or annually, and I subtract the mean of these sums from the general means. A single example will explain what I have just said. Let the tensions of vapour for the N.E. wind in three months be:—

| | | mm. | |
|---|---|---|---|
| December | 10 observations | 3,587 | mean |
| January | 8 „ | 3,091 | „ |
| February | 12 „ | 3,661 | „ |

But the sum of the observations gives as the mean tension of each month :—

| | mm. |
|---|---|
| December | 5,484 |
| January | 4,169 |
| February | 4,563 |
| Winter | 4,738 |

Consequently, we deduce the following differences :—

December . . . 3,587 — 5,484 = — 1,897 mm.
January . . . 3,091 — 4,169 = — 1,078
February . . . 3,661 — 4,563 = — 0,902

Now, let us multiply these differences by the number of observations, and we shall find :—

December . . . 10 × — 1,897 = — 18,970 mm.
January . . . 8 × — 1,078 = — 8,624
February . . . 13 × — 0,902 = — 11,726

Sum . . . . . . — 39,320
Mean by 31 . . . — 1,268

So that, in winter, for the N.E. wind, the mean tension of the vapour is $1^{\mathrm{mm}},268$ below the general mean; it is, therefore, equal to $4^{\mathrm{mm}},738 - 1^{\mathrm{mm}},268 = 3^{\mathrm{mm}},470$.

This method is undoubtedly long and tedious, but I know of no other more accurate mode; and, as it would be of the highest interest to possess these elements in a great number of countries, I would induce observers to make these tables by winds and tensions every day, without which, the number of observations will so accumulate, that we shall lose all courage to calculate them.

I have been led to these results by four consecutive years of observations (1834–7), made at Halle. However, I do not think that these numbers are definitive; because the monthly means are still uncertain. Nevertheless, as I know of no other series that furnishes all the necessary elements, I here give these numbers, which cannot be very far from the truth, so far as middle and southern Germany are concerned; if we first seek the mean tension of vapour during the year, we find, for the different winds, the following numbers :—

TENSION OF THE VAPOUR OF WATER FOR DIFFERENT WINDS.

| | mm. | | mm. |
|---|---|---|---|
| N. | 6,69 | S. | 7,82 |
| N.E. | 6,56 | S.W. | 7,46 |
| E. | 6,90 | W. | 7,26 |
| S.E. | 7,31 | N.W. | 6,90 |

So that the quantity of vapour is as small as possible when the wind blows between the N. and the N.E.; it increases when it turns to the E., the S.E., and the S.; and attains its *maximum* between the S. and the S.W., to diminish again in passing to the W. and the N.W. The cause of these differences is very simple. Before arriving to us, the west winds pass over the Atlantic, and become charged with vapours; whilst those which blow from the east come from the interior of the continents of Europe or Asia. These vapours are resolved into rain when the west winds arrive in France; but this water almost immediately evaporates, and the consequence is, that in Germany these winds will be always more charged with vapour than those from the east. The W.S.W. wind, coming at once from the sea, and from the warmer countries, may become charged with a greater proportion of the vapour of water than the west wind, which is colder. Also, although the latter has less distance to pass over in order to arrive from the sea to Halle, it contains a less proportion of vapour than the S.W.

The same differences exist between the different seasons; I pass them over in silence, to direct my attention solely to relative humidity. Here, the element of temperature enters into the calculation; for the quantity of vapour may vary infinitely, while the degree of heat remains still the same. We shall see, from what follows, the influence which the winds have over the temperature; but every one already knows that in winter, for example, the west winds are warm, whilst those from the east are cold. I have already remarked also, that, in equal latitudes, the winters were colder and the summers warmer, in the interior of the continent than on the western coasts of Europe. If the annual means were taken, the numbers found for Halle will not make the differences prominent. In taking the per-centage of vapour of water capable of saturating each wind, the following table presents the proportion of vapour that this wind contains :—

RELATIVE QUANTITY OF VAPOUR OF WATER FOR EACH WIND AT HALLE.

| | | | |
|---|---|---|---|
| N. | 78,3 | S. | 73,6 |
| N.E. | 77,5 | S.W. | 74,8 |
| E. | 73,0 | W. | 74,4 |
| S.E. | 74,8 | N.W. | 76,5 |

Thus, although during the north wind the air contains a much less proportion of the vapour of water than during the south wind, it is nevertheless infinitely more moist, on account of its low temperature. The seasons give a still further modification to this general rule, on which account I here give the following table:—

RELATIVE HUMIDITY FOR THE DIFFERENT MONTHS IN THE FOUR SEASONS OF THE YEAR.

| WIND. | WINTER. | SPRING. | SUMMER. | AUTUMN. |
|---|---|---|---|---|
| N. | 89,5 | 75,0 | 67,6 | 78,7 |
| N.E. | 91,2 | 72,3 | 67,4 | 82,6 |
| E. | 92,6 | 66,9 | 61,3 | 75,7 |
| S.E. | 85,5 | 71,4 | 66,3 | 79,2 |
| S. | 83,0 | 70,3 | 67,4 | 76,2 |
| S.W. | 81,9 | 70,3 | 69,9 | 78,6 |
| W. | 80,9 | 71,7 | 71,4 | 80,6 |
| N.W. | 83,2 | 73,4 | 68,8 | 82,7 |

(*Vide* Appendix, *fig.* 11).

This table probably contains several anomalies; however, it gives rise to many interesting considerations. We are first struck by the contrast existing between winter and summer. Although, in these two seasons, the proportion of vapour is less during east than during west winds, yet the lower temperature of these winds during winter re-establishes the equilibrium, and in this season the east wind is the moister, and the west, the drier. In summer the contrary is the case; when either of these winds is commencing to blow, the contrast is the more striking. If, for example, in winter, the west winds have prevailed for some time, with a very pure atmosphere, and an E. or N.E. wind suddenly rises, the sky is cloudy in a short time; one part of the vapour of water is precipitated in the state of rain or snow, and thick fogs occupy the lower regions of the atmosphere. In this state of things, the barometer is often at fair, which gives rise to recriminations without end against the false predictions of this instrument. But, if the east wind continues to blow, the sky then becomes serene, although the air remains moist. If the converse takes place, that is to say, if the sky is clouded, the wind being in the east, and it suddenly passes to the south, the sky becomes clear, and the atmosphere dry; because the warmer air dissolves the vapour of water, and is far from the point of saturation. It is only when this wind has prevailed for some days, and has brought to us a large quantity of vapours, that the atmosphere again becomes moist.

I have studied the influence of winds in other localities, and the numbers to which I have arrived differ but little from those that I have given, so that they may be considered as closely approaching to the truth. Without dwelling upon daily means, but by examining the variations which take place during the day, a regular rotation of the winds is recognised. Thus, the wind passes from the E. to the S.E., then to the S., and so on; but the proportions of the vapour of water are not the same for each of these winds. If the vane indicates the S.E. wind, it will soon turn to the S., and, as the circumstances that determine this change already exist, the quantity of the vapour of water gradually increases during the day. For the same reason, this proportion of vapour diminishes if the wind is in the N.E., because it is preparing to pass to the north. M. Dove has demonstrated these facts by taking for his base the four daily observations of the Observatory at Paris. Those which I made hourly, from six o'clock in the morning until ten in the evening, shew it still more evidently.

DIFFERENCE IN MILLIMETRES BETWEEN THE MEAN TENSION OF VAPOUR AT DIFFERENT HOURS OF THE DAY, AND THAT WHICH IT HAS WITH THE PRINCIPAL WINDS, AT HALLE.

| HOURS. | N. | N.E. | E. | S.E. | S. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|---|
| 6 Morning. | —0,314 | —0,595 | —0,426 | —0,108 | +0,104 | +0,165 | +0,079 | —0,013 |
| 7 „ | —0,323 | —0,566 | —0,384 | —0,047 | +0,095 | +0,153 | +0,124 | —0,023 |
| 8 „ | —0,366 | —0,526 | —0,303 | +0,072 | +0,208 | +0,163 | +0,095 | —0,151 |
| 9 „ | —0,440 | —0,645 | —0,294 | +0,187 | +0,278 | +0,185 | +0,045 | —0,189 |
| 10 „ | —0,541 | —0,638 | —0,321 | +0,200 | +0,372 | +0,187 | —0,002 | —0,321 |
| 11 „ | —0,595 | —0,665 | —0,363 | +0,135 | +0,438 | +0,185 | —0,020 | —0,308 |
| 12 „ | —0,609 | —0,720 | —0,361 | +0,095 | +0,465 | +0,200 | —0,061 | —0,310 |
| 1 Evening. | —0,640 | —0,752 | —0,440 | +0,140 | +0,537 | +0,191 | —0,061 | —0,395 |
| 2 „ | —0,606 | —0,738 | —0,458 | +0,174 | +0,569 | +0,196 | —0,041 | —0,420 |
| 3 „ | —0,640 | —0,733 | —0,476 | +0,235 | +0,578 | +0,196 | —0,059 | —0,420 |
| 4 „ | —0,661 | —0,736 | —0,471 | +0,318 | +0,595 | +0,172 | —0,061 | —0,458 |
| 5 „ | —0,686 | —0,747 | —0,443 | +0,420 | +0,548 | +0,180 | —0,039 | —0,501 |
| 6 „ | —0,733 | —0,772 | —0,415 | +0,510 | +0,555 | +0,210 | —0,018 | —0,546 |
| 7 „ | —0,736 | —0,763 | —0,353 | +0,546 | +0,578 | +0,221 | —0,032 | —0,543 |
| 8 „ | —0,714 | —0,778 | —0,275 | +0,604 | +0,541 | +0,246 | —0,052 | —0,507 |
| 9 „ | —0,716 | —0,837 | —0,240 | +0,627 | +0,526 | +0,221 | —0,054 | —0,535 |
| 10 „ | —0,722 | —0,857 | —0,246 | +0,602 | +0,519 | +0,185 | —0,061 | —0,541 |

(*Vide* Appendix, *fig.* 12.)

In comparing the tension of the vapour observed at each hour of the day and for each particular wind, with the general mean tension of that hour, I entirely avoid the diurnal variation; and I find a constant connexion between the rotation of the wind, and the increase or diminution of the quantity of vapour. The preceding table gives the view of these differences. The sign — signifies that the tension of vapour was below, the sign + that it was above, the mean.

This view contains more anomalies than one, because the observations, on which it rests, were not continued for a sufficiently long time. It shews how much the tension diminishes with the N.W., the N., and the N.E. winds, in the course of the day, and how much it increases with those from the S.E., and the S.; the E. and the S. lines also form a remarkable contrast. With the east wind, the quantity of vapour increases during the day; however, at the hottest hours, it diminishes rapidly. With the south wind it increases during precisely the same hours. In summer, these variations are much more marked than in the other seasons, and they depend on the ascending current. With the east wind, when the sky is clear, the vapours rise under the influence of the sun, and the quantity of vapour diminishes until the evening, when it falls to the surface of the earth. With the south wind, the sky is often cloudy; the ascending currents are more feeble or are null; and the vapours, that are formed during the day, remain in the lower strata of the atmosphere.

It would be interesting to seek what the proportions of vapour are, above and below, with the same wind; but observations on this subject are wanting. However, the existing materials give rise to considerations, which I will develope in the sequel.

**PASSAGE OF VAPOURS INTO THE LIQUID STATE.**—Hitherto we have studied the conditions, which influence the quantity of vapour of water contained in the air. Although incomplete, the facts related are sufficient to enable us to comprehend the theory of the transition of vapours into the liquid state. When the air contains a greater quantity of the vapour of water than it can contain in a state of saturation, one part of this vapour is resolved into water, or floats in the air in the state of cloud. The vapour of water is always precipitated under the influence of the same causes, but under a different form. We will, therefore, examine separately dew, white frosts, fog, clouds, rain, and snow. I have purposely avoided mentioning hail; for its fall is accompanied by such a developement of electricity that many philosophers think this fluid to play a great part in its formation; I have, therefore, placed the article on Hail in the chapter on Electricity.

Although these atmospheric precipitations have been observed for a long time, yet positive laws have not supplied the place of gratuitous hypotheses, until within about half a century. In 1784, **Hutton** established the following principle: when two masses of saturated air of unequal temperature meet, there is a precipitation of aqueous vapour. If the masses of air are not in a state of saturation, they nevertheless become moister; and, if the temperatures are very different, there will even be a precipitation, although the two masses of air might not be saturated.

At the epoch of its appearance, this thesis was combatted by **Deluc**, who had laid down a theory, to which time has done justice, whilst that of **Hutton** is still maintained. Suppose that two masses of equally saturated air are mixed, one being at the temperature of 10°, the other at 20°; the mixture will have a temperature of 15°. According to the table p. 72, the elasticity of the vapour of water, in one of the masses, will be $9^{mm},90$, and in the other $18^{mm},20$. So in the state of mixture it will be $14^{mm},05$. But air at 15°, at its *maximum* of saturation, can only contain a quantity of vapour with $13^{mm},44$ of tension. So that the difference, namely, $14^{mm},05 - 13^{mm},44 = 0^{mm},61$, will express the tension of the quantity of vapour that will be precipitated. Suppose now that each of these masses of air only contains 50 per cent of vapour of water, then the elasticities would be $4^{mm},95$ and $9^{mm},10$; and, after the mixture, this elasticity would become $7^{mm},02$. But air at 15° being able to contain only $13^{mm},44$ of vapour, the mixture will have 52 per cent of vapour of water. The quantity of aqueous precipitation will be in proportion to the difference of temperature of the two masses of air, as the very simple calculations that we have just made shew.

**ON DEW AND WHITE FROST.**—When the vapour of water is precipitated during the night, in the form of drops spread on the surface of plants and other bodies, it obtains the name of *dew*. If the temperature is very low, it appears in the state of *white frost*. This kind of precipitation more frequently takes place when the sky is clear; hence a great many hypotheses may explain its formation. Alchemists used carefully to collect the dew, which they regarded as an exudation from the stars, and in which they hoped to find gold. Other philosophers admitted that it was a very fine rain coming from the elevated regions of the atmosphere; whilst others were persuaded that it came out of the earth. There are some, who attributed to it extraordinary properties, among which they especially notice its frigorific qualities. The experiments on this subject made by **Wells**, in London, are a model to be followed in all meteorological researches; they shewed what was the true theory of the formation of dew. Notwithstanding the objections that have been raised against it, I still regard it as that which, above all others, agrees best with the whole range of observed facts.

To measure the quantity of dew deposited each night, an instrument is used, called a *drosometer*. The most simple process consists in exposing to the open air bodies, whose exact weight is known; and then weighing them afresh after they are covered with dew. According to **Wells**, locks of wool, weighing five decigrammes, are to be preferred, which are to be divided into spherical masses, of the diameter of about five centimetres.

The most important phenomena, which accompany the production of dew, are the following:—

1st. The dew falls, for the most part, during calm and serene nights. This law, which was established by **Aristotle**, has been frequently doubted since his time; **Musschenbroeck** in particular has asserted that, in Holland, the dew was abundant during the time of fogs. But, although the drops deposited by fogs on terrestrial bodies resemble those of dew, there is, however, this difference between them, that fog wets all bodies indifferently, whilst dew attaches itself in preference to some of them. When the dew is formed, it often disappears very quickly, if the wind rises or the atmosphere is disturbed.

2d. Dew is deposited in preference on bodies not protected by shelter. Put into the open air two similar locks of wool, but place a piece of cloth a few yards above one of them, and you will find that it will be covered with a less quantity of dew than the other. The piece of cloth acts less as a roof, than because it prevents the lock from subtending an equally large portion of the sky. **Wells** proved it by the following experiment. He placed a lock of wool in the middle of an open cylinder, three decimetres in diameter, and seven high, which he placed vertically; this lock was charged with a less quantity of dew than was another exposed freely to the air on all sides. There also falls more dew in the open country than in cities, where houses conceal a portion of the sky.

3d. All things else being equal, certain bodies are sooner covered with dew than certain others; plants are more wetted than the earth; sand sooner than a trodden soil; glass sooner than metals; chips sooner than a piece of wood.

4th. When circumstances are favourable, dew is deposited during the whole of the night; and not, as ancient philosophers stated, only in the morning and evening.

5th. The most abundant dews are observed on coasts. In the interior of large continents, and particularly in the interior of Asia and Africa, they are almost nothing, and only fall in the neighbourhood of rivers and lakes.

Without stopping at the different hypotheses, which have been given on the formation of dew, I will lay down **Wells's** opinions on the subject. Dew is an effect of the fall of temperature in the strata of air in contact with the soil. When the latter is heated during the day, the vapours rise; and when towards evening the force of the ascending current begins to diminish, they fall again toward the earth, without the air's being saturated. After sunset, and when the weather is calm and the sky serene, the soil radiates and its temperature descends several degrees below that of the contiguous stratum of air, of a few decimetres in thickness. Then the phenomenon of the precipitation of vapour on a cold glass, when brought into a heated room, takes place on a grand scale, and the grass is covered with dew. This fall of temperature always precedes the formation of dew. The more notable it is, the more abundant is the dew, for equal quantities of vapour of water contained in the air. Agriculturists also very well know that nights with heavy dews are very cold; but this cold is the cause, and not the effect of the dew. Every thing which opposes radiation, a screen either above or beside the object, for instance, prevents the formation of dew. Plants placed beneath a tree are much less wetted than others. This cooling taking place chiefly in the neighbourhood of the soil, we can conceive that objects are less wetted by dew, as they are farther from the earth. Every thing proves that an elevation of a few inches above the surface of the soil, is quite sufficient to produce great differences. Radiation having but little intensity when the sky is clouded, there is no dew. It is the same when there is wind; for then the cold strata of air, that are in contact with the soil, are constantly replaced and driven away by others, whose temperature is higher.

All circumstances, that favour radiation, equally contribute to the formation of dew. A body, that is a good radiator and a bad conductor of heat, will therefore be covered with a very abundant dew. Thus glass becomes wet sooner than the metals; organised bodies are wetted more quickly than glass, especially when they are in small fragments; because, as the heat passes with difficulty from one to the other, that which is lost is not replaced by that which is transmitted from the interior to the surface of the body. Thus locks of wool are very well suited to these experiments, and become covered with a very abundant dew.

The moister the air is, all other things being equal, the more considerable is the quantity of dew that falls in a given time. Thus, it is entirely wanting in arid deserts, notwithstanding the intensity of nocturnal radiation. In our countries, nights with abundant dews may be considered as foretelling rain; for they prove that the air contains a great quantity of the vapour of water, and that it is near the point of saturation.*

White frost is produced under the same circumstances as dew. While, at a few yards above the earth, the air is several degrees above the freezing-point, the soil is cooled by radiation, and the vapour is congealed in the form of beautiful crystals. This cooling is very hurtful to vegetation; and, during the serene nights of spring, the products of the kitchen-garden are frequently killed by the cold. Here again all circumstances that oppose radiation, prevent the cooling. Vegetables sheltered by trees suffer less than those that are not so protected. A thin covering of cloth or of straw preserves plants; and the vine has often been prevented from being frozen by lighting fires, that give much smoke.

In like manner, as under the name of dew are comprised all the drops of water that remain attached to the leaves of plants, so also, under that of hoar-frost, are comprised the aqueous precipitations, which assume the form of snow. These precipitations may be formed in different ways. When south winds succeed to continuous cold, and the thermometer rises almost to freezing-point, vapours are precipitated in the solid form; stone buildings are quite white, and the branches of trees are covered with beautiful crystals. This form of white frost, which is observed in our climates every winter, is very frequent in the polar regions during the winter seasons. The rigging of ships is then adorned with sparkling fringes and regular crystallization, which sailors have called *beards*.

---

* *Vide* M. Arago's Notice on Dew (*Annuaire du Bureau des Longitudes*, 1827; pp. 165–198).

The ancient chemists thought that they recognised in dew-water celestial principles; it is of great purity, only containing a little more carbonic acid than rain-water. In its contact with vegetables, it becomes charged with organic principles. For a long time, certain dews were supposed to contain foreign substances, and to be hurtful to vegetation. They were called *honey-white* or *miller* (*Honigthau*, *Mehlthau*, Germ.) They are both sugar secretions, hurtful to vegetables, and to the animals that feed on them. Thus, in the years 1556 and 1669, there was in Switzerland a great murrain; but **Scheuchzer**, who studied it, suspected then that this substance, that covered the plants, did not fall from the sky. After him, **Leche** shewed that the aphides, which often collect there in great quantities, are the immediate cause of these pathological secretions. This matter is secreted from two openings, at the posterior part of the animal; if it is not collected either by the bees or the ants, it is dissolved in the dew, and falls on the lower leaves. It is also probable that this sugary matter is due to the decomposition of the vegetable juices, analogous to that by which starch is converted into sugar in the manufacture of beer.

**ON FOG.**—When the vapour of water is precipitated in the atmosphere, the transparency of the air is disturbed; and this aqueous precipitation takes the name of fog, when it is on the surface of the earth, and of cloud, when it remains suspended at a certain height in the atmosphere. So the traveller, who journeys to the summit of a high mountain, complains that the fog intercepts his view; whilst the inhabitant of the plains says that the summit of the said mountain is enveloped in clouds.

**VESICLES OF FOGS.** — Examined by a lens, the fog is composed of small opaque bodies. A close investigation shews that these small bodies are composed of water. Obedient to the laws of universal gravitation, the molecules of water are grouped into the form of spherules, analogous to those of mercury poured into a porcelain saucer, or water at the bottom of a glass smeared with grease. Are these spherules full or empty? On this question meteorologists are divided. The opinion put forth some time ago by **Halley**, that these spherules are hollow, and that the water only serves as an envelope, appears to have a better foundation than any other. However, it is probable that they are mixed with a great quantity of drops of water; in the sequel, we shall use the terms *vesicular vapour*, *vesicular fog*, to designate this particular condition of the vapour of water. The researches of **De Saussure** and **Kratzenstein** give great weight to this opinion. Take a cup, filled with a liquid of a deep colour, such as coffee, or Indian ink dissolved in water; warm it, and place it in the sun or in a light place: if the air is tranquil, the vapour ascends and soon disappears; if it is observed through a lens, globules of various thicknesses will be seen to ascend from the surface of the liquid. **De Saussure** adds that the little vesicles that rise differ so much from those that fall, that it is impossible to doubt the former being hollow.

The manner in which these bodies conduct themselves with light, is no less favourable to this opinion; they do not present that scintillation which is observed in full drops when exposed to a strong light. Moreover, true rainbows are never observed on clouds, although the spectator, the cloud, and the sun may be often in the relative positions most favourable to the production of the phenomenon; this would not be the case if clouds were composed of drops of water.

**Kratzenstein** made a still more convincing observation, which few authors have taken into consideration. The bubbles formed with soap-water are often ornamented with the most beautiful colours. Colours are also observed on bubbles formed of viscous substances; and they may be studied with the greater facility, as they last a considerable time. A bubble of this kind, placed on black pitch or melted glass, shews, at its upper part, a black or a coloured spot, surrounded by a certain number of coloured rings. These colours are derived from the incident rays being divided into two portions. Some are reflected by the anterior surface; others traverse it, but are partly reflected by the posterior surface. The eye, therefore, receives, almost in the same direction, two classes of reflected rays, some from the anterior, others from the posterior surface. These rays, being variously coloured, react on each other, and are neutralised; but some of the colours of the spectrum remain isolated; and it is not white, but coloured light, which reaches the eye. I shall not examine in this place the causes and the laws of the phenomenon; but I would merely remark that the envelope of the sphere must be very thin, in order that these appearances may be produced, and that they are intimately connected with the thickness of this envelope. In soap-bubbles, these appearances change every moment; because the water which runs on the bubble, and evaporation every moment, vary the thickness of the envelope.[6] In like manner, the colours of a film of mica change every moment, when it is pressed between the fingers, because the thickness of the film of air, which separates the different films, never remains the same.

[6] *Vide* Note *e*, Appendix No. II.

To study these optical effects, **Newton's** process is the best. Take a piece of very level glass, and on it place a convex lens with a long focus; on looking at it, at a certain angle, you will see coloured rings, the centre of which coincides with the point of contact of the two glasses. If the radius of the curvature of the lens were known, the distance of the different points of the lens from the level mirror may be calculated; if, at the same time, the colours are observed, the thickness necessary to produce such or such a colour is deduced. **Kratzenstein**, having examined in the sun, through a magnifying glass, the vesicles rising from hot water, observed at their surface coloured rings, like those of soap-bubbles; and not only was he convinced that their structure was analogous to soap-bubbles, but he was also able to calculate the thickness of their envelope.

**De Saussure** and **Kratzenstein** endeavoured to measure under the microscope the diameter of the vesicles, of which the vapour of water is composed. It is, however, difficult to arrive at a positive result; for the true object is to measure vesicles of fog, and not those arising from hot water: fortunately some of the optical phenomena, that are produced when the sun shines through clouds or fogs, furnish us with a means of arriving at this result. I will hereafter describe the process that I adopted, regretting that it has not been more frequently put into practice. I have made a great number of measurements in Central Germany and in Switzerland. I found that the mean diameter of the vesicles of fog is about $0^{mm},0224$; their diameter varies in different seasons, and appears to be smaller in summer; I find, for instance, the following numbers :—

DIAMETERS OF VESICLES OF FOG IN THE DIFFERENT MONTHS OF THE YEAR.

| | mm. |
|---|---|
| January ..... | 0,02752 |
| February .... | 0,03498 |
| March ...... | 0,01997 |
| April ....... | 0,01917 |
| May ........ | 0,01560 |
| June ........ | 0,01798 |
| July ........ | 0,01695 |
| August ...... | 0,01402 |
| September ... | 0,02244 |
| October ..... | 0,02039 |
| November ... | 0,02454 |
| December.... | 0,03490 |

(*Vide* Appendix, *fig.* 13.)

A very regular progression is seen to exist from winter to summer; for the anomalies depend on the insufficient number of existing observations. So, in winter, when the air is very moist, the diameter of the vesicles is twice as great as in summer, when the air is dry; but in the same month this diameter also changes: it obtains its *minimum* when the weather is very fine; it increases as soon as there is a threatening of rain; and before it falls, it is very unequal in the same cloud, which probably contains a great number of drops of water, mingled with the vesicular vapour. **Kratzenstein** determines the thickness of the envelope of these vesicles from the coloured ring, which he observed on their surface; it is $0^{mm},06$.

**FORMATION OF FOGS.**—When fog becomes visible any where, it is because the air is saturated with moisture; then only can the vapour of water be precipitated incessantly for several hours. It is important to insist on this circumstance; for **Deluc**, and some other philosophers, who have employed imperfect hygrometers, have insisted that the air is often very dry, in regions where fogs are forming. The experiments of **De Saussure**, however, prove the contrary; and I have convinced myself of the fact on the Alps, and in different parts of Germany. An hygrometer suspended before a window in the centre of a city, undoubtedly cannot indicate the degree of saturation during the times of a fog; but this occurs, because the instrument is warmed by the walls of the building: and even this anomaly eventually disappears, when the fog remains for several hours.

The circumstances amid which fog forms, are often very different from those which accompany dew. When the latter is deposited, the soil is always colder than the air; when fog occurs, the contrary is the case: the moist soil is warmer than the air; and the vapours that ascend become visible, like those which rise from boiling water, or like the vapour of expired air, which, in winter, condenses the moment it escapes from the mouth. So, in autumn, we frequently see fogs above rivers, the water of which is much warmer than the air before sun-rise.* †

However, the water and the soil may be hotter than the

---

* *Fig.* 14 in the Appendix clearly shews the relative range of the temperatures of the air and of rivers in the city of Lyon, situated, as is well known, at the influx of the Rhône and the Saône. The inspection of the three curves shews that, from the 1st of November, the mean temperature of the air becomes lower than that of the rivers; a state of things which ceases about the 1st of March; now that intermediate period is the true season of fogs. The comparison of the three curves, of the epochs of *maxima*

† [illegible] fog is [illegible] a moist (saturated) air is cooled. It may be a warm [illegible] on a surface of snow or ice or even [illegible] water

air in which the fog is formed; we may be convinced of this by thermometric measurements; for, if the air were very dry, the vapour of water would not be precipitated; it would remain in the elastic state. This is very well seen at the salt-springs of Halle. In winter, when the weather is dry, there is visible above the concentrating apparatus a column of vapour, which disappears at about a yard above their surface. Should the air become moist, this vapour extends afar, and covers a part of the city, although in both cases the temperature is the same. The same thing is observed above springs of hot water, and above the craters of volcanos. The ancients made an observation respecting the crater of Stromboli, of which the truth may even be verified in our own times. When this volcano is covered with cloud, the inhabitants of the Lipari Isles know that it will soon rain: but, as we well know, this is not because the volcano is more active before rain; it is because the air, already saturated with the vapour of water, cannot dissolve that which escapes from the crater. The inhabitants of Halle also prognosticate rain when the vapour of the salt-springs covers their city; and yet the processes of concentration are not different, as changes of weather approach.

The formation of fog is often accompanied with circumstances which it is at first difficult to explain. When the sky is cloudy, a local fog is often observed on the declivity of mountains, occupying only a small surface: this fog is soon dissipated, but appears again immediately. I was once able, near Wiesbaden, to analyse the circumstances of this singular phenomenon; after a heavy rain, which had penetrated the soil, the clouds opened, the sun appeared, and I saw a column of fog constantly rising from the same point. I ran towards it; it was a mowed meadow, surrounded by pasturage, covered with very high grass, which, by getting less heated than the mowed surface, gave rise to a less active evaporation. In Switzerland the phenomena occurs on a much grander scale; whilst the very finest weather prevailed on the Faulhorn, the lakes of Switzerland were covered with fogs of very various densities; that which concealed the lakes of Zug, Zurich, and Neuchâtel, was very thick, whilst the lakes of Thun and of Brienz were

---

and *minima*, and of the very unequal amplitudes which they present from winter to summer, offers more than one interesting problem for solution; but this study enters rather into the domain of physical geography than into that of meteorology.

It is to the kindness of Professor FOURNET that the translator owes the communication of these three curves. They are the result of observations followed out by the philosopher for four consecutive years.—M.

scarcely covered with a light vapour. This phenomenon recurred so frequently that it was impossible for me to attribute it to chance. The lake of Zug is very deep, and its feeding streams do not come directly from the region of eternal snows. The temperature must be higher than that of the lake of Brienz, into which the Aar is precipitated immediately after having quitted the glaciers of Grimsel. Thus more vapour is raised from the lake of Zug than from that of Brienz; and, at equal temperatures, the former is more easily covered with fog than the latter.

In countries where the soil is moist and hot, and the air moist and cold, thick and frequent fogs may be expected. This is the case in England, the coasts of which are washed by a sea at an elevated temperature. The same is the case with the polar seas of Newfoundland, where the gulf-stream, which comes from the south, has a higher temperature than that of the air.

In London, fogs have sometimes an extraordinary density. Every year, we frequently read in the newspapers that they have been obliged to light the gas in the middle of the day, in the streets and houses. To take one case, for the sake of example. On the 24th of February, 1832, the fog was so thick that, in mid-day, people in the streets could not see distinctly; and, in the evening, the town having been illuminated, to rejoice at the birthday of the Queen, boys went about with torches, saying that they were looking for the illumination. Analogous fogs are recorded as having occurred in Paris and in Amsterdam; and sometimes, at a little distance from these cities, the sky was perfectly serene. Should we, in these cases, admit that the temperature of the air has merely been troubled by vesicular vapour? I doubt it, and think that smoke, especially that from coals, plays here a very notable part. If incandescent charcoal-dust is allowed to cool *in vacuo*, and is then immediately placed in a globe containing any gas, this gas is absorbed, especially if it be charged with vapour of water. The carbon increases even sensibly in weight, so that fifty kilogrammes of incandescent charcoal, when exposed to the open air, will weigh, at the end of several days, 105 to 107 kilogrammes. This fact is well known in manufactories of gunpowder. In escaping from the chimney, therefore, the particles of carbon must absorb air, and increase in weight. However, the wind will carry them some distance before they fall to the earth; but if the air is moist and calm, as is the case in time of fog, the specific weight of the particles rapidly increases, they mix with the fog, and are diffused with it into the neighbourhood.

. It is useless to remark that fog cannot possibly form when the air is very dry. It is never observed in deserts. Travellers have often considered as such the clouds of sand raised by the wind. *Dry* fogs are also mentioned in our climates; but smoke, of which we shall speak presently, or clouds of dust, are concerned in this; for if the definition which we gave of this hydrometeor be remembered, the expression of dry fog contains a contradiction.

Hitherto we have considered that the vapour of water is precipitated into the stratum of air, placed immediately above the liquid, on which it is developed; this vapour may, however, be transported by the winds into colder countries, and be transformed into fog at a notable distance from its place of origin, or else the sudden lowering of temperature determines the formation of fogs, in the same place where the vapour of water is raised from the soil. These phenomena are often observed during the winter in Germany. The S.W. winds bring hither abundance of vapours; or else the N.E. wind beginning to blow, instantly precipitates the vapour of water suspended in the atmosphere.*

**CLOUDS ON MOUNTAINS.**—Fogs, formed of vapours brought from afar, are common in mountains; even in countries where it rains but very rarely, where the sky, consequently, is almost always serene, the elevated summits of mountains are seen to be enveloped in thick clouds: this is observed in the interior of Asia and of Africa. When a moist wind determines an ascending current along the sides of a mountain, it at last reaches atmospheric strata, whose temperature is such that the vapour of water is instantly precipitated. This is especially the case when opposite winds meet on the summit. I have often witnessed these phenomena on the Alps. I will content myself with relating in detail the following fact. A very strong south wind was blowing on the summit of the Rigi, and the clouds that were passing at a great height above my head followed the same direction. The north wind was blowing at Zurich, and ascended along the southern flank of the mountain. When it attained the summit light vapours were formed, which seemed desirous of passing over the ridge; but the

---

* In a recent memoir, M. PELTIER has studied fogs in an electrical point of view. He distinguishes — 1st, Simple, or non-electrical fogs: 2d, Electrical fogs. These are sometimes resinous, but more frequently vitreous. M. PELTIER explains the electrical state of these fogs by the combined influence of the earth and of the upper regions of the atmosphere.—*Mém. des Savants Etrangers de l'Académie de Bruxelles*, t. xv. 2d partie.

south wind drove them back, and they ascended toward the north at an angle of 45°, and disappeared not far from the ridge. The conflict of the two contrary currents lasted several hours. A great many whirls were formed at the point where the two winds met; and travellers, who took little notice of the rest of the meteorological phenomena, were struck with this singular spectacle.*

When a chain of mountains is looked at from a distance, a cloud is often seen attached to each summit, whilst the intervals are perfectly clear. This appearance remains for hours, and even entire days. But this immobility is only imaginary; for, on these summits there often prevails a violent wind, which condenses the vapours as they ascend along the flanks of the mountain; when they are far from the summits they do not fail to dissipate. **De Saussure** often observed this phenomenon on the Alps; and M. **de Buch**, who explained it, says that, in the passages of the Alps the formation, the movements, and the disappearance of clouds, form a sight as various as it is interesting.

Dark clouds, as they pass rapidly over the Hospice of St. Gothard, often precipitate themselves in thick masses in the deep gorge of the vale of Tremola. We might fancy that, in a few moments, the whole of Lombardy would be buried in a thick fog; but, at the exit of the vale of Tremola, it has become dissolved by the hot ascending currents.

**CLOUDS.**—It might seem that all classification would be impossible, in considering the forms, the appearances, and the very varied dispositions of clouds. However, many meteorologists have endeavoured to associate them under certain principal types. These types, important in themselves, are especially so when they are connected with anterior atmospheric modifications; and they furnish us with precise indications on the changes about to occur in the weather.

We have as yet merely admitted that clouds are composed of the vapour of water. However, when we

---

* Clouds which ascend along the declivities of mountains during the day, by virtue of the diurnal ascending currents, frequently dissolve when they attain the summits, under the influence of an upper wind, which is comparatively dry and hot. This effect is most sensible in the evening. North-east and north slopes begin to experience the action of the solar rays; the ascending haze attains the line of the ridge. If the upper wind comes from the south or the south-west, which very frequently happens on high mountains, it meets this haze, partly dissolves it, and throws back towards the north the undissolved particles. This phenomenon is more readily observed on hills, at the summit of the ravines, by which they are permeated. The haze then appears to travel to meet the wind, and yet the surface which terminates it on the side remains stationary.—M.

reflect that they float sometimes in regions whose temperature is many degrees below zero, we can imagine that they may be composed of frozen particles. In winter, during severe cold, we can often observe that the vapours which rise are composed of brilliant needles, that glisten in the sun and resemble small flakes of snow. The same thing must take place in the higher regions of the atmosphere. There exist, therefore, snow clouds and clouds of vapour of water. We will presently make known the characters which may serve to distinguish them, and we shall see that this distinction is important for explaining a great number of atmospheric phenomena.

**Howard** distinguished, according to their forms, three sorts of clouds — the *cirrus*, the *cumulus*, and the *stratus*, to which four forms of transition were attached, viz. *cirro-cumulus*, *cirro-stratus*, *cumulo-stratus*, and *nimbus*.

The *cirrus* (the *cat's-tail* of sailors, or the S.W. clouds of the Swiss peasants [*vide* plate III.]) is composed of thin filaments, the association of which sometimes resembles a brush, at other times woolly hair, and at times slender net-work.

The *cumulus* or summer-cloud (*ball of cotton* of sailors) frequently presents itself in the form of a hemisphere, resting on an horizontal base. Sometimes these hemispheres are built one upon the other, and form those great clouds which accumulate on the horizon, and resemble at a distance mountains covered with snow.

The *stratus* is an horizontal band, which forms at sun-set, and disappears at sun-rise. Under the name of *cirro-cumulus*, **Howard** designates those little rounded clouds which are often called woolly clouds: when the sky is covered with them, it is said to be *fleecy*.

The *cirro-stratus* is composed of little bands of filaments more compacted than those of the *cirrus*; for the sun has sometimes a difficulty to pierce them with his rays. These clouds form horizontal strata, which, at the zenith, seem composed of a great number of thin clouds; whilst at the horizon, when we see the vertical projection, a long and very narrow band is visible.

When the *cumulus* clouds are heaped together, and become more dense, this species of cloud passes into the condition of *cumulo-stratus*, which often assume, at the horizon, a black or a bluish tint, and pass into the state of *nimbus* or rain cloud. The latter is distinguished by its uniform grey tint, and its fringed edges; the clouds of which it is composed are so compounded that it is impossible to distinguish them.

Though it be easy to distinguish these clouds, when their forms are well characterised, it is often a very difficult matter to designate accurately certain forms of transition; and one observer, for example, will call *cirro-stratus*, what another would designate under the head of *cumulo-stratus*. I have given the most remarkable appearances in plate III.

After a continued period of fair weather, and when the barometer slowly begins to fall, well-characterised *cirri* often appear under the form of slender filaments, whose whiteness contrasts with the azure of the sky. At other times they are arranged in parallel bands, scarcely visible, and which are directed from the S. to the N., or from S.W. to the N.E.* Sometimes they separate, and resemble the floating tail of a horse. In Germany these clouds are known under the name of wind-trees (*Windsbæume*). These filaments are also seen to cross each other in various ways. These clouds frequently resemble carded cotton, and pass into the state of *cirro-cumulus* and *cirro-stratus*. The white colour, by which they are characterised, does not always permit their structure to be recognised, or their transformations to be followed; but by means of the mirrors of blackened glass, which landscape-painters use, this may be managed with the greatest facility. The eye is not dazzled, and the cloud reflected in the glass may be studied at leisure.

---

* The tendency which the *cirri* have to arrange themselves in bands parallel to each other is remarkable; and it proves that the cause which directs their filaments to one azimuth rather than another, instead of being merely local and accidental, extends to great distances.

By a well-known law of perspective, parallel bands ought to appear diverging from one point of the horizon, and converging at the point of the horizon diametrically opposite. The observation of these points of convergence greatly facilitates the knowledge of the direction. The observations that I made with M. Bravais, on the Faulhorn, prove, agreeably to M. Kaemtz's observations, that the predominant direction is that of the S.W. to N.E. The meteorological registers of the members of the Commission of the North, who wintered in Lapland, give a slightly different direction merely: from W. ¼ S.W., to E. ¼ N.E. Moreover, the phenomenon occurs more frequently there than in the temperate zones.

At the equator, M. de Humboldt found that the parallel bands were generally directed from N. to S.

The cause, which thus arranges the great axes of these clouds, according to parallel lines, is still unknown. Forster was the first who made the very just remark that these clouds almost always travel along a parallel to their great axis, which greatly contributes to render them apparently motionless. M. Bravais, without being aware of Forster's observations, arrived at the same conclusion. Many meteorologists (Howard, Forster, Peltier) seem to believe that the *cirri* serve as conductors between two distant foci of electricity, of opposite names, the fluids of which tend to combine, and that the flexibility of the conducting clouds terminates in the rectilinear form, which is necessitated by the condition of the shortest path from one focus to the other.—M.

The *cirri* are the most elevated clouds: it is difficult to determine their height. Measures made at Halle have often led me to assign to them a height of 6500 metres. Travellers, who have passed over high mountains, are unanimous in asserting that, from the highest summits, their appearance is the same. During a stay of eleven weeks within sight of Finsteraarhorn, the elevation of which is 4200 metres, I never observed any *cirri* below the summit of that mountain. It is among the *cirri* that halos and parhelia are formed; and on studying these clouds, by means of the blackened mirror, it is a rare case not to find in them traces of halos. These phenomena being due to the refraction of light in frozen particles, we may conclude that the *cirri* are themselves composed of flakes of snow floating at a great height in the atmosphere. Observations, continued for ten years, have convinced me of the truth of this assertion; and I know of no observation tending to prove that these clouds are composed of vesicles of water. We may feel astonished, no doubt, that in summer, when the temperature frequently attains 25°, the clouds, which float above our heads, are composed of ice; but the doubt will disappear when we reflect on the decrease of temperature with height. During one of those hot days, when rain falls on the plains, this rain is snow on the summits of the Alps.

The appearance of *cirri* often precedes a change of weather. In summer, they announce rain; in winter, frost or thaw. Even when the vanes are turned towards the north, these clouds are often carried along by S. or by S.W. winds; and the latter are soon felt also at the surface of the earth. We can admit that these clouds are brought by the south winds, which determine the fall of the barometer, and the vapours of which are precipitated in the form of rain. Such at least is Mr. DOVE's theory: it justifies the denomination under which the Swiss peasants have designated this class of clouds.

When the S.W. wind prevails, and extends to the lower regions of the atmosphere, the *cirri* also become more and more dense, because the air is moister. They then pass into the condition of *cirro-stratus*, which first appear under the form of a mass like carded cotton, the filaments of which are closely interlaced, and they gradually take a greyish tint; at the same time the cloud seems to get lower, and vesicular vapour is formed, which fails not to be precipitated in the form of rain.

The same meteorological circumstances sometimes determine the formation of light *cirro-cumulus*, which are entirely composed of vesicular vapour. They do not weaken the light of the sun, for it passes through them; and M. **de Humboldt** has often been able to see through these clouds stars of the fourth magnitude, and even to recognise the spots on the moon. When they pass before the sun or the moon, these bodies are surrounded with an admirable corona. The *cirro-cumuli* foretell heat: it seems that the hot south winds, which prevail in the lower regions, do not convey a sufficient quantity of vapours to cover the sky entirely with clouds, and that they only act by their elevated temperature.

While the clouds of which I have spoken are the produce of the south wind, the *cumuli* owe their existence to ascending currents: their height varies greatly, but it is always less than that of the *cirri*. The *cumuli* are most characteristic in the fine days of summer. When the sun rises in a clear sky, a few small clouds may be seen appearing about eight o'clock in the morning, which seem to increase from within outward. They become thicker, and accumulate to form masses clearly circumscribed and limited by curved lines, which cut each other in different directions. Their number and size increase till the hour of greatest heat in the day. They then diminish; and at sun-set the sky is again perfectly serene: in the morning they are very low, but they continue ascending until mid-day, when they again re-descend in the evening. I convinced myself of this by direct measurement and observations made in the mountains. How often have I seen the *cumuli* under my feet in the morning! They then rise: toward mid-day I was surrounded by clouds for about an hour, and the rest of the day I saw above my head, clouds, which in the evening re-descended to the plain.*

*Cumuli* are formed when ascending currents draw the vapours into the higher regions of the atmosphere, where

---

* There exist a great number of measurements of the heights of clouds. Kaemtz (*Lehrbuch der Meteorologie*, t. i. p. 385) relates several, which are due to Riccioli, Bouguer, de Humboldt, Lambert, Crosthwaite, and to himself. The extremes are 400 and 6500 metres. During the cruise of the *Venus*, 900 and 1400 metres were found on the Atlantic and the South Sea, as the extreme terms. (*Comptes rendus de l'Académie des Sciences*, t. xi. p. 324. 1840.)

M. Peytier, staff-officer, communicated to the Institut, January 2, 1837, forty-eight measures of the height of clouds, made in 1826, during the triangulation that he executed in the Pyrenees with M. Hossard. The extremes for the lower plane of clouds were 450 and 2500 metres; for the upper plane, 900 and 3000. They obtained these different determinations by aid of the heights previously measured, of the peaks to which the clouds were tangents by their superior or inferior surfaces. On Sept. 29, the two observers were so placed as to see at the same moment the two opposite surfaces of a cloud. Its thickness was 450 metres. Next day it was 850.—M.

the air, being very cold, is rapidly saturated. If the current increases in force, the vapours and clouds become more elevated; but there they increase in greater ratio, on account of the reduction of temperature. Hence it happens that the sky, though fine in the morning, is entirely clouded at mid-day. When the ascending current relaxes toward evening, the clouds descend: as, on arriving into strata of air which are less heated, they again pass into the state of invisible vapour. According to **Saussure,** the rounded form of clouds is due to this mode of formation. Indeed, when one liquid traverses another in virtue of the resistance of the ambient medium, and the mutual resistance of its parts, the former takes a cylindrical form with a circular section, or one composed of arcs of a circle. We may convince ourselves of this by letting a drop of milk or of ink fall into a glass of water. Thus the masses of ascending air are great columns, the shape of which is defined by the clouds. Add to this the little whirlwinds on the borders of the clouds, which are frequently observed in mountains, by means of the blackened mirror, and which also contribute to give to the whole rounded forms, analogous to those of whirls of smoke escaping from a chimney.

The *cumuli* do not always disappear toward evening; on the contrary, they often become more numerous, their borders are less brilliant, their tint deeper, and they pass to the state of *cumulo-stratus*, especially if a stratum of *cirrus* exists below them. We may then expect rains or storms, for in the higher and the mean regions the air is near the point of saturation. The south wind and the ascending currents give rise to changes of temperature which determine the precipitation of aqueous vapour in the form of rain.

The *cumuli*, that are heaped up on the horizon in the fine days of summer, are those which are most fertile for plays of the imagination. Who has not fancied that he recognises in the changing forms of these clouds, men, animals, trees, and mountains? They furnish comparisons to the poets; and **Ossian** has borrowed from them his most beautiful images. The popular traditions of mountainous countries are full of strange events, in which these clouds play a prominent part. As they are often of the same height, an appearance results, which I should mention. When I was living at the Faulhorn, the sky was frequently perfectly clear above my head; but a little above the horizon, a belt of clouds, the width of which did not exceed double or treble that of the moon, extended like a pearl necklace along the West Alps, from France to the Tyrol. My station, at 2683 metres above the sea, was a little more elevated than the clouds, and their projection on the sky formed a narrow belt, although they were spread over a vast extent of the sky. From this projection, it follows that it is often very difficult to distinguish the *cumulus* from the *cumulo-stratus*. How frequently do we see *cumuli* spread over the sky! The horizon appears charged with clouds, it seems that the heavens will in a short time be entirely covered with them; and yet the sun continues to shine without intermission. A very simple reasoning proves that the eye has been deceived by a projection. Imagine (pl. II. *fig.* 4), a series of globular clouds of the same size, equi-distant from each other: if the observer draws two lines from the station he occupies to the limits of the clouds, the interval between those which are at the zenith will be very great, but it will be contracted in proportion as they approach the horizon, when it becomes entirely null.

While the true *cumuli* are formed by day, and disappear during the night, another variety of these clouds is seen under very different circumstances. It is common to observe, in the afternoon, dense cloudy masses, rounded or extended, with borders badly defined, the number of which increases towards evening, until, during the night, the sky is completely overcast. The next day it is still overcast, but, some hours after sun-rise, all disappears; the true *cumuli* then occupy the sky, when they float at a more considerable height. I have determined this by direct measurements. At evening, clouds of the former class again replace the true *cumuli*. These clouds are composed of very dense vesicular vapour, like the *cumulus* and the *cumulo-stratus*. They differ in their dependence on the hours of the day; they have also an analogy with the *stratus*, on account of their extent, and are distinguished from them by their greater height. However, they approach nearer to them than to the *cumulus*, and I propose designating them under the name of *strato-cumulus*. During winter, this kind of cloud frequently covers the whole sky for weeks together; their presence is probably due to the decrease of temperature, reckoning from the ground, being more rapid than usual. But, as the sun rises, its rays dissolve the clouds, the vapours ascend, *cumuli* are formed.

This influence of the sun on the clouds gives rise to atmospheric variations, which are well known to husbandmen. In the morning the sky is clouded, and it rains abundantly; but towards nine o'clock the clouds separate, the sun shines through, and the weather is fine for the rest of the day. At other times, during the morning, the sky is clear, but the air moist. The clouds soon appear; toward mid-day, the sky is covered, the rain falls, but it ceases toward evening. In the former case, they were *strato-cumulus;* in the latter, *cumulo-stratus*. The former are dissipated by the rays of the sun, the latter are formed under their influence. If the temperature and hygrometric conditions of the air at two or three thousand yards above the earth were as well known as at its surface, these apparent anomalies, which astonish us, might be more easily explained.

**CAUSES OF THE SUSPENSION OF CLOUDS IN THE ATMOSPHERE.**—When we see a cloud resolve itself into rain, and pour out thousands of gallons of water, we cannot comprehend how it can float in the atmosphere. Many hypotheses have been made, in order to explain this suspension: it has been said that the air itself is transformed into rain; then the vesicles of water have been supposed to be filled with a gas lighter than air. Chemical analysis has proved the inaccuracy of both these explanations. If the constituent principles of the air were combined, there could only result nitric acid, and not water; and air collected in fogs and in clouds has not given the least trace of gases lighter than air. We must therefore admit, that the vesicles of fog are heavier than the medium in which they are suspended: however, they rise with great rapidity. A very simple consideration will give us the solution of the problem.

Abandoned to itself, a vesicle of fog falls to the ground, like every other heavy body, and, *in vacuo*, it arrives there with a great acquired rapidity; but, as it falls into the air, it displaces the one which is beneath it, and this resistance diminishes the rapidity of its fall more effectually as the envelope of the vesicle is thinner. If we apply the laws of mechanics to this particular case, we shall find that the velocity of the fall of such a vesicle is not very great, and would not be above thirteen decimetres per second after a fall of six or eight hundred metres. In some cases even, it would be scarcely three decimetres.

But, some philosopher might say, it is of no consequence whether the vesicle fall swiftly or slowly, in either case it is not sustained in the atmosphere; and yet observation proves that clouds float at a great elevation. To those who have often observed fogs on the plain, and clouds on mountains, all the marvel disappears. A cloud, indeed, is not a motionless mass, as may be seen by observing it at a distance; it is, on the contrary, in perpetual motion. When the vesicles, as they are carried along by the wind, arrive in a dry air, they dissolve, whilst on the side of the wind the vapour is precipitated in the vesicular state. Thus, a cloud, apparently motionless, often slowly descends, and its lower part is continually dissolved, while the upper continually increases by the addition of new vesicles.

There exists a force directly opposed to the fall of clouds, it is that of ascending currents. During fine weather, the vesicle falls with a velocity of about three decimetres per second; but the ascending current has a much greater velocity, and, consequently, it draws the vesicle onward. On this account it is that the *cumuli* are more elevated at midday than in the morning; towards evening, on the contrary, as soon as this current becomes weaker, the clouds actually descend, and dissolve when they arrive into the warmer regions of the atmosphere. The horizontal currents also oppose the fall of clouds.

I have purposely avoided borrowing any illustration from phenomena foreign to Meteorology. Who has not observed grain, feathers, sand, dust, &c., elevated to a prodigious height, and transported to great distances? At very many leagues from the coast of Africa, ships have been covered with the sand from Sahara; and it is well known that the wind transports to immense distances the ashes vomited from volcanos. Yet these bodies are much denser than the vesicles of water. Let us not, then, seek to explain their suspension by extraordinary causes; it is as easy of comprehension as that of dust.*

**OF RAIN AND SNOW.**—When the vesicles become large and the temperature diminishes, the rapidity of their fall increases; many of them unite and fall to the earth. If they traverse strata of very dry air, their surface incessantly evaporates, the drops become smaller, and less rain falls on the ground than at a certain height; it may even happen that the rain does not reach the earth, but is entirely dissolved in the air. On plains, in spring, when the weather is variable, rain is sometimes seen to fall abundantly from a cloud situated at the horizon; but the bands of rain, which are very readily distinguished by their grey colour, do not reach the earth. Sometimes the rain-drop increases during its descent; for it is of the temperature of the upper strata of the atmosphere, and condenses on its surface the vapour of water, as a decanter of cold water does when brought into

---

* FRESNEL thought that the solar heat, absorbed into the substances of clouds, dilates the air, which separates the vesicles and converts the clouds into a kind of aërostat, which rises to greater heights as the excess of temperature is greater.—(Vide *Bibliothèque Universelle*, t. xxi. p. 260.)

a warm chamber. The quantity of rain which will then moisten the soil will be more considerable than that which falls at a certain height.

Differences of level of thirty metres are sufficient to render these phenomena sensible. In order to determine the quantity of rain, instruments are used, called *pluviometers*, *ombrometers*, *hyetometers*, *udometers*. They consist of vessels open above, which are placed in an exposed situation, so as to receive directly the rain or snow that falls from the atmosphere. After each rain, the quantity of water contained in them is measured; if it has been snowing, the snow is first melted. But in our climates the quantity of rain that falls in each shower is reduced to so little, that the accumulated errors of observation may have a great influence over the annual mean. The most unexceptionable apparatus, but, at the same time, the most complicated, is that which has been devised by Professor **Horner** of Zurich (*vide* **Kaemtz**, *Treatise on Meteorology*, t. i. p. 413, and pl. III. *fig*. 19).

Very simple measuring apparatus are generally employed; a glass tube, from two to four centimetres in diameter, is divided exteriorly into corresponding parts, each of two or three cubic centimetres in capacity. The mouth of the pluviometer is measured with equal accuracy: suppose that it be equal to 0,2 square metres; after rain, the water found in the pluviometer is poured into the graduated tube, and we thus learn how many cubic centimetres of water have fallen. We also calculate what would have been the height of the water fallen into the pluviometer, by dividing the number of cubic centimetres by the surface of the mouth, expressed in square centimetres. I suppose that 0,10283 cubic metres have been found, the water would have had a height of

$$\frac{0{,}10283}{0{,}20000} = 0^{\mathrm{m}}{,}051.$$

It is, moreover, indispensable to measure immediately after rain, otherwise a portion of the water evaporates, and the numbers found are too low.[*]

---

[*] M. **Flaugergues**, professor at the School of Naval Artillery at Toulon, presented to the Society of Sciences of that city, in the course of 1841, a new gyratory udometer, arranged not only for measuring the quantity of rain that falls, but also to make known, by mere inspection, the portions of this quantity which have fallen for each determinate wind.

This instrument is composed, 1st, Of a funnel movable round a vertical axis, covered at its upper part, and carrying, at its lower extremity, an escape-tube, the axis of which is in the same vertical plane with the axis of

Place two pluviometers, one on the roof of a building and the other on the level of the ground, as is done at the Paris Observatory; the same quantity of rain will rarely be found in both instruments; in general, it will not be so great above. The effect is especially remarkable when the air is moist and agitated in the neighbourhood of the ground: it is probable that the wind takes away the drops of rain which rebound, and drives them into the pluviometer, as we see snow accumulate at certain points. It is also admitted that the drops increase by the vapour of water, which is added to them in the height which separates the ground from the roof of the building.*

The water which falls from the higher regions of the atmosphere is generally in the state of snow or rain. However, even in the midst of summer, it sometimes falls in the form of hail. In winter, frozen drops of rain are observed, which are composed of pure ice, especially when, after a rigorous and continued frost, the south winds heat the higher regions of the atmosphere. Drops of rain are then formed, which congeal before they reach the ground; however, the water frequently arrives in a liquid state, but it freezes on

---

rotation, and with a vane fixed on the very body of the funnel; so that the escape of water, accumulated there, takes place in a direction constantly parallel with that of the wind: 2d, Of a cylindrical receptacle divided by eight vertical partitions, radiating into eight chambers, and corresponding to the eight principal points of the compass. This receptacle is in the outset duly adjusted, and solidly fixed on a base at the bottom of each of the divisions, by a tube which ascends vertically outside the receptacle, and on which the height of the water in the corresponding cell is observed.

A udometer of this kind has been used, since the commencement of 1841, at the naval battery at Toulon; and it leaves nothing to be desired.—M.

* The pluviometer of the terrace of the Paris Observatory is elevated twenty-seven metres above that in the court. From 1817 to 1827 there fell, at a mean, fifty-seven centimetres of rain in the court, and only fifty centimetres on the terrace. (*Vide* Arago, *Ann. du Bureau des Longitudes*, for 1824; and Pouillet, *Eléments de Physique*, t. ii. p 579.)

The quantity of rain which falls in the upper pluviometer being 1, M. Schouw finds the following numbers for that which falls in the lower pluviometer:—

| TOWNS. | DIFFERENCE OF LEVEL. | LOWER PLUVIOMETER. |
|---|---|---|
| | m | |
| Copenhagen . . . | 39,0 | 1,27 |
| York . . . . . . | 65,0 | 1,72 |
| London . . . . . | 23,0 | 1,29 |
| Paris . . . . . . | 27,0 | 1,14 |
| Penzance . . . . | 14,0 | 1,51 |
| Pavia . . . . . . | 17,6 | 1,01 |

(Schouw, *Climat de l'Italie*, p. 134.)—M.

touching the earth, which it covers with a coat of ice called *rime*. These two phenomena generally coincide with a very low barometer, and they announce thaw.

When the temperature of the air is near the freezing-point, or lower, snow generally falls; but the lower the temperature of the air is, and the less vapour of water it contains, the more does the quantity of snow diminish. With a cold of —20°, we can scarcely conceive that more than four or five centimetres would fall; however, I saw it snow continuously on January 18, 1838, during a cold of —18,02; but the flakes, or rather the grains, were very small.*

**FORMS OF FLAKES OF SNOW.**—If flakes of snow are received on objects of a dark colour, and at a temperature below the freezing point, a great regularity is observed in their forms: this has, for a long time, struck attentive observers. **Kepler** speaks of their structure with admiration, and other philosophers have endeavoured to determine its cause; but it is only within the period in which we have learned to know the laws of crystallisation in general, that it has been possible to throw any light on the subject.

The molecules of almost all bodies that pass from the liquid to the solid state have the property of grouping themselves, so as to form solids terminated by planes inclined to each other by a constant angular quantity. The number of the facets, and the value of the angles, vary in bodies whose chemical composition is different, but are constant in those whose chemical composition is the same, and which are formed under the same circumstances. These regular solids are named *crystals*, and we may, as it were, assist them in their formation. Pour water on sea-salt (chloride of sodium) until all the salt is dissolved, and put the solution into a hot place; a part of the water will evaporate, and, not being able to hold in solution the molecules of salt, they will be deposited, forming small masses of a cubical form. Take one of these crystals, remove one of the edges by which it is terminated, and place it again in the solution, and you will see this edge reproduced at the same time that the crystal increases in volume. Each time that the experiment is made under similar circumstances, the crystals will be cubical; but, if you heat the solution, or if you mix with it a foreign substance, the crystals will have a differ-

---

* In the morning of the 1st of December, 1838, the observers at Bossekop (Lapland) saw snow fall with a temperature of −20°,6. On the evening of the same day there was an abundant fall of snow, with temperatures of −19°,8 and −18°,1. This snow was very fine.—M.

ent form; their edges will be replaced by plane surfaces, which, by uniting, will sometimes entirely disguise the six primitive faces. The forms of crystals may always in laboratories be made to vary. Nature also offers to us the most varied arrangements, but all relating to a single primitive form, of which they are only a variety. The temperature, the concentration of the solution, the vicinity of another body, are sufficient disturbing circumstances. In the preceding example, the crystallisation took place because, one part of the water having evaporated, the remaining portion could no longer hold the salt in solution.

In fusing certain bodies, and allowing them to cool, the same phenomena are observed. Melt sulphur in an earthen pot, and then remove it from the fire, the liquid mass will soon be covered with a solid crust; break this, and pour off through the opening the sulphur that still remains liquid, you will then see that the vessel is coated with a solid crust of sulphur, the interior of which is studded with regular acicular crystals. As soon as the mass is solidified by cooling, the smallest molecules are regularly arranged; but if the entire mass is allowed completely to solidify, the crystals would be so confounded that a body of crystalline texture would be obtained, but not a single crystal: the same occurs in rolls of brimstone. On the contrary, by letting the sulphur, which separates the crystals already formed, flow out while still liquid, the latter remain separate and become visible.

Water presents a phenomenon analogous to that of sulphur; it crystallises under the influence of cold alone. However, on examining the ice of rivers, we do not discover the smallest trace of crystals; it is a confused mass, like that of the rolls of brimstone. But if the progress of crystallisation is followed on the banks of a river, needles are seen to dart from the bank, or rather from the ice already formed, and to advance parallel to each other, or making angles with each other of from thirty to sixty degrees. Other needles dart from these at the above angles, and so on until a compact uniform mass is the result of their interlacing. If a sheet of ice thus formed is raised, very regular crystals are often discovered on its lower surface. Similar phenomena are observed in winter on panes of glass. The secondary crystals are seen to make a constant angle with the crystals, which serve as a common axis; and if the glass were a perfect plane, very regular figures would be seen. They occur sometimes when the pane of glass is very thin. The air of the room is moist, then each scratch, each grain of dust, becomes the centre of a crystalline formation; and, by radiating in all directions, these crystals form a net-work, which excites admiration by its astonishing complication.

The crystals of ice are never so regular as when they are formed by the vapour of water deposited on solid bodies, as hoar-frost, which is precipitated in still weather with a moist air, or when snow falls without being driven by the wind; but temperature, moisture, the agitation of the air, and other circumstances, have a great influence over the form of the crystals. Notwithstanding their variety, they may be all associated under a single law. We see that isolated crystals unite under angles of 30, 60, and 120 degrees. Flakes, which fall at the same time, have generally the same form; but, if there is an interval between two consecutive falls of snow, the forms of the second are observed to differ from those of the first, although always alike among themselves.

The English navigator, **W. Scoresby**, who made a great many voyages in the polar seas, as captain of a whaler, has given the greatest number of details on this subject. He has described the different forms of snow, in his excellent work on the North. They may be associated under five principal types: 1st, thin laminæ; 2d, a spherical nucleus, or plane, studded with ramified needles; 3d, fine hexagonal needles, or prisms; 4th, pyramids with six faces; 5th, needles terminated at one of their extremities, or at both, with a small lamina. I will describe the most remarkable varieties according to **Scoresby**.

1st. Crystals with a laminated form. They are distinguished by the variety of forms which they present. Generally, the laminæ are very thin, transparent, and of a very delicate structure. Several varieties are distinguished.

A. Starred figures with six rays radiating from a centre, and frequently studded with parallel points, so arranged as to be in the same plane with the rays. According to **Scoresby**, this form is often observed when the thermometer is near the freezing point (pl. IV. *figs.* 1 and 2).*

B. Regular hexaëdrons. They are observed during moderate cold, and with very low temperatures. The colder it is, the thinner, the smaller, and the more delicate they are. Some are a simple transparent lamina (pl. IV. *fig.* 3).

---

* This stellated form (*fig.* 2) is one of the most frequent forms of snow. The lowest temperature at which a fall of stellated snow has been observed at Bosekop, is −12°. The stars were scarcely two millimetres in diameter. The weather was almost calm.—M.

In others, white lines are seen in the interior of their perimeter, which in their turn form little hexaëdrons or analogous figures. The most varied forms result from these combinations (*vide* pl. IV. *figs.* 4, 5, 6, 7, 8, and 9). Their size varies between that of laminæ scarcely visible, and others of two or three-tenths of a millimetre in diameter. In looking sideways at one of these laminæ, I have always observed that little facets unite the parallel faces; however, they are not visible without a powerful magnifier. *Fig.* 10, represents the section of a hexaëdral lamina.

C. Combinations infinitely varied of hexaëdral figures of very different sizes. They are observed during intense cold (pl. IV. *figs.* 11–15).

D. Combinations of hexaëdral figures, with rays and salient angles. This is one of those forms which, according to **Scoresby,** vary the most, and which present the most elegant arrangements (pl. IV. *figs.* 16–25). The parallel lines of the figures appear white in nature.

2d. Flakes with a spherical nucleus, or a plane with rays ramifying in different planes. This form, according to **Scoresby,** comprehends two principal varieties.

A. Flakes composed of a thin crystal of the same kind as those described and figured. Small needles occasionally stud these planes on all sides. They are sometimes raised on one face, at other times on both. They make an angle of more than sixty degrees with the plane of the lamina. Their diameter is sometimes five millimetres. According to **Scoresby,** they are observed in temperatures several degrees below freezing-point.

B. Figures with a spherical nucleus studded with needles tending in all directions. Sometimes the nucleus is a transparent crystal, or a white and unequal body. I have, however, convinced myself, by examining this form under a considerable magnifying power, that the nucleus is always crystallised. This, moreover, is very easily verified when the crystallisation is not made according to the three dimensions, and when the nucleus only carries six rays arranged in the same plane. A vertical section of a crystal of this kind is figured in pl. IV. *fig.* 26.

3d. Fine hexagonal needles or prisms. They are sometimes very slender, and with a crystalline appearance, or even white and shapeless. The most delicate varieties, which resemble a white hair five millimetres long, are so fine that it is no easy matter to determine their form. These crystals are not always hexaëdral, but often with merely three faces.

4th. **Scoresby** only once saw pyramids with six faces (pl. IV. *fig*. 27).

5th. Needles or prisms, one or both extremities of which carry polyhedral laminæ of six sides, are also very rare. The same navigator only observed them twice; but they fell in such abundance that his ship was in a few hours covered with several centimetres of snow (pl. IV. *figs*. 28—30.

Plate IV. is a copy of the most remarkable forms observed by **Scoresby**. The total number of those seen by him amount to ninety-six. Yet, I have met with at least twenty, that he has not figured; but I never found a single one in which the crystals were in planes perpendicular to each other. The varieties probably amount to several hundreds. Who would not here admire the infinite power of Nature, which has known how to create so many different forms in bodies of so small a bulk!

It is during calm weather without fog that they may be admired in all their beauty. In hoar-frost, the crystals are generally irregular and opaque; and it seems that great numbers of vesicles are solidified at their surface without having had time to unite intimately with the crystalline molecules. During wind, the crystals are broken and irregular; rounded grains are then found composed of unequal rays. In the Alps, and in Germany, I have often seen perfectly symmetrical crystals fall. Should the wind rise they become grains of the size of millet or small peas, whose structure is any thing but compact; or even bodies having the form of a pyramid, the base of which is a spherical cup. These bodies might be compared to sleet; yet they are formed under the influence of the same meteorological circumstances as the flakes which fall before gales of wind. I will return to this subject when treating on hail.

**SHOWERS WITHOUT CLOUDS.**—When the sky is serene, and the cold intense, numerous brilliant particles are often observed in the air; these are little flakes of snow, which reflect the rays of the sun. They form in the midst of the vapours that are rising from the ground, and often fall in so great a quantity that they entirely cover the ground. This formation of snow without clouds only occurs in calm weather. When the equilibrium of the higher regions is violently disturbed, especially when very cold north winds come into collision with those from the south, it may also happen that rain falls from a serene sky. Large drops are seen to moisten the earth, and yet at the zenith the sky is blue. The vapours condense into water, without passing through the intermediate state of vesicular vapours. M. **de Humboldt** gives several examples of this kind, and from my own observations, this fact is not very rare, for I have observed it twice or thrice annually.*

**QUANTITY OF WATER WHICH FALLS DURING A SINGLE SHOWER.**—No general rule can be established respecting this. While certain rains are reduced to a few drops, in other cases torrents of water fall from the sky. These deluging rains are more particularly observed within the tropics. Thus M. **de Humboldt** saw, on the banks of Rio-Negro, a quantity of water fall in five hours equal to forty-seven millimetres. Almost the same quantity fell every day. At Bombay, it has been proved that the earth receives in a day 108 millimetres of rain. At Cayenne, Admiral **Roussin** found that the quantity of water collected from eight o'clock in the evening till six in the morning, was $0^{m},277$. In the higher latitudes, less water falls in a given space of time; and when the quantity which falls per day exceeds three centimetres, the low plains of Europe are soon inundated. Prodigious showers are, however, recorded. At Joyeuse, there one day fell twenty-five centimetres of water; at Gênes, in the same space of time, eighty-one centimetres; at Geneva, in three hours, sixteen centimetres. In mountainous countries these showers are not so rare, because the winds frequently blow with violence in several contrary directions.†

**RAINS WITHIN THE TROPICS.**—The frequency of rains in different seasons is so intimately connected with other conditions of climate, that the earth may in this respect be divided into several regions. Let us first consider

---

* The following are instances:—Aug. 9, 1837, M. WARTMANN saw a shower fall at Geneva, which lasted two or three minutes; the sky was cloudless. M. DE NEVEU was in a shower at Constantinople, for ten minutes; the sky was perfectly serene. M. BABINET observed the same phenomenon at Paris. Finally, according to LE GENTIL, it would appear that this phenomenon is common in the island of Mauritius. In the seasons of S.E. winds fine rain is often seen, he says, to fall especially about evening, although it is the finest weather in the world, and the stars are shining brilliantly. (Vide *Comptes rendus de l'Académie des Sciences*, t. v. p. 549; t. xii. p. 777; t. xiv. p. 765; and t. xi. p. 327).—M.

† The following are some more recent examples of deluging rains:—June 4, 1839, a rain fell, which, says M. QUETELET, was only very heavy for three hours. $112^{mm},78$ of water were collected on the terrace of the Observatory of Brussels, in twenty-four hours. From 1833-8 inclusive, never more than $50,^{mm}3$ of water had been known to fall at Brussels in twenty-four hours.

In the basin of the Saône there exists a little town called Cuiseaux, where it always rains more than in any other part of the valley. Thus, immediately before the terrible inundations of 1841, there fell $270^{mm}$ of water in sixty-eight hours. In the same interval only $150^{mm}$ fell at Oullins, near Lyons. (*Comptes rendus de l'Académie des Sciences*, t. viii. p. 980. 1839; t. xii. p. 260. 1841.)—M.

countries situated within the tropics, because a much greater regularity is observed there than in our own climates.

In all places where the trade-wind blows constantly seaward, it does not rain; the sky is always serene, especially when the sun is in the other hemisphere; but it often rains in the region of calms. The ascending current draws with it a mass of vapours, which condense as soon as they arrive at the line of junction between the upper and lower trade-wind. The sun almost always rises in a clear sky; toward mid-day, isolated clouds appear, which pour out prodigious quantities of rain. These showers are accompanied with violent gales. Towards evening the clouds dissipate, and when the sun sets the sky is perfectly clear. Thus the masses of air discharge the water they contain, into the very regions from which they rise; and hence arises the absence of rains in countries more distant from the equator, where the east wind regularly blows.

On shore, between the tropics, we find during a part of the year disturbances in the direction of the trade-winds; and the year is divided into two seasons,—the wet and the dry season. Europeans have found this climacteric division adopted by all indigenous people, and it is the more characteristic, as entire months frequently pass away during the dry seasons without a single cloud having been seen in the sky.

Notwithstanding local differences a great regularity is every where observed in the succession of phenomena, but I will content myself with pointing them out according to M. **de Humboldt**, inasmuch as his researches have thrown a bright light on the causes of the variations that are observed in our climates.

In the part of South America situated on the north of the equator, the sky is perfectly serene from December to February; the wind blows from the E. or E.N.E.; the air is dry, and vegetation is leafless. Toward the end of February, and at the commencement of March, the blue of the sky becomes deeper, the hygrometer denotes more moisture in the air, and the leaves of the trees begin to burst forth. A slight curtain of vapour dulls the twinkling of the stars, which is dense toward the zenith, where it is sometimes visible. The trade-wind blows less violently, and the air is occasionally entirely calm. Clouds resembling mountains gradually collect in the S.S.E., and sometimes traverse the sky with incredible velocity. Toward the end of March, lightnings shine in the heavens at the south; and the wind passes for several hours to the W. and W.S.W. The atmospheric electricity becomes stronger, especially at sun-set; and this is a certain sign of the approach of the rainy season, which, on the banks of the Oronoko, begins at the end of April. The sky is troubled, and, from its former blue, becomes grey. In the afternoon, at the moment when the heat is at its *maximum*, a storm, accompanied by heavy showers, rises in the plains. At the commencement, the clouds and rain are only formed during the burning hours of the afternoon, and disappear toward evening. But in proportion as the season advances, especially when the sun is at the zenith, they both commence being manifest in the morning, but at the end of the season they again appear in the afternoon.

In many countries, the night is almost always serene; in others, it rains in the night also, and even more so than in the day; but it is probable that this difference is due to the neighbourhood of large chains of mountains. M. **Boussingault** determined this on the table-lands and in the valleys of the Andes, at Peru;[*] **Lyall**, at Madagascar; Admiral **Roussin**, at Cayenne. Other travellers have confirmed these facts by isolated observations.

All these phenomena tend to prove that the ascending current, which is, for the most part, very strong in the place that has the sun in its zenith, causes a disturbance in the atmosphere. Hence there is first the scintillation of the stars, and then a change in the direction of the winds. The evaporation of the water that falls over night so saturates the air with vapours, that, even in Africa, cloaks, shoes, in a word, all things which are not placed near the fire, become moist; and the inhabitants live in a kind of perpetual vapour-bath. This is the epoch of the endemic diseases so fatal to Europeans. In Africa, the approach of the rainy season is also announced by changes in the direction of the winds.

These rains being a consequence of the ascending currents, the place where they fall changes with the declination of the sun, the presence of which determines the cur-

---

[*] In the neighbourhood of the gold mines of Marmarto, lat. 5° 27′ N.; long. $5^h$ $11^m$ W., absolute elevation 1426 metres, mean temperature 20°, 4, this philosopher obtained the following results:—

RAIN IN MILLIMETRES.
1827.

| | Day. | Night. |
|---|---|---|
| October . . . | $34^{mm}$ | $151^{mm}$ |
| November . . . | 18 ,, | 208 ,, |
| December . . | 2 ,, | 159 ,, |

(Vide *Comptes rendus de l'Acad. des Sciences*, t. ii. p. 109. 1836.)—M.

rent. In Africa, for example, near the equator, the season of rain commences as early as April. Between 10° of N. lat. and the tropics, principally in the countries watered by the Senegal, it lasts from the commencement of June to the commencement of November. It is the same in the interior of countries, as may be seen by the recitals of **Mungo Park, Denham, Browne, Bruce,** and others. In like manner, at Panama, on the western coast of America, the rain commences in the early days of March; and at San-Blas, in California, it rarely rains before the middle of June. As the sun passes twice over the zenith of each place, we find that in those which are near to the tropics a very considerable quantity of rain falls twice a-year, and at very near intervals. In countries situated near the equator, where the times of the passage of the zenith are separated by a longer interval, there are two rainy and two dry seasons.

The northern limit of these periodical rains is not exactly known. At Havanna, in the island of Cuba, and at Rio de Janeiro, climacteric conditions have been noticed, which have some analogy with those of high latitudes. In the desert of Sahara the limit appears to be about 16° of N. lat., but on the two seas that wash the coast of Africa it is some degrees more northerly.

In India, the alternation of seasons, compared with that existing between the tropics, is no less anomalous than the direction of the winds. The west coast of this peninsula has its season of rains during the S.W. monsoon; whilst its dry season prevails during the N.E. monsoon. When the wind that blows from the S.W. is forced to ascend along the flanks of the Ghauts, the vapours condense on their summits, and there are violent storms almost every day. In the interior of the country the rains are rare, and on the eastern coast the sky is serene. The rains are most abundant in July. During the N.E. monsoon the same succession is noticed on the coast of Coromandel; but the mountains not being so steep, the rains are not so heavy. During this time, the sky is perfectly serene on the west coast. The table-land of the Deccan partakes in the climate of the two coasts. The distribution of rain, during the seasons, depends on the distance of the different points from the sea. According as they are nearer the western or the eastern coasts, the course of the seasons is analogous to that of the corresponding coast. Some places, situated to the middle of the peninsula, have partial rains throughout the year; or else they have two *maxima* in the year.

The quantity of water that falls in these countries during the space of each month, is more considerable than that of the whole year with us. In places situated near the sea, we may admit that from 190 to 320 centimetres of water fall during the year. Let us add that it never rains but in certain months, and only during one or two hours of the day, which renders the contrast still more striking. The drops of water are enormous, very close together, and reach the earth with great violence. But if we penetrate into the interior of countries, or ascend considerable heights, the quantity of rain diminishes. At Seringapatam, in India, and at Bogota, in America, it is hardly greater than that observed in Germany.

**RAINS IN HIGHER LATITUDES.**—The periodicity of rain disappears as we go further from the equator. Yet we are in want of certain facts in order to determine, in a positive manner, the transition from one system of climate to another. While, between the tropics, the greatest quantities of rain fall when the sun is at the zenith, that is to say, in a season corresponding to our summer; north of the tropics, it rains more abundantly in winter. If we designate the annual quantity of rain by 100, we have, for the few places hitherto observed:—

RELATIVE QUANTITIES OF RAIN IN THE DIFFERENT SEASONS.

| | MADEIRA. | LISBON. | MAFRA. |
|---|---|---|---|
| Winter . | 50,6 | 39,9 | 53,4 |
| Spring . | 16,3 | 33,9 | 27,5 |
| Summer . | 2,8 | 3,4 | 2,7 |
| Autumn . | 30,8 | 22,8 | 16,4 |

So that, under this parallel, it rains most in winter, and the quantity of rain that falls in summer is altogether insignificant. The same relation is found on the N.W. coast of Africa, and in the Canary Isles. This contrast between climates situated on the two sides of the trade-winds is very remarkable; it is a sudden, not a gradual transition, as might, *à priori*, be imagined. I insist on this fact, to shew how much it is in contradiction to the assertions hazarded by ancient meteorologists.

This sudden change is easily deduced, from what I have said in general of the precipitation of aqueous vapours. The cause may most frequently be recognised in a mixture of strata of air of unequal temperatures. Now, variable winds often bring about this conflict. In summer, the regular east wind extends as far as the coast of Portugal (p. 47). Hence, there are less disturbances in the equilibrium of the atmosphere. The formation of clouds is then much more rare than during the variable winds of winter.

**RAINY WINDS IN EUROPE.**—On collecting all that is known in the different climates of Europe, we are led to establish three hyetographic regions: 1st, that of England and the west of France, which extends in a modified form even into the interior of the Continent; 2d, that of Sweden and Finland; 3d, that of the coasts of the Mediterranean. The limits of these regions are not always rigorously defined; they are not clearly recognised, except in points where they are marked by great chains of mountains. Every where else the transitions are found to be very orderly. The differences of these three groups consist in the different direction of the rainy winds, and of the distribution of the quantity of water which falls each year.

Let us consider the part of Europe north of the Alps and the Pyrenees; the predominance of west winds, a vast ocean on one side, a great continent on the other, are the determining circumstances of the distribution of rains. If the N.E. wind always prevailed, even at a considerable height, it would never rain; for it passes over lands before arriving at the low latitudes, where the elevation of temperature removes the vapours from their point of condensation. If the S.W. wind, on the contrary, blew without ceasing, it would always rain; for, as soon as the moist air gets cool, the vapour of water is precipitated. In spite of their alternations, these winds always preserve their relative character. If we inquire, with M. **de Buch**, how many times each wind brings rain, these results become evident. In 100 showers, which fell at Berlin, the different winds blew in the following proportions:—

| N. | N.E. | E. | S.E. | S. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|
| 4,1 | 4,0 | 4,9 | 4,9 | 10,2 | 32,8 | 24,8 | 14,4 |

Thus, scarcely any rain fell with the N.E. wind, whilst at least half are brought by the W. and S.W. winds. But the winds do not all blow an equal number of times in the course of the year. The number of times that each wind has blown must, therefore, be divided by the number corresponding to each wind in the preceding table. We then obtain the following numbers:—

| N. | N.E. | E. | S.E. | E. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|
| 5,8 | 8,1 | 8,8 | 6,9 | 3,8 | 2,8 | 4,2 | 4,5 |

The law is always the same: out of nine times, which the east wind blows, it only rains once; whilst it rains once in three times during the S.W. wind. The influence of seasons is also recognised. Whilst it frequently rains in winter during E. or N. winds, these same winds are almost always dry in summer. This fact accords very well with what we have said on the relative humidity of the different winds; for with east winds the air is very dry in summer, but very moist in winter.

Rains brought by N.E. winds, are even very different from those brought by the S.W. When the N.E. wind suddenly begins to blow, the temperature falls; large drops of rain fall in abundance for several moments: the sky then again becomes serene. In S.W. winds the rain is fine, and lasts a long time.

So the rains are in general due to a cooling, and to the precipitation of the vapour brought by the S.W. winds. In high latitudes, on the contrary, the N.E. winds suddenly cool masses of air, which can then no longer contain vapours in the elastic state. As these winds succeed each other with a certain regularity, which we will treat of in detail in Barometry, there must follow a very regular succession of changes in the weather: on this we will now make a few observations.

When the weather has been fine for a long time, and a S.W. wind begins to blow in the higher regions of the atmosphere, *cirri* make their appearance, and soon cover the sky. Beneath them is formed a stratum of *cumulus*, which allows a light rain to escape. The wind turns to the west, the clouds become thicker, the rain falls more abundantly, and the air becomes colder. With the N. or N.W. wind the rain continues, although the thermometer falls. In winter, the rain passes into the state of snow. If the rain does not entirely cease with the N. wind, it is not, however, continuous; the blue of the sky is seen in the intervals which separate the clouds. Showers alternate with sunshine, especially with the N.E. wind; but if the wind passes to the E. or the S., the sky is then covered with small rounded *cumuli*, or else it becomes perfectly serene.

These phenomena succeed each other, in an almost uniform manner, over large surfaces. Mountain chains alone have the power of slightly modifying the succession of phenomena. If they extend from N. to S., they arrest the S.W. wind, and it will rain more on their western than on their eastern side. Thus, the S.W. is not the rainy wind in the south of Germany, but the N.W.; because the S.W. winds lose the water with which they are charged when they arrive on the other side of the Alps.

The same thing happens in the Scandinavian peninsula. On the W. side of Norway, the rain falls for entire days during S.W. winds; the summits of the Scandinavian Alps are covered with hoar-frost; and on the other side of the chain only a few drops disturb the serenity of the sky of Sweden. The sea-winds lose the moisture with which they were charged in traversing the large table-land that separates the two countries, so that it rains more frequently in Sweden with E. than with W. winds. The proof that this is not connected with the vapours which rise from the Baltic, is, that a similar relation is found in Finland. Where-ever this region of rainy east winds comes into contact with that of the rainy west winds, it rains indifferently with all winds: this is remarked at St. Petersburg. We are still in want of a sufficient number of observations, in order to follow out these laws into their details.

I leave the considerations of the Mediterranean climate to the end of the following chapter.

**DISTRIBUTION OF RAIN AMONG THE DIFFERENT SEASONS.**—If the quantity of rain that falls in different parts of Europe is measured, it is found to be less, other things being equal, as we recede from the sea-shore. Thus, on the west coast of England, 95 centimetres fall per year. On the east coast, in the interior of the country, not more than 65 centimetres fall. In passing over the country, the W. winds have already discharged a large portion of the water they held in suspension. On the coasts of France and Holland, the quantity of rain is 68 centimetres; in the interior, 65 centimetres; in the plains of Germany, 54; and at Petersburg and Buda, 43 and 46 centimetres.[*] We arrive at this same result by calculating the number of rainy days in each country, comprising, under this denomination, all those during which it has rained little or much.

---

[*] The mean annual quantity of rain that fell at Paris, from 1689 to 1754, according to M. ARAGO (*Annuaire* for 1824), is 456$^{mm}$. From 1805 to 1822, there fell at Paris, at a mean, 508$^{mm}$ of water per year; and at London, from 1812 to 1827, 633$^{mm}$, according to HOWARD. Between 1831 and 1841, this quantity at London was 460$^{mm}$ (*L'Institut*, Nov. 10, 1841); at Maestricht, 704$^{mm}$ between 1823 and 1833 (CRAHAY, *Mém. Acad. Brus.* t. x). In the west of France, the annual quantity of rain is also very considerable: at Bourdeaux, 657$^{mm}$; at La Rochelle, 654$^{mm}$. It is, however, less than in the east; for at Strasbourg, from 16 years of observations, 691$^{mm}$ fall annually; and at Mulhouse, 768$^{mm}$. The latter number was deduced from a series of only six years. (*Vide* KAEMTZ, *Lehrbuch der Meteorologie*, t. i. pp. 455—459.)—M.

In England and the west of France there are, at a mean, 152 rainy days in the year; in the interior of France, 147; in the plains of Germany, 141; at Buda, 112; at Kasan, 90; and in the interior of Siberia, only 60.

Not only does less rain fall in the E. than in the W. regions of Europe, but this rain is sufficiently shared among the seasons. If we express the annual quantity of rain by 100, we shall find the following number for that which falls in each season:—

PROPORTIONAL QUANTITIES OF RAIN IN EUROPE, IN THE DIFFERENT SEASONS.

| | WEST of England. | INTERIOR of England. | WEST of France. | EAST of France. | GERMANY. | PETERSBURGH. |
|---|---|---|---|---|---|---|
| Winter | 26,4 | 23,0 | 23,4 | 19,5 | 18,2 | 13,6 |
| Spring | 19,7 | 20,5 | 18,3 | 23,4 | 21,6 | 19,4 |
| Summer | 23,0 | 26,0 | 25,1 | 29,4 | 37,1 | 36,5 |
| Autumn | 30,9 | 30,4 | 33,3 | 27,3 | 23,2 | 30,5 |

(*Vide* Appendix, *fig.* 15.)

In spring, about the fifth part of the total quantity falls every where; we will not, therefore, dwell on this season, in order that we may turn all our attention to winter and summer. Let us compare these two seasons, and represent by 1 the quantity of rain that falls in winter; that which falls in summer will be expressed by the following numbers:—

RELATIVE QUANTITY OF RAIN IN SUMMER.

| | |
|---|---|
| West of England . | 0,868 |
| East of England . | 1,131 |
| West of France . | 1,071 |
| East of France . | 1,540 |
| Germany . . | 2,042 |
| Petersburg . . | 2,670 |

Thus, while in the west of England the quantity of water that falls in summer is to that which falls in winter as 9 to 70, this relation entirely changes as we penetrate into the continent. On the west coasts of France, the quantities of water are very nearly equal. In Germany, twice as much water falls in summer as in winter; and at Petersburg, the quantity of rain in winter is only a little more than a third of that which falls in summer. The days of rain follow the same laws. On the west coast of England, they are more numerous in winter than in summer; while in the interior of Siberia, it rains four times more frequently in summer than in winter.*

In the sequel we shall often have occasion to revert to the laws that we have established. Let us simply add, that a clouded stratum of the sky and the longer or shorter periods of fine weather are their more immediate consequences. During whole days, the sun is invisible in England, whilst a clear sky is extended over continental Europe; in summer it is precisely the contrary.

These climatologic differences are connected with two causes. In equal latitudes, the air is hotter above the Atlantic Ocean than above the earth. When the west winds,

---

* To M. de GASPARIN we are indebted for an extensive work on the distribution of rains in Europe. Representing the annual quantity of rains by 100, he expresses the quantities that fell in the different seasons by aliquot parts of this number, which seasons he divides differently from other meteorologists: his summer months are July, August, and September. This being laid down, he divides Europe into two regions—the one on the N.E., where the greatest quantity of rain falls in summer; the other on the S.W., where it falls in autumn. The region of the autumnal rains extends as far as the Atlas. Continental Germany belongs to that of summer rains. Paris is on the limit of the two regions. (Vide *Bibliothèque Univ.* t. xxxviii. pp. 54 and 264.)

When a month is very rainy, the generality of mankind are apt to imagine that the climate of the place which they inhabit, or even that of the whole world, is deteriorated. This took place at Paris, in the month of April, 1837. To put an end to these ridiculous reports, M. ARAGO opened the registers of the Observatory, and shewed that the quantity of rain which fell in April, 1837, and which amounted to $63^{mm}$, was lower than that of four anterior years, when it was,

| | |
|---|---|
| In 1829 | $69^{mm}$ |
| 1821 | 68 ,, |
| 1818 | 66 ,, |
| 1833 | 64 ,, |

In April, 1837, the days of rain were 17 in number. Now their number in other years is,

| | |
|---|---|
| 1833 | 29 days. |
| 1829 | 25 ,, |
| 1830 | 22 ,, |
| 1804 | 19 ,, |
| 1818 | 18 ,, |
| 1821 | 18 ,, |
| 1805 | 17 ,, |

It is the same with the conclusions that are drawn from the somewhat elevated mean temperatures that are observed in certain months. (*Comptes rendus de l'Acad. des Sciences,* t. iv. pp. 653 and 822. 1837.)—M.

loaded with the vapour of water, begin to blow, the latter is precipitated as soon as they come into collision with the colder winds of the Continent. Add to this, that the clouds are much lower in winter than in summer, and are stopped by less elevated chains of mountains. In summer they pass above, and discharge the water with which they are loaded, into the interior of the continents; this latter circumstance is the more influential, as the greater part of the summer rains are due to ascending currents, which draw the vapours and clouds toward the higher regions of the atmosphere; a phenomenon that occurs much more frequently on the continent than in England. For example,

In Scandinavia the transition of a sea-climate into a continental climate is seen in a small space. At Bergen, there fall annually $2^{m},25$ of water, which is more than at any other city in Europe, and more than on many points situated within the tropics. This is because the clouds are driven forward by the S.W. winds into the fiords of Norway, where they are arrested by the mountains; they there accumulate, and the water is, as it were, mechanically squeezed out. In Sweden only fifty-four centimetres of water fall at a mean, and the relation between the summer and the winter rains is entirely changed; for whilst, in Norway, the quantity of water that falls in summer is only three-fourths of that which falls in winter, localities are found in Sweden where the relations are the same as on the Continent.

**RAINS ON THE COASTS OF THE MEDITERRANEAN.**—The Atlantic is the great reservoir of rains for the European regions that we have hitherto been considering, but it has little influence over the climate of countries situated on the north of the Mediterranean. The west winds discharge the water they contain on the Pyrenees, the mountains of the Spanish peninsula, and those of the south of France. The S.W. wind, coming from the equator, prevails at the same time with the south, engendered by the burning deserts of Sahara, and which gives rise to many local whirlwinds, while the north winds blow on the Mediterranean (*vide* p. 45). This wind is distinguished by its dryness and its elevated temperature; also, when the ascending current takes the vapours upward, they arrive in a dry air, and do not condense, especially if the wind blows violently.

The valley of the Rhône, in the south of France, is watered by an annual quantity of rain scarcely superior to that which falls in Germany; but its division among the various seasons is very different, for, in summer, scarcely ten per cent of the total quantity falls, and, in autumn, forty per cent. If, starting from the sea-coast, we ascend the valley, the quantity of rain falling in summer increases at every step, and the relations that exist in the east of France are found. The influence of the Mediterranean climate is even felt at Geneva.[*]

With respect to the distribution of rains, Italy shews very remarkable local differences, but we cannot follow them into their details on account of the deficiency of observations. Not only are the rainy winds not the same as in Europe, but differences are found between those of the plains of Lombardy and those of the western coast. At Padua, it more frequently rains with north and N.E. winds; for, one-third of the total quantity of rain falls with the former of these two winds. The south and S.W. winds bring only one-twentieth of the total quantity. If we note the frequency of the winds, we shall see that the south and S.W. winds blow ten times without any rain falling, while the N.E. wind never blows four times without its raining: this is precisely the contrary to what happens in Germany. But the north winds, that so frequently bring rain to Padua, only blow along the surface of the ground; the south winds, which prevail in the higher regions of the atmosphere, accumulate the clouds against the Alps; and the north wind, which is reflected on the mountains, brings them back to the plains of Lombardy. On the contrary, if high clouds come from the north to the south, fine weather may be calculated on.

---

[*] The following table, due to M. BRAVAIS, shews the mode of the distribution of rain according to the different seasons of the year in the valley of the Saône and the Rhône, both to the north and the south of the parallel of Viviers. He has placed the numbers relating to Geneva and Milan opposite, on account of the proximity of these cities, and of the transition which they exhibit between the climate of the valley of the Rhône and that of Germany and Italy; and, finally, because these numbers might inspire great confidence, as they are the mean of a *very great many* years of observation:—

| | BASIN OF THE RHÔNE. | | GENEVA. | MILAN. |
|---|---|---|---|---|
| | North of VIVIERS. | South of VIVIERS. | | |
| | mm. | mm. | mm. | mm. |
| Winter . | 19,6 | 22,0 | 21,6 | 20,9 |
| Spring . . | 23,8 | 24,7 | 21,8 | 24,1 |
| Summer . | 22,0 | 12,6 | 29,7 | 23,4 |
| Autumn . | 34,6 | 40,6 | 26,9 | 31,6 |
| Year . . | 100,0 | 100,0 | 100,0 | 100,0 |

At Rome, it rains with north and south, but rarely with intermediate winds. With regard to frequency, out of twelve times that the wind blows from the north, rain is once brought, while the south wind never blows three times without water falling. At Padua, the north wind is reflected on the Alps; at Rome, the rain comes from the Apennines, which are situated to the east of that city.

On examining the distribution of rain in Italy, we must distinguish the coasts of the Adriatic Sea, and in particular Dalmatia, from the countries situated beyond the Apennines. On the entire west coast, ten per cent of the whole annual quantity of rain falls in summer. The fact was even known by the ancients, when they said that in Italy it does not rain with the *etesian* winds;[*] it is the same in Greece. The current of Sahara is very violent in the higher regions, and the vapours that are raised are not able to saturate this dry and hot air. This does not happen if the regularity of the winds is disturbed, and when the ascending current blows with much force; the sky is then cloudy; and there are soon drops of rain and storms, but the clouds are not long before they disappear again.

As soon as we traverse the Apennines other relations are established; the superior is no longer the prevailing current: this is especially striking in the great valley of the Po. On the coasts of the Adriatic Sea analogous relations are found, although less marked than on the west coast; in ascending toward the north, the summer rain increases without ceasing, the winter rains diminish; and, in this respect, the climate of Turin is entirely comparable with that of Germany.[†]

---

[*] "Venti modo adducunt nubes, modo diducunt, ut per totum orbem pluviæ dividi possent. In Italiam Auster impellit, Aquilo in Africam rejicit: Etesiæ non patiuntur apud nos nubes consistere. Iidem totam Indiam et Æthiopiam continuis per id tempus aquis irrigant."—(Senec., *Quest. Nat.* v. 18.)

[†] In his beautiful work, entitled, *Table of the Climate of Italy* (Copenhagen, 1839), M. Schouw has divided this country, in a hyetographic point of view, into four principal belts.

The first, called *the Alpine belt*, comprehends twenty-three stations, situated to the north of the south declivity of the Alps, such as Udine, Bellune, Conegliano, Feltre, Castelfranco, &c. The mean annual quantity of rain that falls there is $1^m$,363.

The *transpadane belt* comprises Trieste, Venice, Mantua, Milan, &c. The annual quantity of rain is $0^m$,869.

In the *cispadane belt*, containing Parma, Bologna, Ferrara, &c. it is as low as $0^m$,665.

Finally, in the *Apennine belt*, which comprises all the towns occupying the west and the east sides of this chain, from Genoa to Palermo, the quantity of rain diminishes from north to south; for it is great at Genoa and Lucca; one-half less at Rome and at Palermo, and still less at the east of

The same appears to be the case on all the coasts of the Mediterranean; in Syria, as well as in the north of Africa, it rarely rains in summer, but frequently in winter. Hence that perpetually serene sky, of which travellers speak with so much enthusiasm. Such a climate may be conceived to have a great influence over vegetation; that of the south coasts of the Mediterranean is characterised by a great many peculiar species. Those species, first distinguishable around Montpellier and Marseilles, are found on all the west coast; but, as soon as the hill of Tende is passed, a vegetation is seen which approaches that of Germany. These differences are not connected merely with that existing between the mean temperatures, but also with the influence of a more uniform temperature.

The distribution of rains in Europe, and particularly the summer rains of Germany and the autumn rains of Italy, have been deduced by M. **Dove** from a law somewhat different. As the vapour of water is abundantly precipitated when two winds contend, he explains them by the greater extension of the trade-wind in summer. Then the upper S.W. currents touch the ground only in the high latitudes, while, in winter, they arrive here even in lower latitudes. This is why the greatest quantity of water which falls in summer in the north of Europe is due to the collision of two winds. At the equinoxes, they touch the earth in the Mediterranean region; hence the violent autumnal showers in these countries. When the declination of the sun is south,

---

the Apennines. Also, at Lucca and Turin, only 0m,488 of water falls per year.

I have extracted from M. SCHOUW's tables the mean quantity of rain that falls in the different seasons of the year in each of the belts that he has traced out:—

MEAN QUANTITY OF RAIN IN THE DIFFERENT SEASONS, IN ITALY.

| REGIONS. | SPRING. | SUMMER. | AUTUMN. | WINTER. |
|---|---|---|---|---|
| | mm. | mm. | mm. | mm. |
| Alpine belt . . . | 321 | 394 | 480 | 301 |
| Transpadane belt . | 210 | 229 | 291 | 197 |
| Cispadane belt . . | 137 | 137 | 219 | 140 |
| Apennine belt . . | 210 | 121 | 321 | 263 |

We at once recognise in this table the influence of latitude and that of mountains. Thus, the annual quantity diminishes as we approach the south; and the neighbourhood of mountains determines heavy rains in spring, autumn, and winter.—M.

the winter rains inundate the north of Africa; in spring, the conflict is in the south of Europe; and, in this season, the rains are abundant.

Although this theory, which has so many relations with the distribution of rains within the tropics, explains to us many obscure points, we should nevertheless not forget the relations that exist between the countries situate north and south of the Mediterranean. In spring and autumn, periods when the Sahara current begins and finishes, eddies, like those which accompany changes in the monsoons, determine frequent rains. But the winter rains, so abundant on the west coast of Europe, cannot be explained otherwise than we have given them.

It is to be regretted that we do not possess a greater amount of information on the distribution of rains in the rest of the world. Existing observations are insufficient. Let us simply observe, that the west coasts of the two Americas are distinguished by abundant winter rains, whilst the contrary occurs on the eastern coast; the total want of continuous series made in these latitudes does not permit of our establishing more precise laws.

# IV.

# DISTRIBUTION OF TEMPERATURE ON THE SURFACE OF THE GLOBE.

OUR researches on the modification of the atmosphere commenced by the study of Heat; from which we deduced the theory of winds and hydrometeors. These two orders of phenomena exercise, in their turn, the greatest influence over the range of temperature, and determine the anomalies which it presents. To this subject we will now specially direct our attention.

**REDUCTION OF CALORIFIC INTENSITY IN THE PASSAGE OF HEAT THROUGH BODIES.**—Calorific, like luminous rays, undergo certain modifications in their passage through bodies. Although transparent media are also those which allow heat to pass with the greatest facility, there are yet, in this respect, notable differences between substances. Thus a diathermal body allows all the rays of heat to pass without itself becoming heated. If a piece of very pure ice is made into the form of a lens, tinder, placed in its focus, may be ignited by the simple action of the solar rays, without the ice being melted.

To determine whether a body is diathermal, we first place a delicate thermometer in the focus of a concave mirror, that reflects on the bulb of the instrument the light of a taper: another thermometer is freely suspended in the air. The difference of the indications of the two instruments shews the influence of the source of heat. Suppose this difference to be 3°. Now interpose between the mirror and the taper a plate of the substance you desire to examine. Grant that the difference of the two thermometers is not more than 1°,5. It follows from this experiment, that the plate did not allow more than half the calorific rays to pass, whilst the other half contributed to raise its temperature. If we increase the number of plates of the said body, or the thickness of this body, the proportion of the rays absorbed will be greater; for we still suppose it composed of plates similar to the former, each of which absorbs the same proportion of heat. For the sake of simplicity, let us suppose that 100 rays arrive, and that the first plate absorbs one-tenth, the second will not receive more than $100-10=90$ rays. The latter will also absorb one-tenth, that is to say, 9. The third will, therefore, receive $90-9=81$ rays, and will absorb 8,1; the fourth will receive 72,9 rays, and so on. By expressing these relations mathematically, we may reduce all bodies to the same thickness, and calculate the relative quantity of heat which they have absorbed.

Experiments of this kind, when carefully conducted, not only lead us to recognise the different diathermanity of bodies, but to divide calorific sources into two orders; those which are luminous, such as the sun, the light of a taper, incandescent metals; and those which emit merely dark calorific rays, such as a vessel filled with hot water. Every thing proves that diathermic bodies absorb a much more considerable portion of obscure than of luminous rays. Without seeking to explain this fact, let it suffice us to remark that it is of high importance towards our understanding all that is to follow.

**REDUCTION OF SOLAR HEAT DURING ITS PASSAGE THROUGH THE ATMOSPHERE.**—If we follow the march of the sun on a fine day, we shall recognise, without the aid of any instrument, that the intensity of its heat diminishes with its height, because the atmosphere absorbs a portion of the luminous rays. As the sun descends toward the horizon, the rays are obliged to traverse a greater thickness of the atmosphere, in order to reach us. At the moment of its setting, its light is so feeble that we can contemplate it with the naked eye. It is the same with its calorific power. Take a lens, when the sun is passing the meridian, and measure the time necessary to inflame tinder, for example; in proportion as the sun approaches the horizon more time will be required to light it, and it will be even impossible when this planet is at a few degrees above the horizon.

In order to measure this reduction accurately, we must employ a thermometer sufficiently protected against the wind and other influences. **De Saussure** called this instrument a *heliothermometer*. Take a box, the interior of which is coated with bodies that are black, and also bad conductors of heat, and which is closed on one side by panes of transparent glass; then place in it a thermometer with a blackened bulb, and adjust the apparatus so that the sun's rays fall perpendicularly on those plates of glass. **Herschel** proposed a very different apparatus, which he named an *actinometer*.[7] But the heliothermometer is more easy to construct, and answers the same purpose.

If this apparatus is exposed for a minute to the sun's rays, the thermometer rises. However, a small correction is here necessary. Suppose that the instrument has a temperature lower than that of the medium in which it is placed, the thermometer would rise without the direct influence of the sun; it will then indicate too high a temperature. To find the correction, observations must be made for three minutes. After having arranged the apparatus conveniently, a screen is placed between it and the sun, and the indications of the thermometer are read during this space of time: suppose that it has risen 0°,3. The screen is then removed; in the minute, during which it receives the solar rays, it will rise 1°,5 for example. The screen is then replaced, and, in the third minute, it will rise, say 0°,1. Thus, under the influence of the circumambient medium, it rose in the first minute 0°,3; in the third minute 0°,1; consequently, in the second minute it must have risen

$$\frac{0{,}3 + 0{,}1}{2} = 0^\circ{,}2.$$

So that, during the second minute, the sun made the thermometer rise $1^\circ{,}5 - 0^\circ{,}2 = 1^\circ{,}3$. If the instrument has fallen during the first and the third minute, the mean of those fallings should have been added to the solar action. To avoid errors of observation, the observations are made for eleven minutes. The thermometer is exposed to the solar light during the second, fourth, sixth, &c. minutes; the mean of the five observations is then taken.

Measurements of this kind, when made during days that are perfectly serene, shew that the solar action increases with the height of the sun above the horizon. The following is an example:—

---

[7] *Vide* note *f*, Appendix, No. II.

| Height of the Sun. | Ascent of the Heliothermometer. |
|---|---|
| 40° 30′ | 2°,16 |
| 37 35 | 2 ,03 |
| 24 30 | 1 ,77 |
| 21 30 | 1 ,50 |

In order to deduce from these observations the reduction of solar light in its passage through the atmosphere, we should know exactly the course of the rays in the atmosphere, and the amount to which the thermometer would rise, if it were placed at the limits of our atmosphere; that is to say, if the rays were not weakened. These two elements cannot be exactly determined; but, if we suppose the atmosphere limited by a plane parallel to the horizon, at a height of about 20°, which is true, and if we designate by 1 the shortest distance from the observer to this plane, we may express the length of the course of the sun's luminous rays by multiples of this unity. By repeating the experiment at different heights of the sun, we may conclude approximately the quantity that the instrument would rise, if it were at the limits of the atmosphere. With the instrument that I employed, this quantity was 3°,2. Thus, when the height of the sun is 40° 30′, only two-thirds of the rays reach the earth; when at 21° 30′, only half: the rest are absorbed by the atmosphere, or reflected toward the earth and celestial space.

In order to express this value, which depends on the height of the sun, it is better to seek how many rays would have reached the earth had the sun been at the zenith. If we represent the number of rays that arrive at the atmosphere, during the most serene days, by 100, scarcely 70 or 80 will reach the earth. Thus the fourth are absorbed or reflected by the atmosphere. The total number of rays that reach the ground during a day, is only the half of that which falls on the atmosphere. This is true of a day perfectly serene; but on calculating serene and also cloudy days, we see that the earth does not profit by more than a very small portion of the rays that arrive at the atmosphere.

The heat that the earth receives from the sun radiates into space; but, as it is dark heat, it is probable that it experiences a much greater difficulty in traversing the atmosphere than do the luminous rays of the sun. When the transparency of the air is disturbed by vapours, the dark and also the luminous rays experience a still greater resistance in their progress; but if they prevent the heating of the soil by the rays of the sun, they also oppose its cooling by radiation.*

**TEMPERATURE OF THE EARTH AND OF SPACE.**—Hitherto, we have considered the sun as the only source of heat that warms our globe; but **Fourier** has shewn that there exist two other very influential causes, namely, the proper heat of the earth itself, and also that of space. Although their action cannot in any degree modify the indications of the thermometer, it is, however, well to analyse it briefly.

If we bury thermometers in the ground, at different depths, and so that their bulbs shall be in contact with the earth, the annual variations will be smaller as the instruments are

---

* M. Pouillet devised two instruments, much more perfect than that of Herschel, for estimating the quantity of solar heat absorbed by the atmosphere. One is the *direct pyrheliometer*, the other, the *lenticular pyrheliometer*. The latter is composed of a lens 24 or 25 cent. in diameter, with a focal distance of 60 or 70 cent., in the focus of which is a plated vessel, containing about 600 grammes of water, in which the bulb of a thermometer is plunged. The form of the vessel and the arrangement of the lens are so combined, that, for all heights of the sun, the rays fall perpendicularly on the lens, and on the surface of the vessel; which latter is covered with lampblack, and is intended to receive them in the focus and to absorb them. (For the description of these two instruments, vide *Les Comptes rendus de l'Académie des Sciences*, t. vii., p. 24 [1838]; and *Eléments de Phys.* t. ii. p. 528, and *fig.* 375 and 376.)

Numerous experiments made with these two instruments have led to the following results:—When the atmosphere has every appearance of perfect serenity, it yet absorbs nearly one-half of the total quantity of heat which the sun emits toward the earth; and it is the other half alone of this heat which falls on the surface of the earth, and which is more variously distributed, according as it has traversed the atmosphere with greater or less obliquity.

If the total quantity of heat, which the earth receives from the sun in the course of a year, were uniformly spread on its surface, and employed without any loss to melt a bed of ice, which should envelope the entire globe, it would be capable of melting a bed thirty-one metres thick.

Mr. Forbes communicated to the Royal Society of London, on the 26th of May, and the 2d of June, 1842, the results of the correspondent experiments which he had made in September, 1832, with M. Kaemtz, at Brienz, and on the Faulhorn, upon the transparency of the atmosphere. The difference of level was 2119 metres. The following are some of the results, which are as new as they were unexpected.

1st. The bundle of calorific solar rays, on entering into our atmosphere, is composed of two sorts of rays; the one easily absorbable by the atmosphere, the other absolutely refusing all extinction; the former form nearly 0,8 and the latter 0,2 of the total number.

2d. The law of the extinction of the rays of the first order is a geometrical progression (according to the hypothesis of Bouguer, Kaemtz, &c.), such that the *vertical* transmission through the atmosphere, taken from its base (the level of the sea) to its superior limit, reduces the eighty absorbable rays to thirty-three.

It follows, from this new theory of Mr. Forbes's, that the portion of the heat which is not absorbed in the case of vertical transmission, instead of being 75 per cent of the extra-atmospheric heat, is only 53 per cent. (Vide *Phil. Mag.* Sept. 1842.)—M.

more deeply buried in the earth. At about six or seven metres, the instrument is stationary for the whole year, and indicates a degree of temperature which approaches closely to that of the annual mean. This temperature increases the more we penetrate into the soil. Experiments made in mines and in artesian wells put this general fact beyond doubt. The nature of the soil and local circumstances modify the law of increase, which varies between twelve and thirty-five metres for one degree centigrade.

In all countries, the temperature increases with the depth. To say that this increase has no limit is what experience cannot teach us, and we are reduced to conjectures. Some philosophers admit an indefinite increase: it would follow from this, that, at a depth of about 3200 metres, a temperature of boiling water would be found; and the centre of the earth would be composed of matter in the state of fusion, or in the gaseous state, the heat of which would surpass all that the imagination can conceive. Add to this that the globe, having been formerly in the liquid state, has been cooled by radiation alone. The surface became cool first, and one part of its loss was repaired by the heat that was transmitted from within outwards. This transmission took place without cessation; but it has been calculated that this quantity of heat is insignificant, in comparison of that which comes to us from the sun. It was much greater before man existed on the earth. At certain geologic epochs, all the points of the globe were hotter; and this explains to us why we find in high latitudes fossil vegetables and animals, the analogues of which cannot at the present moment live any where but within the tropics.

At first sight, it seems incredible that the nucleus of the globe is incandescent, while at the surface we do not feel this heat. This fact is only explained by the want of conductibility in the rocks that compose the crust of the earth. Volcanos have made us familiar with phenomena of this kind. The lava that runs from the crater of a volcano possesses so great a heat that it almost melts all metals; but a crust is soon formed on its surface; it breaks, and its fragments swim in the current of lava like blocks of ice on a river. They solidify so quickly, that travellers have been able to traverse the liquid lavas by walking over them. If the current is stopped, these fragments, by uniting, form a solid crust, which prevents the mass from becoming cold; and, after several years, a notable heat is found in the centre of these streams. **Gemellaro** observed on Etna a mass of ice, over which a current of lava had flowed without melting it.*

The earth, as it turns round the sun, moves in a medium, the temperature of which, no doubt very low, is completely unknown to us. On the other hand, the stars, notwithstanding the infinite distances by which they are separated from us, send us rays both luminous and calorific. Some regions of the heavens also, being more rich in stars, the quantity of heat that reaches us from different points of space is not the same. But, like as the different indications of the thermometer, during the course of a year, are all reduced to a mean, so may we presume that the heat of the sky is uniformly spread through all the celestial vault. This heat, combined with that of the space in which the earth moves, gives us the temperature that **Fourier** named the temperature of space, and what he states to be from —50° to —60°; whilst M. **Pouillet** fixes it at —140°.† The

---

* In the *Annuaire* for 1834, M. ARAGO published a notice on *The Thermometric State of the Globe*. He proved with his usual clearness:—

1st. That there exists in the earth a central focus of heat.

2d. That, for 2000 years, the general temperature of the mass of the earth has not varied a tenth of a degree; and yet the surface has become cold in the course of ages, so as scarcely to preserve any sensible trace of its primitive temperature.

3d. He shews that the changes we have observed, or think we observe, in certain climates, are not connected with cosmical causes, but with circumstances entirely local; such as the clearing of woods and mountains, the drying up of morasses, extensive agricultural works, &c. &c. Thus, on comparing the thermometric observations made at Florence, according to the instructions of the Academy of Cimento, towards the close of the 16th century, with those comprised between 1820 and 1830, it was found that the mean remained sensibly the same. It would merely appear that *the winters are not quite so cold*, and the *summers not quite so hot*; a result probably due to the clearings that have been made since this epoch. In the United States, an analogous effect has been observed, in consequence of the vast clearings of which this country is the theatre. M. ARAGO then applied these notions to the climate of France; and he shews that there is nothing to prove its having undergone any other changes than those derived from the labours of man. With regard to the temperature of the terrestrial crust, at a depth of twenty-eight metres, which is that of the cellars of the Observatory, it has not changed for a century; for an observation made by MESSIER, in 1776, gives exactly the same cipher as in 1826, namely, 11°,8.—M.

† In endeavouring to determine the temperature of space, M. POUILLET proposed an instrument which he called an *actinometer*. It is composed of four rings, of two decimetres in diameter, covered with swan's down, and resting on each other in such a manner that the swan's down shall not be compressed. The skin of the swan itself forms the base of the circle of each of the rings. This system is enveloped in a first cylinder, which is itself enveloped in swan's down, and contained in a larger cylinder. A thermometer rests in the centre of the upper swan's down; and the border of the exterior cylinder has such a height, that the thermometer can subtend only two-thirds of the hemisphere of the heavens. This border is pierced with holes, in order that the cold air may escape readily.

This apparatus being exposed in an open place, and on a serene night, to the radiation of the sky, its thermometer, and a neighbouring thermometer, suspended freely in the air, are observed from time to time. From the dif-

difference of these two results shews how difficult this question is; and, moreover, the temperature of space appears to have but a feeble influence over that of the lower strata of the atmosphere.

Supposing a different temperature in the different regions of space, **Poisson** deduced the proper heat of the earth. For all our system being sustained *in vacuo*, it is possible that it may have traversed very hot regions. Hence the heat that is still observed in the deep strata of the earth, which have not yet had time to cool.

**INFLUENCE OF HYDROMETEORS OVER TEMPERATURE.**—Let us abandon theories to study causes, whose action is more powerful and more easy of demonstration. Among these causes hydrometeors occupy the first rank. We may, indeed, readily conceive that the state of the sky exercises an immense influence. When on a summer's morning the sky is calm, and the air serene, the temperature rises notably in a few hours. But if clouds cover the sky, and intercept the rays of light, the thermometer rises but little, or even falls considerably before the moment of the *maximum* of heat. The converse takes place when the sky is cloudy in the morning and serene in the afternoon. In winter, on the contrary, the thermometer

---

ference of these two thermometers, or from the fall of that one attached to the *actinometer*, the zenith temperature is deduced.

Experiments made with this instrument gave M. Pouillet two limits for the temperature of space, — 115° and — 175°, the mean of which is 140°.

From these researches he deduces many consequences of great interest.

The total quantity of heat which space sends to the earth and to the atmosphere, in the course of a year, would be capable of melting on our globe a bed of ice twenty-six metres thick.

We have seen that the quantity of solar heat is expressed by a bed of ice of thirty-one metres; so that the earth receives in all a quantity of heat represented by a bed of ice fifty-seven metres thick.

We shall undoubtedly be astonished that space, with its temperature of — 140°, can communicate to the earth so considerable a quantity of heat, that it is found almost equal to the mean heat of the sun. But we should remark that, with respect to the earth, the sun occupies only the five-millionth of the celestial vault; that it must, consequently, send two hundred thousand times more heat in order to produce the same effect.

If the action of the sun were not felt on our globe, the temperature of the surface of the ground would be every where uniform, and at — 89°. Now, since the mean temperature at the equator is 27°,5, we must conclude that the presence of the sun increases the temperature of the equatorial zone 116°,5.

To extend these calculations to other regions, we have merely to take account of the decrease of the temperature of the earth, in proportion as the latitude increases. (Vide *Comptes rendus de l'Acad. des Sciences*, t. vii. p. 53 [1838], and *Eléments de Physique*, t. ii. p. 538, and *fig.* 377.)

M. Arago having found, in the relation of the voyage of Capt. Back, that at Fort Reliance the thermometer descended to — 56°,7, concluded that the temperature of celestial space could not fail to be notably lower than —57°. (*Comptes rendus de l'Acad. des Sciences*, t. ii. p. 575, 1836.)—M.

rises when the sky is clouded, and sensibly falls as soon as the clouds are dissipated.

The summary of observations accords with these isolated facts. If in an isolated month we take the mean of the serene days and of the cloudy days, we find a notable difference between these two numbers. In winter, the cloudy days are several degrees hotter; in summer, it is the reverse.

This difference between the two seasons results from what we have said of the absorption of calorific rays by the atmosphere, and (p. 24) from the range of heat in these two seasons. In summer, as in winter, the earth loses by radiation one part of the heat that it has received from the sun, but in summer it receives much more than it loses. Although the dark calorific rays are relatively much more absorbed than the others, yet the heat received is greater than the heat emitted; but if, during summer, the sky is clouded, there is a fall of temperature. In winter, on the contrary, the earth becomes generally cold, the loss due to nocturnal radiation at night being greater than the heating by solar action. But, as clouds oppose radiation, and reflect back to the earth a portion of the obscure rays that it emits, there is an elevation of temperature in cloudy weather. Add to this, that the vapours precipitated during winter are at a much less height than in summer, and that the latent heat, which becomes free at the moment of their condensation, may act on the ground.

The fall of temperature that is noticed in summer, when the sky is clouded, is still more considerable when it rains; then, not only are masses of water precipitated from the high and cold regions of the atmosphere, and notably reduce the temperature in virtue of their great capacity for heat, but this water, in evaporating, again absorbs a notable quantity of heat, which it takes from the earth and air that are in contact with it. Hence arises the cold that is observed after rain-storms. If, in like manner, we study a long series of observations, we shall find the evident differences of temperature that exist between the rainy and the dry months of winter and summer: every one remembers the rainy and cold summers of 1833 and 1838, the serene and hot summer of 1834, the mild and rainy winter of 1833-4, as well as the clear and cold weather of that of 1829-30.

Within the tropics, the influence of the state of the sky over the temperature is especially remarkable. The meridian height of the sun varying but little in these climates, the rains are the more immediate cause by which the range of temperature is regulated,—a range totally different from that which takes place in our climates. When the sun is very far from the zenith, that is to say, when it is in the northern hemisphere during the months of December and January, the temperature is relatively very low. In proportion as the meridian height of the sun increases, the heat increases also, and would go on increasing without cessation until the sun is at the zenith; but then the rain commences and the heat diminishes; and it is not until later, when the sun, having passed the zenith, is in the other hemisphere, that there is an increase in the temperature, which attains its *maximum* when the rain is about to cease, and then diminishes to attain the *minimum* of which we have spoken. Thus, while in our climates the temperature has one *minimum* and one *maximum*, two *maxima* and two *minima* occur in hot countries. The two latter are one in the middle of the dry, and the other of the wet season, when the zenith distance of the mid-day sun is as great as possible. The two *maxima* occur at the beginning and the end of the wet season. Each locality within the tropics presents a different range of temperature: the *minimum* is an instantaneous effect of rain, but which lasts only a short time, or else remains for several months, without any very notable *maximum* afterwards following; because, as the sun recedes from the zenith, the heat diminishes.

Among the great many places situate within the tropics, where I find the confirmation of what I have just said, let me mention three cities in India. In the following table I give for each of them the quantities of rain, and the mean monthly temperatures; the last column presents the sum of the monthly quantities of water, and the mean of the temperatures:—

## QUANTITIES OF RAIN, AND CORRESPONDING MONTHLY TEMPERATURES, IN INDIA.

| MONTHS. | ANJARAKANDY. | | MADRAS. | | CALCUTTA. | |
|---|---|---|---|---|---|---|
| | RAIN. | TEMPERATURE | RAIN. | TEMPERATURE | RAIN. | TEMPERATURE. |
| | mm. | | mm. | | mm. | |
| January . . | 2,26 | 26°,5 | 18,05 | 24°,0 | 0, 0 | 18°,4 |
| February . . | 2,26 | 27 ,7 | 2,26 | 25 ,1 | 67,68 | 21 ,5 |
| March . . . | 6,77 | 28 ,4 | 11,28 | 26 ,5 | 24,82 | 25 ,6 |
| April . . . | 29,33 | 29 ,8 | 9,02 | 28 ,0 | 130,84 | 28 ,5 |
| May . . . . | 175,96 | 28 ,6 | 33,84 | 30 ,5 | 16,24 | 29 ,7 |
| June . . . | 794,05 | 26 ,6 | 22,56 | 31 ,2 | 575,24 | 29 ,3 |
| July . . . | 807,59 | 25 ,8 | 74,44 | 29 ,8 | 338,38 | 28 ,1 |
| August . . . | 572,98 | 26 ,0 | 99,26 | 29 ,3 | 311,31 | 28 ,3 |
| September . . | 311,31 | 26 ,4 | 110,54 | 28 ,8 | 254,91 | 28 ,0 |
| October . . . | 157,91 | 26 ,8 | 311,31 | 27 ,7 | 42,86 | 27 ,2 |
| November . | 65,42 | 26 ,9 | 354,17 | 25 ,9 | 20,30 | 23 ,0 |
| December . . | 29,33 | 26 ,5 | 191,75 | 26 ,6 | 0, 0 | 19 ,2 |
| Year . . . | 2955,14 | 27°,2 | 1238,45 | 27°,6 | 1928,74 | 26°,4 |

(*Vide* Appendix, *fig.* 16.)

Anjarakandy is situated on the coast of Malabar, between 12° and 13° of north latitude; Madras, on the contrary, is on the west coast of Hindostan, in 13° of latitude; Calcutta, in an angle of the gulf of Bengal, at 22° 30′ In all these places, the *minimum* of temperature is in December or January, when the sun has attained its greatest zenith distance. This fall of temperature is more sensible at Calcutta, because the distance of the sun from the zenith is relatively greater for this city than for the other two. As soon as the sun rises the heat increases; but in April, the direction of the monsoons changes (p. 42). The S.W. wind accumulates clouds on the coast of Malabar, and the abundant rains that are discharged reduce the temperature; the *maximum* takes place in April. In July, when the rains are very heavy, we find another *minimum* at Anjarakandy; and the thermometric mean is less than in January. Calcutta is much under the influence of the monsoons; but as these winds do not pass over a great extent of liquid surface, and do not meet with chains of mountains so abrupt as those in the neighbourhood of Anjarakandy, the rains are not very abundant. The heat increases until the end of May, and does not fall until after that time; but it never attains so low a mean as that of Anjarakandy, because the rains are not nearly so heavy. In autumn, the rains cease on the coast of Malabar, and the heat increases; and at the end of October, when the sun again begins to act with force, we find a second *maximum*, after which the temperature falls again until the month of January. This *maximum* does not exist at Calcutta; for in autumn, while the N.E. monsoon clears the sky, the sun gets further from the zenith than in places situated near the equator, and the length of the nights increases. When, by the S.W. monsoon the rains are abundant on the west coast of Hindostan, less rain falls at Madras, and the temperature rises until June. It is not until the month of July that clouds sometimes traverse the table-land; the rains then increase, and there is a fall of temperature, at first insensible, but which is notable during the torrents of rain that fall in the months of October and November.

It is evident from what we have just seen, that the countries with a rainy climate, situated between the tropics, have a mean temperature lower than countries with a dry climate. This difference is very sensible on the west coast of South America. In the neighbourhood of the equator, from the bay of Cupica to the gulf of Guayaquil, it rains almost the whole of the year; and according to the excellent observations of M. **Boussingault**, the mean temperature is only about 26°. More southward, at Payta, where rains are rare, as also on the east coast at Cumana, the mean is above 27°, although these points are further from the equator than the preceding.

**INFLUENCE OF WINDS OVER TEMPERATURE.**—Every one has experienced in winter that the south winds are warm, and the north cold. But, if we wish to arrive at more rigorous results, it becomes indispensable to inquire what the temperature is during different winds. In order to avoid the disturbing influences of diurnal and annual variations, we shall employ the method that we have already made use of for vapours (p. 97). Contenting ourselves with the annual means, we obtain the following results:—

MEAN TEMPERATURE FOR THE DIFFERENT WINDS.*

| WIND. | LONDON. | HAMBGH. | HALLE. | PEST. | MOSCOW. | STOCKLM. |
|---|---|---|---|---|---|---|
| N. | 9°,14 | 7°,75 | 7°,50 | 9°,17 | 0°,59 | 3°,74 |
| N.E. | 10 ,53 | 7 ,75 | 6 ,89 | 9 ,55 | —0 ,68 | 5 ,51 |
| E. | 11 ,03 | 8 ,75 | 7 ,59 | 10 ,10 | 2 ,78 | 8 ,23 |
| S.E. | 11 ,97 | 9 ,12 | 9 ,54 | 10 ,64 | 3 ,91 | 9 ,41 |
| S. | 11 ,32 | 10 ,13 | 10 ,57 | 12 ,44 | 4 ,14 | 8 ,78 |
| S.W. | 11 ,77 | 10 ,62 | 10 ,31 | 12 ,62 | 3 ,51 | 8 ,46 |
| W. | 10 ,42 | 9 ,88 | 9 ,66 | 10 ,40 | 3 ,30 | 7 ,21 |
| N.W. | 9 ,86 | 9 ,12 | 7 ,38 | 9 ,55 | 1 ,04 | 3 ,13 |

(*Vide* Appendix, *fig.* 17).

We cannot deny that these numbers contain more than one anomaly; however, they shew very evidently that the north winds bring a very low temperature, compared with

---

* M. OTTO EISENLOHR has given a *résumé* of thirty-four years of observations made at Carlsruhe. The following table was constructed by him, by taking simply the means of the temperatures observed during each wind at Paris, Carlsruhe, London, Hamburg, and Moscow.

| CITIES. | N. | N.E. | E. | S.E. | S. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|---|
| Paris . . . | 12°,03 | 11°,76 | 13°,50 | 15°,25 | 15°,43 | 14°,93 | 13°,64 | 12°,39 |
| Carlsruhe . | 9 ,88 | 8 ,30 | 8 ,51 | 12 ,20 | 12 ,61 | 11 ,00 | 12 ,20 | 11 ,50 |
| London . . | 7 ,65 | 8 ,08 | 9 ,63 | 10 ,58 | 11 ,35 | 10 ,86 | 10 ,24 | 8 ,71 |
| Hamburg . | 8 ,00 | 7 ,63 | 8 ,38 | 9 ,50 | 10 ,00 | 10 ,13 | 9 ,25 | 8 ,38 |
| Moscow . . | 1 ,21 | 1 ,44 | 3 ,53 | 4 ,63 | 5 ,96 | 5 ,69 | 5 ,40 | 3 ,33 |

M.

that which accompanies south winds. The thermometer rises very regularly, when the wind turns from north to south. If we desire to establish the law, which expresses the relation existing between the direction of the wind and the temperature, or in other words, which are the coldest points of the horizon, and what are the corresponding degrees of temperature, we shall construct the following table:—

WINDS WITH EXTREME TEMPERATURES.

| | Coldest Wind. | Hottest Wind. | Difference. |
|---|---|---|---|
| London . . | N. | S. 12° W. | 2°,79 |
| Hamburg . | N. 30°E. | S. 16 W. | 2 ,50 |
| Halle. . . | N. 30 E. | S. 17 W. | 3 ,81 |
| Pesth. . . | N. 16 W. | S. 11 W. | 3 ,07 |
| Moscow . . | N. 19 E. | S. 42 W. | 4 ,84 |
| Stockholm . | N. 2 E. | S. 26 W. | 6 ,14 |

Thus, almost every where the coldest wind blows in a direction between north and east; the N.N.E. wind may hence be regarded as the coldest wind. Buda is a remarkable exception to this law; although the number corresponding to it is doubtless connected with some anomaly. The hottest wind, in all places, blows very nearly from the S.S.W. In proportion as we penetrate into the interior of the continent, it approaches nearer to the west.

These influences are sensible throughout the entire year; however, they are most marked in winter. The direction of the wind also depends on the seasons; for, while in winter the coldest and the hottest winds almost coincide with the N.E. and the S.W. we find in summer that they are the N.N.W. and the S.E.

Like as there exists a diurnal variation in the quantity of vapour dependent on the rotation of winds discovered by M. **Dove**, so does there exist an analogous thermometric variation. The following table contains the results of observations made by myself at Halle; I chose the hours of morning and afternoon, when the temperature is equal to the mean of the different months; and the hours of two and three o'clock, which are those of the diurnal *maximum*. The signs + and — indicate that the quantities found are above or below the mean of the whole of the observations. The last line, marked *variation*, gives the difference between the means of three observations made in the morning and three made in the evening. The sign + indicates that the thermometer rises, the sign — that it falls.*

---

* During the winter of the arctic polar regions, the sun being below the horizon, and no longer heating the air within any great distance of the station where the observations are being made, it is of very little consequence, in estimating the temperature of any particular wind, to know whether it comes from the equator or from the pole; but, on the other hand, it is of great importance to be able to say whether the wind blows from the open sea or from the interior of countries. We here give the thermometric card of winds at Bosekop (lat. 69° 58′), during the period of the sun's absence, that is, from November 15, to February 1 :—

TEMPERATURES FOR THE DIFFERENT WINDS AT BOSEKOP.

| | |
|---|---|
| N. | − 5°,36 |
| N.E. | − 6 ,92 |
| E. | −10 ,35 |
| S.E. | −11 ,15 |
| S. | − 5 ,69 |
| S.W. | − 1 ,68 |
| W. | − 2 ,28 |
| N.W. | − 4 ,58 |
| Calm. | − 6 ,92 |

The arrangement of seas and continents around the North Cape, and the temperature of the sea, which is much higher in winter than that of the earth, explain the anomalies presented by the preceding table.

The passage of the land-breeze into the sea-breeze brings about rapid changes in the temperature. At the moment when the wind changes, our observations shew that an interval of six hours is sufficient to obtain a change of four degrees one way or other in the temperature.

It is probable that an accidental cold pole is then formed in the interior of Lapland, doubtless situated at the S.E. of the North Cape; and this explains the predominance of S.E. winds in Finmark, during the winter of this country.

These interesting results are extracted from the immense meteorological registers of the hybernating members of the Commission of the North, by one of them, M. A. Bravais.—M.

DIFFERENCES BETWEEN THE MEAN HOURLY TEMPERATURES FOR ANY ONE WIND, AND THESE SAME TEMPERATURES FOR THE DIFFERENT WINDS, AT HALLE.

| HOURS. | N. | N.E. | E. | S.E. | S. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|---|
| 8 morn. | −1°,26 | −2°,37 | −2°,00 | −0°,50 | +1°,00 | +1°,20 | +1°,06 | −0°,86 |
| 9 ,, | −1 ,50 | −2 ,37 | −1 ,80 | +0 ,01 | +1 ,21 | +1 ,27 | +0 ,98 | −1 ,26 |
| 10 ,, | −1 ,62 | −2 ,39 | −1 ,60 | +0 ,37 | +1 ,50 | +1 ,31 | +0 ,86 | −1 ,48 |
| 2 even. | −1 ,92 | −2 ,23 | −1 ,11 | +1 ,25 | +2 ,15 | +1 ,23 | +0 ,34 | −2 ,19 |
| 3 ,, | −1 ,78 | −2 ,14 | −1 ,05 | +1 ,28 | +2 ,21 | +1 ,25 | +0 ,28 | −2 ,25 |
| 7 ,, | −1 ,62 | −1 ,93 | −1 ,24 | +0 ,86 | +1 ,84 | +1 ,21 | +0 ,31 | −1 ,92 |
| 8 ,, | −1 ,66 | −1 ,94 | −1 ,29 | +0 ,62 | +1 ,79 | +1 ,22 | +0 ,34 | −1 ,78 |
| 9 ,, | −1 ,48 | −1 ,95 | −1 ,35 | +0 ,52 | +1 ,71 | +1 ,26 | +0 ,39 | −1 ,68 |
| Variation. | −0°,13 | +0°,13 | +0°,51 | +0°,50 | +0°,54 | −0°,03 | −1°,62 | −0°,59 |

(*Vide* Appendix, *fig.* 18).

If we confine ourselves to comparing the degrees of this table, that are observed in the morning and evening, with the hours of the mean temperature of the day, we shall find that the thermometer still falls a little during the north wind; for, while the wind passes regularly from the north to the N.E., it is only at the N.N.E. that it comes from the coldest point of the horizon: the temperature, therefore, always falls until it blows in this direction. With the N.E. the thermometer rises, because the wind is tending to turn to the east, which is not so cold, until it blows from a point that is intermediate between the south and the S.W., a point from which the hottest wind comes. The thermometer is then stationary; but, if it passes to the west or N.W., it comes from colder countries, and the consequent diminutions of temperature are observed in the course of the day.

The facts that we have related, prove that the same law occurs in the greater portion of Europe. The cause is easy of comprehension: the winds preserve a part of the properties that they have brought from the countries they have traversed; therefore it is that the north are colder than the south winds. But we shall see presently that the coldest countries are not situated at the north, but at the N.E. or the N.W. However, we must pay attention to the position which the places occupy in Europe; for while, during winter, the S.W. winds bring us a moist and warm air, that is opposed to the cooling of the earth, their temperature must be higher than that of the south continental winds, which often favour radiation. Inversely, east winds contain less of the vapour of water, and the temperature is lowered by the cold due to evaporation.*

All that precedes is a further confirmation of this truth, that in Meteorology no phenomena is isolated; all act and react on each other. Scarcely does the S.W. wind blow in our countries than it acts on the temperature, not only by its heat, but also by the vapours that it brings and the state of sky which results from them. In winter, the moist west winds are remarkably warm, because they cover the sky with clouds, and thus oppose terrestrial radiation; in summer they are fresher, for they prevent the rays of the sun from reaching the earth. Thus in winter the coldest wind blows from the N.E.; in summer, from the N.W. The warmest wind in summer is the S.E.; in winter, the S.W.

---

* Since printing his *Course on Meteorology*, M. KAEMTZ has published a memoir on the relations that exist between temperature, pressure, and the direction of the wind. This work appeared in M. SCHUMACHER's *Annuaire* for 1841. He shews that, under the influence of certain winds, there exist *temporary poles of cold*. Thus on January 29 and February 4, 1837, there was an anomalous distribution of temperature in Europe; the cold pole being in the neighbourhood of Konigsberg, when the temperature was 6°,30 below the mean of January. The following table, in the first column, presents the mean temperature of this period of five days, and in the second

Another phenomenon is consequent on the preceding. If in the above table we look first for the laws of diurnal va-

column the number of degrees which this mean was above (+) or below (−) the mean of January:—

| CITIES. | MEAN TEMPERATURES. | DIFFERENCES according to the Mean of January. |
|---|---|---|
| Stutgard . | + 0°,30 | + 2°,27 |
| Vienna . . | − 3 ,32 | − 0 ,65 |
| Prague . . | − 1 ,59 | + 1 ,79 |
| Halle . . . | − 2 ,14 | + 0 ,07 |
| Berlin . . | − 4 ,09 | − 1 ,80 |
| Stettin . . | − 5 ,55 | − 2 ,62 |
| Dantzic . . | − 8 ,71 | − 4 ,45 |
| Konigsberg | −11 ,07 | − 6 ,30 |
| Memel . . | −11 ,20 | − 6 ,24 |
| Stockholm . | − 6 ,81 | − 2 ,04 |
| Petersburg . | − 7 ,74 | + 2 ,10 |
| Warsaw . . | −10 ,80 | − 4 ,93 |
| Cracow . . | −10 ,51 | − 5 ,39 |
| Odessa . . | − 9 ,54 | − 7 ,04 |

The position of these poles is intimately connected with the direction of the wind; and, by combining a great number of observations, M. KAEMTZ found that, in winter, when the east wind is blowing at Halle, the temperature of all continental Europe is above the mean, and the pole of cold is in the neighbourhood of Warsaw. It then occupies the middle of an elliptic surface, containing the cities of Konigsberg, Dantzic, Berlin, Dresden, Breslau, Cracow, Minsk, and Wilna. Halle, where the author made his observations, is found on the limit of this zone. In this region the temperature is at about 5° below the mean of this portion of the year. In a second zone, concentric with the first, in which are contained the towns of Riga, Hamburg, Hanover, Prague, Lemberg, Kiou, and Smolensk, the temperature is 4° below the mean. In a third zone, in which we observe the towns of Revel, Gottenburg, Amsterdam, Brussels, Stutgard, Munich, Vienna, Pesth, Odessa, Charkow, Moscow, and Novogorod, the temperature is maintained at 3° below the mean. A very narrow zone, comprising Petersburg, Helsingfors, Stockholm, Christiania, London, Lille, Rouen, Paris, Strasburg, Basle, Trieste, Bucharest, the Crimea, enjoys a temperature which is only 2° below the mean. In a fourth zone, comprising Shetland, Edinburgh, Manchester, the centre of France, Lyons, Milan, Venice, and Belgrade, the temperature is not more than 1° below the mean. Finally, a region, very irregularly bounded, containing the Hebrides, Ireland, the county of Cornwall, Brittany, Nantes, Bordeaux, Toulouse, Barcelona, Marseilles, Genoa, Corsica, Florence, Rome, Naples, and Ragusa, enjoys a temperature which is equal to the mean of these different points. Thus, as we see, in going from Warsaw as a centre, and directing ourselves along any radius, we find temperatures that increase as we go toward the north or toward the east, as well as when we go toward the south and toward the west.

These poles are not permanent, but are continually displaced, according to the changes in the direction of the wind and variations in atmospheric pressure. Thus, from January 12 to 19, 1838, this pole was at Halle.

When the winds blow from the west, the temperature of continental Europe is below the mean of the month, and a pole of *heat* situated at the east of Halle, and in the centre of a zone, comprising the towns of Memel, Warsaw, Dantzic, and Konigsberg, replaces the pole of cold of the east winds.—M.

riation of temperature, according to the different winds; if we then subtract the hourly temperature of the mean of two and three o'clock, and compare these differences with those of the temperatures of 8, 9 and 10 A. M., and 7, 8 and 9 P. M., mutually compared, we shall not find any connexion between these three groups. Thus, with the S.E. wind, we find an increase of heat from morning till evening; it is very considerable at the moment of *maximum* diurnal heat; and from this moment the temperature goes on rising until evening. The reverse occurs with the N.W.; for the difference from the mean diminishes from morning till mid-day, and then increases. This fact, which at first sight seems to contradict what we have said respecting the influence of the rotation of the wind, is intimately connected with the state of the sky: for, with the S.E., the sky is generally clearer; with the N.W., on the contrary, it is generally more clouded than in the mean state. In the former case there is a more energetic influence; in the latter, a less marked effect on the part of the sun; an effect that is felt the most at the period of the *maximum* of the diurnal temperature. This fact, that the coldest wind comes from the countries of the north, the hottest, on the contrary, from the sea, occurs also on the east coasts of the continents, as is proved by observations made at Cambridge in Massachusetts, and at Pekin in China.

What we have hitherto said is sufficient to enable us to recognise the cause of the anomalies presented by the annual range of temperature. The months during which the south winds prevail will have a different temperature from that of the same months during a year when north winds have predominated. If winds have blown long from the west, and are replaced by those of the east, a corresponding change is observed in the temperature. But, it might be said, the greatest difference between the hottest and the coldest wind is not 10°, and yet the hottest and the coldest day of each month differ by a much greater quantity; it is, therefore, impossible that the causes mentioned above can explain this phenomenon. First, we must not forget that winds have not always their normal temperature; then that there is frequently no prevailing wind; local differences of temperature cause the vane in one locality to be directed toward the south, while, in a place not far distant from the former, it is turned toward the north. If the temperature of these two points approaches the mean, and one is ranged in the column N., and the other in the column S., each of these figures will be somewhat removed from the truth. Moreover, the temperature that accompanies each wind is compounded of its proper heat, and of that of the air which was at rest before it commenced blowing. Suppose that in winter we have had a succession of very warm west winds, and that the wind suddenly passes to the east, there will be a fall of temperature; but the heat of the ground and that of the air will concur in making the thermometer rise, so that it will indicate a higher temperature than that peculiar to the east wind.

These anomalies are very frequently further exaggerated by the state of the sky, especially in winter, when phenomena are observed which are in contradiction to what we have said respecting the influence of winds: this principally happens when continued S.W. winds sustain the mildness of the temperature. With west winds, whether the sky be serene or cloudy, if the wind passes to the north or N.E., thick clouds oppose terrestrial radiation; the thermometer does not then fall under the influence of change of wind; it remains stationary, and sometimes it even rises. When the barometer falls rapidly, and the wind passes suddenly to the S.E. or the south, the sky becomes clear; and, instead of heat, an intense cold follows. The high temperature of the wind is manifested in the upper regions of the atmosphere; by dissolving the clouds, it favours terrestrial radiation. But the heat is soon propagated to the lower strata of the air, and finally to the ground; the sky is covered with *cirrus* and *cumulus*, and twenty-four hours afterwards the thaw commences. The succession of these phenomena may be observed every winter; and it follows that the north wind is attended by too high a thermometric state, the south wind by too low a temperature.[*]

---

[*] In the *Memoirs of the Academy of Berlin*, for 1840 and 1841, M. Dove published a large work, entitled, *Ueber die nicht periodischen Aenderungen der Temperaturvertheilung auf der Oberflaeche der Erde*. It embraces the interval comprised between 1782 and 1839. The places situated in the tropical, temperate, and cold parts of Europe and America, of which he gives the thermometric series, are 191 in number.

The following are the results to which M. Dove was led:—

1st. The earth receives the same quantity of heat each year, distributed over its surface differently for each year.

2d. The tropical atmosphere of the Indian seas does not appear to have a marked influence over the atmospheric modifications of Europe.

3d. The thermometric conditions of the region of trade-winds of the Atlantic Ocean are very closely connected with the meteorological changes of the temperate zone contiguous to it.

4th. The colds of winter are generally propagated from north to south; unusual heats march in an opposite direction.

5th. Analogous atmospheric states are more frequently found under the same meridian than under the same parallel. Thus, in December 1829, the cold was intense at Berlin and Paris, sensible at Kasan, very moderate at Irkutzk, while an unusual heat prevailed in North America. The winter of 1794–5, celebrated by the conquest of Holland, and that of 1809, so severe

**EXTREMES OF TEMPERATURE OBSERVED IN DIFFERENT PLACES.**—Man is able to support extreme degrees of temperature, which no animal can resist. In the burning deserts of Africa, and in the frozen regions of the pole, observations have been made on this subject. We may, therefore, inquire what are the extreme degrees that have been noted. An indication of this kind is always approximative; for, on the one hand, the observer does not always consult the instrument at the moment when it attains its *maximum* or *minimum;* and, on the other, a host of little circumstances, apparently indifferent, exercise a great influence over the result. A greater or less proximity to the ground, or a little dust on the bulb of the thermometer, is sufficient to change its indications. Can we then be astonished, after this, that observers have obtained numbers differing so much from each other!

Thus we read that, in the polar regions, the mercury has often remained frozen for whole weeks; and as it solidifies at the temperature of —39°,5, we must conclude that, during this period the temperature was below —40°. The following table contains the lowest and the highest temperature observed in different places.*

---

in Europe, were very mild in America. On the contrary, the winter of 1790–1, which was hot in Europe, was very cold in America. The month of January 1837, mild in Europe, presents a very low mean in America. The Danes have observed that the unusually moderate winters of Iceland correspond to intense cold at Copenhagen.

6th. In equal latitudes, the mean variation of temperature is less in Europe than in America.—M.

* I have interpolated into these tables extreme temperatures, gathered from the *Comptes rendus de l'Académie des Sciences*, the *Annales de Chimie et de Physique*, the *Meteorological Registers* of the Commission of the North, the *Résumé of Meteorological Observations made at Milan from* 1763 *to* 1840, and the *Table of the Climate of Italy*, by M. SCHOUW.

The towns whose extreme temperatures I have interpolated are, for the table of *minima* temperature, Athens, Florence, Rome, Pisa, Camajore, Lucca, Nice, Milan, Montpellier, Bologna, Turin, Charlestown, Paris, Bosekop, Washington, Montreal, and Bangor. I have added to that of *maxima* temperature the following towns: Palermo, Pisa, Cagliari, Naples, Paris, Catania, Lucca, Rome, Pavia, Bologna, Turin, Verona, Milan, and Nice.—M.

## MINIMA OF TEMPERATURE OBSERVED IN DIFFERENT PLACES.

| PLACES. | LATITUDE. | MINIMA TEMPERATURES. | OBSERVERS. |
|---|---|---|---|
| Surinam . . . . . . | 5°38′ S. | 21°,3 | " |
| Pondicherry . . . . | 11 42 N. | 21 ,6 | Cossigny. |
| Madras . . . . . . . | 13 45 | 17 ,3 | " |
| Martinique . . . . | 14 35 | 17 ,1 | Chanvalon. |
| Cairo . . . . . . . | 30 2 | 9 ,1 | Niebuhr. |
| Charlestown . . . . | 32 40 | —17 ,8 | *Ann. de Chim.* |
| Bagdad . . . . . . | 33 21 | — 5 ,0 | Beauchamp. |
| Cape of Good Hope . | 33 55 S. | 5 ,6 | La Caille. |
| Aleppo . . . . . . . | 36 12 N. | 4 ,4 | Russel. |
| Athens . . . . . . . | 37 58 | — 4 ,0 | Peytier. |
| Washington . . . . | 38 53 | —26 ,6 | *Ann. de Chim.* |
| Rome . . . . . . . | 41 54 | — 5 ,9 | Schouw. |
| Cambridge (Massachus.) | 42 25 | —24 ,4 | Williams. |
| Padua . . . . . . . | 43 18 | —15 ,6 | Toaldo. |
| Montpellier . . . . | 43 36 | —16 ,1 | Fuster. |
| Nice . . . . . . . . | 43 42 | — 9 ,6 | Schouw. |
| Pisa . . . . . . . . | 43 43 | — 6 ,3 | *Id.* |
| Lucca . . . . . . . | 43 51 | — 8 ,9 | *Id.* |
| Florence . . . . . . | 43 46 | — 5 ,3 | Peytier. |
| Camajore . . . . . . | 43 55 | — 5 ,7 | Schouw. |
| Bologna . . . . . . | 44 30 | —16 ,9 | *Id.* |
| Bangor (U. S.) . . . | 45 0 | —40 ,0 | *Ann. de Chim.* |
| Turin . . . . . . . | 45 4 | —17 ,8 | Schouw. |
| Milan . . . . . . . | 45 28 | —15 ,0 | Observatory. |
| Montreal . . . . . . | 45 30 | —37 ,2 | *Ann. de Chim.* |
| Paris . . . . . . . | 48 50 | —23 ,1 | Arago. |
| Prague . . . . . . . | 50 5 | —27 ,5 | Strnadt. |
| London . . . . . . . | 51 31 | —11 ,4 | Royal Society. |
| Cumberland House . . | 54 0 | —42 ,2 | Franklin. |
| Copenhagen . . . . | 55 41 | —17 ,8 | Bugge. |
| Moscow . . . . . . | 55 45 | —38 ,8 | Stritter. |
| Stockholm . . . . . | 59 20 | —26 ,9 | Nicander. |
| Petersburg . . . . . | 59 56 | —34 ,0 | Euler. |
| Fort Enterprise . . . | 64 30 | —49 ,7 | Franklin. |
| Winter Island . . . | 66 11 | —38 ,6 | Parry. |
| Ingloolik Isle . . . | 69 20 | —42 ,8 | *Id.* |
| Fort Reliance . . . | 62 46 | —56 ,7 | Back. |
| Bosekep (Lapland) . . | 69 58 | —23 ,5 | Com. of North. |
| Port Elizabeth . . . | 69 59 | —50 ,8 | Ross. |

## MAXIMA OF TEMPERATURE OBSERVED IN DIFFERENT PLACES.

| PLACES. | LATITUDE. | MAXIMA TEMPERATURES. | OBSERVERS. |
|---|---|---|---|
| Surinam . . . . . . | 5°38′ N. | 32°,3 | Humboldt. |
| Pondicherry . . . . | 11 55 | 44 ,7 | Le Gentil. |
| Madras . . . . . . . | 13 45 | 40 ,0 | Roxburgh. |
| Beit-el-Fakih . . . | 14 31 | 38 ,1 | Niebuhr. |
| Martinique . . . . | 14 35 | 35 ,0 | Chanvalon. |
| Vera-Cruz . . . . | 19 12 | 35 ,6 | Orta. |
| Philœ (Egypt) . . . | 24 0 | 43 ,1 | Coutelle. |
| Esné (Egypt) . . . | 25 15 | 47 ,4 | Burckhardt. |
| Cairo . . . . . . . | 30 2 | 40 ,2 | Coutelle. |
| Bassora (Mesopotamia) | 30 45 | 45 ,3 | Beauchamp. |
| Catania . , . . . . . | 37 30 | 38 ,3 | Schouw. |
| Palermo . . . . . | 38 8 | 39 ,7 | *Id.* |
| Naples . . . . . | 40 52 | 38 ,7 | Pilla. |
| Rome . . . . . . . | 41 54 | 38 ,0 | Schouw. |
| Pavia . . . . . . . | 45 11 | 37 ,5 | *Id.* |
| Cambridge (Massachus.) | 42 25 | 33 ,5 | Williams. |
| Padua . . . . . . . | 43 18 | 36 ,3 | Toaldo. |
| Pisa . . . . . . . . | 43 36 | 39 ,4 | Schouw. |
| Nice . . . . . . . . | 43 42 | 33 ,4 | *Id.* |
| Cagliari . . . . . | 43 43 | 39 ,1 | *Id.* |
| Lucca . . . . . . . | 43 51 | 38 ,1 | *Id.* |
| Bologna . . . . . | 44 30 | 37 ,1 | *Id.* |
| Turin . . . . . . . | 45 4 | 36 ,9 | *Id.* |
| Verona . . . . . . . | 45 26 | 35 ,6 | *Id.* |
| Milan . . . . . . . | 45 28 | 34 ,4 | Observatory. |
| Paris . . . . . . . | 48 50 | 38 ,4 | Arago. |
| Prague . . . . . . . | 50 5 | 35 ,4 | Strnadt. |
| North America . . . | 55 0 | 30 ,5 | Franklin. |
| Copenhagen . . . . | 55 41 | 33 ,7 | Bugge. |
| Moscow . . . . . . | 55 45 | 32 ,0 | Stritter. |
| Nain (Labrador) . . | 57 0 | 27 ,8 | De la Trobe. |
| Stockholm . . . . | 59 20 | 34 ,4 | Ronnow. |
| Petersburg . . . . | 59 56 | 33 ,4 | Euler. |
| Eyafiord (Iceland) . . | 66 30 | 20 ,9 | Van Scheels. |
| Melville Isle . . . . | 74 45 | 15 ,6 | Parry. |
| Port Elizabeth . . . | 69 59 | 16 ,7 | Ross. |
| North America . . . | 65 30 | 20 ,0 | Back. |

Although these tables are far from being complete, they yet give rise to several interesting considerations. The highest temperature, 47°,4, was recorded by **Burckhardt**, at Esné, in Upper Egypt, during a *chamsin*. The lowest, —56°,7, was experienced by Captain **Back** in North America, when he traversed this continent for the purpose of joining Captain **Ross**. The difference is 104°. Man can, therefore, support temperatures differing from each other by 104°, that is to say, more than the temperature of boiling water differs from that of melting ice.

We also recognise that the variations between the higher temperatures are less than between the lower. Between the highest temperatures of Esné, 47°,4, and Melville Isle, 15°,6, there is a difference of 31°,8; whilst the lowest temperature at Pondicherry, 21°,6, and that of Fort Reliance, —56°,7, differ by 78°,3, that is to say, by double. The mean, therefore, in high latitudes, is reduced by the colds of winter.

The extremes occur in the interior of continents; the difference is less on the coasts. No voyager has observed in the open sea a higher temperature than 31°; the greater number are below 30°, and consequently lower than those which have been recorded at Petersburg, In the interior of continents, the *minima* are much below those which are found on the coasts. Compare Cairo with Bagdad and the Cape of Good Hope, and London with Prague, and you will see that these assertions are not without foundation.

**MARINE AND CONTINENTAL CLIMATES.**—The capacity of water for heat, and the great quantity of caloric that becomes free, when vapours are precipitated, and latent, when liquids pass into the aëriform state, are the causes to which must be attributed the constantly increasing difference between the temperature of summer and that of winter, as we leave the coasts to penetrate into the interior of continents. This difference increases also when we leave the tropics to approach the pole; we must, therefore, choose points situated very nearly under the same latitude. In marine climates the means of winter and summer differ but little; but, as we advance into the interior of a continent, they depart from each other. The following tables contain some of these determinations :—

SUMMER AND WINTER MEANS IN THE BRITISH ISLES.

| PLACES. | WINTER. | SUMMER. | DIFFERENCE |
|---|---|---|---|
| Feroe . . . . . | 3°,90 | 11°,60 | 6°,70 |
| Unst Isle (Shetland) | 4 ,05 | 11 ,92 | 7 ,87 |
| Isle of Man . . . | 5 ,59 | 15 ,08 | 9 ,49 |
| Edinburgh . . . | 3 ,47 | 14 ,07 | 10 ,60 |
| Aberdeen . . . . | 3 ,39 | 14 ,57 | 11 ,18 |
| Kinfauns Castle. . | 2 ,94 | 14 ,17 | 11 ,23 |
| London . . . . | 3 ,22 | 16 ,75 | 13 ,53 |
| Lancaster . . . . | 3 ,58 | 15 ,32 | 11 ,74 |
| Kendal . . . . | 2 ,03 | 14 ,32 | 12 ,29 |
| Penzance . . . . | 7 ,04 | 15 ,83 | 8 ,79 |
| Helston . . . . | 6 ,19 | 16 ,00 | 8 ,81 |

In all these places, the mean temperature of winter is above the freezing point. Even in the Shetland and the Feroe Islands, at 62° of north latitude, the winter mean is higher than that of London; but the summers are colder, and the difference between the two seasons is scarcely 8°. This trifling difference is also shewn at Penzance and at Helston, towns on the Cornish coast; whilst London, situated in the east part of the island, presents a difference of even 13°,5.

The S.W. winds, so common in England during the winter, bring with them the moist and warm air of the Atlantic Ocean. As these vapours are precipitated they disengage heat, and they also oppose radiation from the earth. And hence the mildness of English winters is explained by their extreme humidity. On the Azores, and along their coasts, where the wind accumulates vapours, the winter will be still milder than in places situated, like London, on the east coast of England, whither the winds do not arrive until after they have lost a great portion of the humidity with which they were charged. But in summer the same cause reduces their temperature; as we may be convinced of by comparing Helston and Penzance with London. These two truths become more and more evident, in proportion as we penetrate into the interior of the continents.

### SUMMER AND WINTER MEANS IN FRANCE AND IN HOLLAND.

| PLACES. | WINTER. | SUMMER. | DIFFERENCE. |
|---|---|---|---|
| Amsterdam . . . | 2°,67 | 18°,79 | 16°,12 |
| Middleburg . . . | 1 ,92 | 16 ,92 | 15 ,00 |
| Maëstricht . . . | 2 ,84 | 18 ,12 | 15 ,28 |
| Brussels . . . . | 2 ,56 | 19 ,04 | 16 ,45 |
| Franecker . . . | 2 ,56 | 19 ,57 | 17 ,01 |
| The Hague . . . | 3 ,46 | 18 ,63 | 15 ,17 |
| Saint-Malo . . . | 5 ,67 | 18 ,90 | 13 ,23 |
| Dunkirk . . . . | 3 ,56 | 17 ,68 | 14 ,12 |
| La Rochelle . . . | 4 ,78 | 19 ,22 | 14 ,44 |
| Paris . . . . . | 3 ,59 | 18 ,01 | 14 ,42 |
| Montmorency . . | 3 ,21 | 18 ,96 | 15 ,75 |

These different cities enjoy a mean winter temperature of about 3°, like that of England, Penzance and Helston excepted. But the summer mean is about 18°. This is an effect of the continental east winds, which maintain the serenity of the sky. The difference between summer and winter, which, in England, was only 13°, is raised to 15°.

### SUMMER AND WINTER MEANS IN GERMANY.

| PLACES. | WINTER. | SUMMER. | DIFFERENCE. |
|---|---|---|---|
| Dantzic . . . . | —1°,11 | 16°,62 | 17°,83 |
| Baireuth . . . . | —1 ,20 | 16 ,03 | 17 ,23 |
| Berlin . . . . . | —1 ,01 | 17 ,18 | 18 ,19 |
| Augsburg . . . . | —1 ,08 | 16 ,80 | 17 ,88 |
| Apenrade . . . . | 0 ,73 | 16 ,21 | 15 ,48 |
| Dresden . . . . | —1 ,20 | 17 ,21 | 18 ,41 |
| Cuxhaven . . . . | 0 ,51 | 16 ,76 | 16 ,25 |
| Tubingue . . . . | —0 ,02 | 17 ,01 | 17 ,03 |
| Sagan . . . . . | —2 ,65 | 18 ,20 | 20 ,85 |
| Munich . . . . | 0 ,12 | 17 ,96 | 17 ,84 |
| Ratisbon . . . . | —1 ,93 | 19 ,68 | 21 ,61 |
| Hamburg . . . . | 0 ,40 | 18 ,96 | 18 ,56 |
| Lunenburg . . . | 0 ,95 | 17 ,25 | 16 ,30 |
| Prague . . . . . | —0 ,44 | 19 ,93 | 20 ,37 |
| Vienna . . . . | 0 ,18 | 20 ,36 | 20 ,18 |

Although this table presents more than one anomaly, it yet shews very evidently the influence of continents. Notwithstanding the very high latitude of Cuxhaven, Lunenburg, and Apenrade, the mean of the winters is above the freezing-point. This is in consequence of the vicinity of the sea, counterbalanced, however, by the continental influences, which reduce their mean below that of the towns of England situated under the same latitude. In all other parts of Germany, the winter mean is below the freezing-point; but the summers are also hotter, as may be seen by comparing the table of England with that of Germany, keeping in view the height above the level of the sea. There results from this a greater difference between the winter and the summer; it is 16° in west Germany, in the neighbourhood of the sea, and rises as high as 20° in the east part. At Dantzic, the feeble influence of the neighbourhood of the Baltic is felt.

The more we penetrate into the interior of the continent, the colder do the winters become; and the more does the difference between winter and summer tend to increase, as the following table shews:—

WINTER AND SUMMER TEMPERATURES IN THE INTERIOR OF THE CONTINENT.

| PLACES. | WINTER. | SUMMER. | DIFFERENCE. |
|---|---|---|---|
| Petersburgh . . . | — 8°,70 | 15°,96 | 23°,66 |
| Abo. . . . . . . | — 5 ,79 | 16 ,14 | 21 ,91 |
| Moscow . . . . | —10 ,22 | 17 ,55 | 27 ,77 |
| Kasan . . . . . | —13 ,66 | 17 ,35 | 31 ,11 |
| Barnaul . . . . | —14 ,11 | 16 ,57 | 30 ,68 |
| Slatoust . . . . | —16 ,49 | 16 ,08 | 32 ,57 |
| Irkutsk . . . . | —17 ,88 | 16 ,00 | 33 ,88 |
| Jakoutsk . . . | —38 ,90 | 17 ,20 | 56 ,10 |

Whilst in England the thermometer rarely descends 10° below zero, we find in the interior of the continent, under almost equal latitudes, a mean of —10°; and it is not uncommon to see the mercury freeze at Kasan. In the interior of Siberia, it often remains solid for several weeks together. The serenity of the sky in these countries favours the radiation of the ground in winter, and its heating in summer; so that the summers are hotter than in England. The difference between the means of the two seasons, which is 23° in west Russia, is as great as 33°, and even 56°, in the interior of the empire; it is, therefore, four or five times greater than in England.

This law prevails every where. The west coast of Norway enjoys a winter relatively very mild, and the mean of which does not differ one-tenth of a degree from that of the summer. But scarcely have we traversed the crest of the Scandinavian Alps than we find a continental climate. The same relations prevail in North America. Whilst the west coast is distinguished by mild winters and cold summers, the difference of the seasons is greater in the interior; it then diminishes as we approach the Atlantic. However, it is always greater than in Europe. This is due to the predominance of west winds, which, as they traverse a great extent of land, communicate to the climate of these countries something of continental climates. Thus, in east America, the winters are colder and the summers warmer than they would be were it not for this circumstance.

**ISOCHIMENALS AND ISOTHERALS.**—If we collect into a map all the places whose hibernal mean is the same, we shall obtain curves called *isochimenal* (ἴσος, *equal;* χειμὼν, *winter*). These which pass through the points, where the summer means are equal, are called *isotherals* (ἴσος, *equal;* θέρος, *summer*). The number of observations is not yet sufficiently large to enable us to trace these curves with perfect exactitude; but they are sufficient to shew that these lines are far from coinciding with the parallels which join the places, and which are situated at the same distance from the equator; for the isochimenal lines fall toward the south, as we leave the west coast of Europe on our way toward the east; because the countries situated toward the east have much severer winters than those that are at the west. The isotherals, on the contrary, rise toward the pole as we go from west to east; and it is only in the interior of the continent that, at equal latitudes, the summer means are the same. In North America something similar is observed; for, at an equal distance from the equator, places situated west of the Alleghanis have colder winters and hotter summers than those which are on the borders of the sea.

We may easily comprehend that these climateric conditions have the greatest influence over the geographical distribution of organised beings. Many animals, especially quadrupeds, that cannot make such great migrations as birds, avoid extreme climates. If, therefore, a curve is passed through the points which limit on the north the area inhabited by these animals, this curve will almost coincide with an isochimenal. This is shewn in the chart published by M. **Ch. Ritter,** on the distribution of wild and domestic mammifera in Europe. Thus, in Sweden, the elk still lives under 65° of latitude; but, in the interior of Siberia, it does not pass the 55th degree.

The same observations apply to the distribution of vegetables on the earth; but we must carefully distinguish arborescent vegetables from those which are merely annuals, and die each year after having produced seed. Trees cannot so effectually resist the rigours of winter as perennial herbaceous vegetables; however, if their period of flowering and fructification is not long, they rise even to high latitudes along the coasts of the Atlantic, while they remain much nearer to the south in the interior of the continent. Thus, in the neighbourhood of Penzance, on the west coast of England, myrtles, *Camelia*, *Fuschia* and *Budleia*, pass the whole winter in the open air, although their fruits do not ripen in summer. The coasts of Brittany present the same phenomena. The beech (*Fagus silvatica*) extends in Norway as far as the 60th degree. On the west coast of Sweden its extreme limit is below the 58th; in Smoland, at 57°, and also on the east coast in the neighbourhood of Calmar. In Lithuania, it is between 54° and 55°; in the Carpathians, about 49°; and in the mountains of the Crimea, about 45°.* The holly (*Ilex aquifolium*), which advances even as far as Scotland and Norway, is sometimes frozen in the neighbourhood of Berlin and Halle. Several kinds of heath, alder, black poplar, lilac, ivy, mistletoe, thorn, and myrtle, have an analogous geographic distribution.

---

* The small table that follows represents the indication of the latitudinal limits of many trees in Scandinavia:—

| TREES. | LATITUDINAL LIMITS. |
|---|---|
| Beech (*Fagus silvatica*) . . . . . . . . | 60° 0′ N. |
| Hard Oak (*Quercus robur*) . . . . . . . | 61 0 |
| Fruit trees . . . . . . . . . . . . . | 63 0 |
| Hazel (*Corylus avellana*) . . . . . . . | 64 0 |
| Fir (*Abies excelsa*) . . . . . . . . . | 67 40 |
| Service tree of Fowlers (*Sorbus aucuparia*) | 70 0 |
| Wood Pine (*Pinus silvestris*) . . . . . . | |
| White Birch (*Betula alba*) . . . . . . . | 70 40 |
| Dwarf Birch (*Betula nana*) . . . . . . . | 71 0 |

For further details, see the note entitled, "On the distribution of large Vegetables along the coasts of Scandinavia, and on the north side of the Grimsell." (*Annales des Sciences Naturelles*, Oct. 1842.)—M.

Annual vegetables, and especially those of the corn tribe, act in a different manner. The hardness and rigour of the winter little concerns them; the only thing essential to them is the period during which they are developed; thus the curves that indicate their northern limits are parallel to the isotherals. In Norway, barley is cultivated in certain places situated under the 70th degree. Toward the east, its limit falls southerly; and in Siberia none of the corn tribe are found north of 60°. In France, the north limit of maize is determined by the same laws. On the borders of the Atlantic it is south of Rochelle, at 45° 30′; but on the Rhine it is between Manheim and Strasburg, at 49° of lat.

The arborescent vegetables which are not very sensible to the colds of winter, but which require hot summers, have, on the west coast of Europe, a limit dependant on the curve of the isotherals. Thus the vine is no longer cultivated with advantage on the coasts of France beyond 47° 30′. In the interior of the country it rises toward 49°, and cuts the Rhine at Coblentz at 50° 20′. In Germany, it does not pass 51°, to which it is sensibly parallel in the east of the European continent.

**MEAN TEMPERATURE OF THE EARTH.**—Before studying the distribution of heat on the surface of the globe, it is necessary to give a table of the mean temperatures of a great number of places on the earth.*

---

* We have substituted for M. KAEMTZ's table the more recent and extended one of M. MAHLMANN, who has recalculated all the means with the greatest care.[8]

This table is extracted from the third volume of the important work which M. DE HUMBOLDT has just published, on Central Asia, under the title of *Researches on Mountain Chains, and Comparative Climatology*.

In this table the seasons are those used in meteorology, namely, for winter, December, January, and February; for spring, March, April, and May; for summer, June, July, and August; for autumn, September, October, and November. The temperatures enclosed between a pair of brackets do not merit so much attention as the others. The number of years of observation is generally related to the annual mean. The heights above the level of the sea are in metres, as in the whole course of the work.—M.

---

[8] *Vide* Note *g*, Appendix, No. II.

# MEAN TEMPERATURE OF THREE HUNDRED AND FIVE PLACES,

ACCORDING TO **Mahlmann.**

| PLACES. | LATITUDE. | LONGITUDE from Paris. | Height above the Sea. | MEAN TEMPERATURE. | | | | | | | Number of Years of Observation. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Winter. | Spring. | Summer. | Autumn. | Coldest Month. | Hottest Month. | |
| Melville Isle.......... | 74° 47′ N | 113° 8′ W | — | — 18,7 | — 33,5 | — 19,5 | 2,8 | — 18,0 | — 35,8 Feb. | 5,8 July. | 1 |
| Ingloolik Isle ........ | 69 19 | 83 23 | — | — 16,6 | — 29,7 | — 16,8 | 1,7 | — 14,0 | — 33,5 Dec. | 3,9 ,, | 1 |
| Ustjansk ........ ... | 70 55 | 136 4 E | — | — 16,6 | — 38,4 | — 14,7 | 9,2 | — 23,9 | — 40,3 Jan. | 13,7 ,, | 1-3 |
| Port Bowen.......... | 73 14 | 91 15 W | — | — 15,8 | — 31,7 | — 21,0 | 2,7 | — 11,9 | — 33,8 ,, | 3,8 ,, | 1 |
| Boothia Felix ........ | 70 2 | 94 10 | — | — 15,7 | — 33,2 | — 20,7 | 3,4 | — 12,4 | — 35,6 Feb. | 5,1 ,, | 2-3 |
| Winter Island ........ | 66 11 | 85 31 | — | — 14,0 | — 29,1 | — 14,2 | 1,7 | — 8,0 | — 31,1 ,, | 2,7 Aug. | 1 |
| Fort Enterprise ....... | 64 28 | 115 26 | 253 | .. | — 30,9 | — 13,2 | .. | — 7,3 | — 34,2 Dec. | ...... | 1 |
| Jakoutsk ............ | 62 1 | 126 47 E | 117 | — 9,7 | — 38,9 | — 8,3 | 17,2 | — 6,6 | — 40,5 Feb. | 20,3 July. | many |
| Nova Zembla ...... | 70 37 | 55 27 | — | — 9,5 | — 16,0 | — 15,9 | 2,0 | — 7,9 | — 23,7 Mar. | 3,1 Aug. | 1 |
| | 73 0 | 51 30 | — | — 8,4 | — 19,0 | — 11,8 | 3,6 | — 6,3 | — 22,1 Feb. | 5,0 ,, | 1 |
| Fort Franklin ........ | 65 12 | 125 33 W | 68 | — 8,2 | — 27,2 | — 10,0 | 10,2 | — 6,0 | — 30,2 Jan. | 11,2 July. | 1-2 |
| Fort Reliance ........ | 62 46 | 109 1 | 107 | .. | — 29,1 | — 10,7 | .. | .. | — 31,7 ,, | ...... | 1-2 |
| Spitzbergen .......... | 80 — | 14 — E | — | .. | .. | .. | 3,4 | .. | .... | 4,6 July. | 1 |
| Sea of Greenland...... | 78 — | 7 — | — | (— 7,7) | .. | — 9,4 | 1,4 | .. | .... | 2,8 ,, | 6-12 |
| Nova Zembla ........ | 73 57 | 52 28 | — | — 6,9 | — 14,1 | — 10,3 | 4,2 | — 7,4 | — 17,2 Nov. | 5,3 ,, | 1 |
| Sea of Greenland.... | 72 — | 21 — W | — | .. | .. | .. | 1,4 | .. | .... | 1,8 Aug. | 1 |
| | 80 — | 8 — E | — | .. | .. | .. | 1,4 | .. | .... | 2,2 July. | 1 |
| Nain (Labrador)...... | 57 10 | 64 10 W | — | — 3,6 | — 18,5 | — 5,8 | 7,6 | 2,2 | — 20,9 Feb. | 9,3 Aug. | 3 |
| Fort Simpson ........ | 62 11 | 123 52 | 78 | — 3,5 | — 23,5 | — 2,8 | 15,1 | — 2,8 | — 24,8 Jan. | 17,5 June. | 1-3 |
| Enontekis............ | 68 40 | 20 0 E | 435 | — 2,7 | — 17,0 | — 3,9 | 12,6 | — 2,7 | — 17,8 ,, | 14,5 July. | 4 |
| Casino on Etna ....... | 37 6 | 12 41 | 2990 | — 1,3 | — 8,6 | — 2,7 | 6,6 | — 0,6 | ,, | ,, | ,, |

| PLACES. | LATITUDE. | LONGITUDE from Paris. | Height above the Sea. | MEAN TEMPERATURE. | | | | | | | Number of Years of Observation. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Winter. | Spring. | Summer. | Autumn. | Coldest Month. | Hottest Month. | |
| St. Bernard.......... | 45° 50′ N | 4° 45′ E | 4843 | —1,0 | — 7,8 | —2,0 | 6,1 | —0,4 | — 8,7 Jan. | 6,8 July. | 21 |
| St. Gothard.......... | 46 33 | 6 14 | 2095 | —0,8 | — 7,6 | —2,7 | 6,7 | 0,0 | — 8,4 Feb. | 7,5 Aug. | 10-11 |
| Slatoust .... ....... | 55 8 | 57 8 | 322 | —0,7 | —16,6 | 0,8 | 15,2 | 0,2 | —18,0 ,, | 15,8 July. | 4 |
| Haapakyla ........... | 66 27 | 21 27 | .. | —0,5 | —14,2 | —2,3 | 14,4 | 0,1 | —15,9 Jan. | 16,4 ,, | 30 |
| Irkoutsk ............ | 52 16 | 101 58 | 409 | —0,2 | —17,6 | 4,5 | 15,9 | —2,2 | —19,5 ,, | 17,5 ,, | 10 |
| Eyafiordur .......... | 65 40 | 22 0 W | — | 0,0 | — 6,2 | —2,2 | 7,7 | 1,4 | — 7,6 Dec. | 8,3 ,, | 2 |
| North Cape.......... | 71 10 | 23 30 E | — | 0,1 | — 4,6 | —1,3 | 6,4 | —0,1 | — 5,5 Jan. | 8,1 ,, | 1 |
| Uleaborg ............ | 65 3 | 23 6 | — | 0,7 | —11,1 | —2,7 | 14,3 | —2,2 | —13,5 ,, | 16,4 ,, | 6 |
| Umeo ............... | 63 50 | 17 56 | — | 2,1 | —10,2 | 0,6 | 14,1 | 3,1 | —11,3 ,, | 16,2 ,, | 23 |
| Kazan ............... | 55 48 | 46 47 | 58 | 2,2 | —14,3 | 2,6 | 17,0 | 2,8 | —16,5 ,, | 18,4 ,, | 12 |
| Hernoesand.......... | 62 38 | 15 33 | — | 2,3 | — 8,1 | 0,2 | 13,4 | 3,6 | — 8,7 ,, | 14,8 ,, | 28 |
| Petersburg .......... | 59 56 | 27 59 | — | 3,5 | — 8,4 | 1,7 | 15,7 | 4,7 | —10,3 ,, | 16,9 ,, | 25 |
| St. John's .......... | 47 34 | 54 58 W | 43 | 3,5 | — 4,9 | 0,2 | 12,2 | 6,5 | — 6,2 Feb. | 14,4 Aug. | 5 |
| Moscow ............. | 55 45 | 35 18 E | 146 | 3,6 | —10,3 | 6,3 | 16,8 | 1,6 | —10,6 Jan. | 17,6 July. | 25 |
| Reikiavig............ | 64 8 | 24 16 W | — | 4,0 | — 1,6 | 2,4 | 12,0 | 3,3 | — 2,1 Feb. | 13,5 ,, | 14 |
| Iloulouk ............ | 53 52 | 168 45 | .. | 4,1 | 0,1 | 2,0 | 10,5 | 3,7 | — 1,1 Dec. | 13,4 Aug. | 1-2 |
| Falun ............... | 60 39 | 13 25 E | 121 | 4,4 | — 5,5 | 3,2 | 14,6 | 5,3 | — 7,4 Jan. | 15,8 July. | 9 |
| Abo ................. | 60 27 | 19 57 | .. | 4,6 | — 5,4 | 2,6 | 15,7 | 5,4 | — 6,1 ,, | 17,6 ,, | 17 |
| Tambow ............ | 52 47 | 39 8 | 62 | 5,1 | — 8,7 | .. | 18,4 | .. | —12,7 ,, | 20,0 ,, | 12 |
| Port Famine ......... | 53 38 S | 73 14 W | — | .. | 1,1 | .. | .. | 5,7 | 0,6 ,, | .... | 1 |
| Upsal .... ......... | 59 52 N | 15 18 E | -- | { 5,2 | — 3,7 | 3,4 | 15,1 | 6,2 | — 4,9 ,, | 16,3 July. | 27 |
| | | | | { 5,3 | .. | .. | .. | .. | — 5,0 ,, | 16,8 ,, | 83 |
| Soendmoer .......... | 62 30 | 4 0 | — | 5,3 | — 2,7 | 4,0 | 13,3 | 6,5 | — 4,4 ,, | 14,3 ,, | 19 |
| Christiania .......... | 59 54 | 8 25 | — | 5,4 | — 3,8 | 4,0 | 15,3 | 5,8 | — 4,8 ,, | 16,5 ,, | 10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Eastport | 44 54 | 69 16 W | — | 5,4 | —5,4 | 3,6 | 16,1 | 7,6 | — 6,8 ,, | 17,2 ,, | 6 |
| Stockholm | 59 21 | 15 43 E | 41 | 5,6 | —3,6 | 3,5 | 16,1 | 6,5 | — 4,5 ,, | 17,6 ,, | 65 |
| Pompey | 42 56 | 78 25 W | 390 | 6,1 | —5,3 | 5,3 | 17,7 | 6,8 | — 6,2 ,, | 19,0 ,, | 14 |
| Köningsberg | 54 43 | 18 10 E | — | 6,2 | —3,3 | 5,3 | 15,9 | 6,7 | — 4,2 ,, | 17,0 ,, | 24 |
| Stift-Tepl | 49 58 | 10 33 | 643 | 6,2 | —2,9 | 6,3 | 14,7 | 6,8 | — 5,2 ,, | 15,8 ,, | 11 |
| Hohe-Peissenberg | 47 48 | 8 41 | 975 | 6,2 | —1,6 | 5,4 | 14,4 | 6,5 | (—1,6? Feb.) | 15,0 ,, | 20 |
| St. Lawrence | 44 40 | 77 20 W | 121 | 6,2 | —6,8 | 5,9 | 18,6 | 7,4 | — 7,9 Jan. | 20,1 ,, | 12 |
| Halifax | 44 39 | 65 57 | — | 6,2 | —4,4 | 2,9 | 17,2 | 9,0 | — 5,2 ,, | 19,2 ,, | 2-9 |
| Carlstadt | 59 23 | 11 10 E | 53 | 6,3 | —2,7 | 4,7 | 16,2 | 6,9 | — 3,6 ,, | 17,5 ,, | 10 |
| Wilna | 54 41 | 22 58 | 117 | 6,3 | —4,6 | 5,7 | 17,6 | 6,5 | — 5,9 ,, | 18,5 ,, | 6 |
| Montreal | 45 31 | 75 55 W | .. | 6,5 | —8,1 | 6,8 | 20,6 | 8,4 | — 9,7 ,, | 21,7 ,, | 13 |
| Lead-Hills | 55 25 | 6 8 | 390 | 6,6 | 0,2 | 6,4 | 13,1 | 6,5 | — 0,2 ,, | 14,0 ,, | 10 |
| Hof | 50 19 | 9 35 E | 487 | 6,6 | —1,5 | 5,8 | 15,9 | 6,2 | — 3,4 ,, | 16,7 ,, | 7 |
| Tegernsée | 47 42 | 9 25 | 735 | 6,6 | —1,9 | 5,7 | 15,3 | 7,3 | .... | .... | 8 |
| Fort Snelling | 44 53 | 95 28 W | 240 | 6,6 | —9,8 | 8,2 | 21,3 | 7,2 | —11,9 Jan. | 22,4 July. | 5 |
| Fort Haward | 44 40 | 89 22 | 185 | 6,6 | —7,3 | 5,8 | 20,5 | 6,9 | — 7,9 Dec. | 23,0 ,, | 4 |
| Tilsit | 55 4 | 19 33 E | .. | 6,7 | —3,6 | 5,9 | 16,7 | 7,3 | — 5,4 Jan. | 17,5 ,, | 20 |
| Hohenelbe | 50 38 | 13 14 | 458 | 6,7 | —2,6 | 6,5 | 15,6 | 7,2 | — 4,3 ,, | 16,4 ,, | 15 |
| Hohenfurth | 48 37 | 12 0 | 555 | 6,7 | —3,3 | 7,2 | 13,4 | 6,0 | — 5,0 ,, | 17,5 ,, | 11 |
| Genkingen | 48 25 | 6 50 | 780 | 6,8 | —1,6 | 6,8 | 14,8 | 7,1 | — 4,1 ,, | 15,7 ,, | 7 |
| New Archangel | 57 3 | 137 38 W | .. | 6,9 | 0,7 | 5,2 | 12,7 | 8,6 | — 0,2 Feb. | 13,5 Aug. | 3-5 |
| Wexioe | 56 53 | 12 25 E | 146 | 6,9 | —2,3 | 5,3 | 17,7 | 7,1 | — 2,8 Jan. | 18,9? July. | 34 |
| Braunsberg | 54 19 | 17 34 | — | 6,9 | —3,8 | 6,0 | 15,8 | 7,4 | — 5,3 ,, | 16,5 Aug. | 7 |
| Dover | 43 13 | 73 14 W | .. | 6,9 | —5,0 | 5,7 | 19,0 | 8,0 | — 5,5 Feb. | 21,1 July. | 6-7 |
| Concord | 43 12 | 73 49 | .. | 6,9 | —5,2 | 6,7 | 18,5 | 7,6 | — 6,0 Jan. | 19,5 ,, | 10 |
| Fayetteville | 42 58 | 75 2 | .. | 7,0 | —5,6 | 6,0 | 19,0 | 7,9 | — 6,7 ,, | 19,7 ,, | 7 |
| Ullensvang | 60 19 | 4 20 E | — | 7,2 | —0,1 | 6,0 | 15,6 | 7,4 | — 0,7 ,, | 16,9 ,, | 25 |
| Lund | 55 42 | 10 51 | — | 7,2 | —1,4 | 5,4 | 16,7 | 8,3 | — 1,9 ,, | 17,4 ,, | 54 |
| Freyberg | 50 55 | 11 0 | 403 | 7,2 | —1,7 | 7,2 | 15,9 | 7,5 | — 3,2 ,, | 16,4 ,, | 9 |
| Alford | 57 13 | 5 2 W | 127 | 7,3 | 1,9 | 6,0 | 13,7 | 7,4 | 0,8 ,, | 14,7 ,, | 7 |

| PLACES. | LATITUDE. | LONGITUDE from Paris. | Height above the Sea. | MEAN TEMPERATURE. | | | | | | | Number of Years of Observation. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Winter. | Spring. | Summer. | Autumn. | Coldest Month. | Hottest Month. | |
| Gotha | 50° 57′ N | 8° 23′ E | 308 | 7,3 | —1,3 | 7,3 | 15,5 | 7,6 | — 3,2 Jan. | 16,8 July. | 8 |
| Tabor | 49 24 | 12 19 | 429 | 7,3 | —2,7 | 7,3 | 16,9 | 7,7 | — 4,6 ,, | 18,0 ,, | 15 |
| Dunfermline | 56 5 | 5 46 W | .. | 7,4 | 2,6 | 6,1 | 12,9 | 7,8 | — 2,1 ,, | 13,8 ,, | 20 |
| Applegarth Manse | 55 13 | 5 32 | 55 | 7,4 | 2,4 | 6,2 | 13,4 | 8,0 | 1,2 ,, | 14,1 ,, | 13 |
| Utica | 43 7 | 77 33 | 146 | 7,4 | —4,0 | 6,7 | 19,0 | 8,4 | — 5,1 Feb. | 20,4 ,, | 14 |
| Thorshavn | 62 2 | 9 6 | — | 7,5 | 4,3 | 5,6 | 12,2 | 8,2 | 3,3 Jan. | 13,4 ,, | 2-5 |
| Warsaw | 52 13 | 18 42 E | 121 | 7,5 | —2,5 | 7,0 | 17,5 | 8,0 | — 4,0 ,, | 18,2 ,, | 26 |
| Dantzig | 54 21 | 16 18 | .. | 7,6 | —1,2 | 6,7 | 16,4 | 8,4 | — 2,6 ,, | 17,5 ,, | 26 |
| Zittau | 50 54 | 12 28 | 247 | 7,6 | —1,7 | 7,5 | 16,5 | 8,3 | — 3,4 ,, | 17,2 ,, | 12 |
| Bayreuth | 49 57 | 9 16 | 341 | 7,6 | —1,3 | 7,9 | 15,9 | 8,0 | — 2,9 ,, | 16,9 ,, | 19 |
| Wartenberg (Poland) | 51 19 | 15 21 | 146 | 7,8 | —2,0 | 7,9 | 17,1 | 8,4 | — 3,7 ,, | 17,8 ,, | 15 |
| Kielce | 50 52 | 18 18 | 273 | 7,8 | —1,7 | 7,8 | 16,0 | 8,8 | — 3,8 ,, | 16,9 Aug. | 7 |
| Coburg | 50 16 | 8 39 | 220 | 7,8 | —0,9 | 7,2 | 17,1 | 8,2 | — 1,7 ,, | 17,6 July. | 12 |
| Berne | 46 57 | 5 6 | 585 | 7,8 | —0,9 | 7,7 | 15,8 | 8,5 | — 2,8 ,, | 16,6 Aug. | 20 |
| Gottenberg | 57 41 | 9 36 | — | 7,9 | —0,3 | 6,5 | 16,9 | 8,7 | — 1,1 ,, | 17,8 July. | 46 |
| Augsburg | 48 22 | 8 34 | 493 | 7,9 | —0,7 | 8,3 | 16,6 | 8,2 | — 3,8 ,, | 17,5 ,, | 22 |
| Stromness (Orkneys) | 58 57 | 5 49 W | .. | 8,0 | 4,0 | 6,5 | 12,5 | 9,0 | 3,4 ,, | 13,0 ,, | 12 |
| Præstoe | 55 7 | 9 43 E | — | 8,0 | —0,3 | 6,5 | 16,2 | 9,4 | — 1,3 ,, | 16,8 Aug. | 10 |
| Cracow | 50 4 | 17 37 | 201 | 8,0 | —3,3 | 6,9 | 19,1 | 8,0 | — 5,3 ,, | 19,6 ,, | 13 |
| Landskrona | 49 55 | 14 17 | 331 | 8,0 | —2,3 | 8,3 | 17,7 | 8,1 | — 4,6 ,, | 18,8 July. | 14 |
| Kinfauns Castle | 56 24 | 5 39 W | 45 | 8,1 | 3,3 | 7,4 | 14,1 | 8,7 | 2,7 ,, | 14,9 ,, | 27 |
| Breslau | 51 6 | 14 42 E | 140 | 8,1 | —1,0 | 7,2 | 17,3 | 8,1 | — 1,5 ,, | 19,1 ,, | 18 |
| Clunie Manse | 57 12 | 4 55 W | 58 | 8,2 | —3,2 | 7,9 | 14,8 | 7,9 | 2,5 ,, | 15,2 ,, | 28 |
| Copenhagen | 55 41 | 10 14 E | — | 8,2 | —0,4 | 6,5 | 17,2 | 9,3 | — 1,4 ,, | 18,2 ,, | 52 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Stralsund | 54 19 | 10 45 | | — | 8,2 | —0,2 | 7,0 | 16,5 | 9,3 | — 1,6 ,, | 17,9 ,, | 11 |
| Medfield | 42 15 | 73 20 | W | .. | 8,2 | —3,0 | 6,8 | 19,6 | 9,4 | — 4,6 ,, | 20,5 ,, | 12 |
| Apenrade | 55 3 | 7 5 | E | — | 8,3 | 0,6 | 6,9 | 16,2 | 9,0 | — 0,4 ,, | 16,9 ,, | 16 |
| Kendal | 54 17 | 5 6 | W | 43 | 8,3 | 2,9 | 7,5 | 14,5 | 8,5 | 1,6 ,, | 14,9 ,, | 21 |
| Alderley Rectory | 53 20 | 4 40 | | .. | 8,3 | 2,7 | 7,6 | 14,0 | 8,9 | 2,1 ,, | 14,4 ,, | 10 |
| Arnstadt | 50 50 | 8 37 | E | 292 | 8,3 | —1,3 | 8,5 | 17,2 | 8,9 | .... | .... | 10 |
| Fulda | 50 34 | 7 24 | | 273 | 8,3 | —2,6 | 8,1 | 18,7 | 8,9 | — 3,5 Jan. | 19,6 Aug. | 11 |
| Kremsmunster | 48 3 | 11 48 | | 361 | 8,3 | —1,9 | .. | 17,6 | .. | .... | .... | ,, |
| Carlisle | 54 54 | 5 17 | W | — | 8,4 | 3,0 | 7,5 | 14,2 | 8,7 | 2,3 Jan. | 14,9 July. | 24 |
| Giengen | 48 37 | 7 55 | E | 481 | 8,4 | 0,0 | 8,9 | 17,0 | 8,0 | — 2,9 ,, | 17,1 ,, | 16 |
| Swinemunde | 53 51 | 11 57 | | — | 8,5 | —0,7 | 7,4 | 17,4 | 9,5 | — 2,6 ,, | 18,4 ,, | 9 |
| Dresden | 51 3 | 11 24 | | 121 | 8,5 | —0,4 | 8,4 | 17,2 | 8,4 | — 2,0 ,, | 18,0 ,, | 10 |
| Jena | 50 56 | 9 17 | | 162 | 8,5 | —0,7 | 8,9 | 16,5 | 9,1 | — 2,8 ,, | 18,1 ,, | 10 |
| St. Gall | 47 26 | 7 2 | | .. | ( 8,5 ) | 0,0 | 7,7 | (17,2) | 8,9 | — 1,7 ,, | (19,8) ,, | 10 |
| Edinburgh | 55 57 | 5 32 | W | 88 | 8,6 | 3,6 | 7,6 | 14,4 | 8,9 | 2,9 ,, | 15,0 ,, | 17 |
| Cuxhaven | 53 53 | 6 24 | E | — | 8,6 | 0,3 | 7,5 | 17,2 | 9,2 | — 0,4 ,, | 17,5 ,, | 18 |
| Hamburg | 53 33 | 7 38 | | — | 8,6 | 0,3 | 8,0 | 17,0 | 8,8 | — 1,3 ,, | 17,5 ,, | 19 |
| Berlin | 52 31 | 11 3 | | 39 | {8,6 | —0,8 | 8,0 | 17,3 | 8,8 | — 2,4 ,, | 18,0 ,, | 25 |
| | | | | | 8,6 | —0,7 | 8,4 | 17,6 | 9,1 | — 3,1 ,, | 18,3 ,, | 22 |
| Ratisbon | 49 1 | 9 46 | | 335 | 8,6 | —1,4 | 9,4 | 17,9 | 8,7 | — 2,8 ,, | 18,9 ,, | 59 |
| Tubingue | 48 31 | 6 43 | | 331 | 8,6 | —0,2 | 8,6 | 17,1 | 8,9 | — 2,2 ,, | 17,8 ,, | 13 |
| New Malton | 54 8 | 3 7 | W | — | 8,7 | 2,5 | .. | 15,1 | .. | 1,9 ,, | 15.9 ,, | 7-9 |
| Manchester | 53 29 | 4 35 | | 47 | 8,7 | 2,8 | 7,9 | 14,8 | 9,2 | 2,1 ,, | 15,2 ,, | 25 |
| Andover | 42 38 | 73 27 | | 58 | 8,7 | —2,9 | 7,2 | 20,6 | 9,6 | — 4,2 ,, | 21,3 ,, | 11 |
| Sagan | 51 39 | 12 59 | E | 123 | 8,8 | —2,6 | 7,0 | 18,2 | 8,2 | — 3,7 ,, | 18,9 ,, | 7 |
| Halle | 51 31 | 9 37 | | 111 | 8,8 | 0,0 | 8,6 | 17,5 | 9,1 | — 2,3 ,, | 19,2 ,, | 5-10 |
| Saaz | 50 20 | 11 13 | | 257 | 8,8 | —1,4 | 9,1 | 18,3 | 9,1 | — 2,7 ,, | 19,5 ,, | 13 |
| Andechs | 47 58 | 8 52 | | 702 | 8,8 | —1,2 | 8,8 | 18,6 | 9,1 | — 1,6 ,, | 19,3 ,, | 8 |
| Munich | 48 9 | 9 14 | | 526 | 8,9 | —0,4 | 9,0 | 17,4 | 9,1 | — 1,5 ,, | 18,0 ,, | 32 |
| Salem | 42 31 | 73 14 | W | — | 8,9 | —2,6 | 7,2 | 20,6 | 10,5 | — 3,8 ,, | 21,9 ,, | 45 |

| PLACES. | LATITUDE. | LONGITUDE from Paris | Height above the Sea. | MEAN TEMPERATURE. |  |  |  |  |  |  | Number of Years of Observation. |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  | Year. | Winter. | Spring. | Summer. | Autumn. | Coldest Month. | Hottest Month. |  |
| Cambridge (U. S.) | 42°22′ N | 73°28′ W | — | 8,9 | —2,8 | 7,4 | 20,7 | 10,1 | —4,1 Jan. | 22,0 July. | 23 |
| Erfurt | 50 59 | 8 42 | 209 | 9,0 | 0,6 | 8,5 | 17,3 | 9,5 | —0,7 ,, | 17,7 ,, | 17 |
| Innsbruck | 47 16 | 9 4 | 526 | 9,0 | —1,9 | 10,0 | 18,3 | 9,6 | —3,8 ,, | 18,4 ,, | 51 |
| Göttingen | 51 32 | 7 36 | 132 | 9,1 | 0,6 | .. | 17,6 | .. | .... | .... | 0/0 |
| Wangen | 48 46 | 6 55 | 277 | 9,1 | 0,4 | 9,3 | 17,9 | 9,4 | .... | .... | 13 |
| Rochester | 43 8 | 80 11 | 156 | 9,1 | —2,5 | 8,5 | 20,3 | 10,2 | —3,0 Feb. | 22,3 ,, | 10 |
| Albany | 42 39 | 76 5 | 39 | 9,2 | —3,0 | 8,7 | 20,9 | 9,7 | —3,9 ,, | 22,2 ,, | 17 |
| Salzufflen | 52 5 | 6 25 E | 97 | 9,3 | 1,5 | 8,9 | 17,3 | 9,6 | —0,6 Jan. | 18,1 ,, | 16 |
| Elberfeld | 51 16 | 4 49 | 131 | 9,3 | 2,2 | 8,8 | 16,3? | 9,7 | 1,1 ,, | 17,2 ,, | 12 |
| Nicolaïef | 46 58 | 29 39 | — | 9,3 | —3,4 | 9,6 | 21,8 | 10,0 | —5,3 ,, | 22,6 ,, | 15 |
| Boston | 42 21 | 73 24 W | .. | 9,3 | —1,6 | 7,7 | 20,5 | 10,4 | —3,3 ,, | 21,8 ,, | 10 |
| Dublin | 53 23 | 8 41 | — | 9,5 | 4,6 | 8,4 | 15,3 | 9,8 | 4,3 ,, | 16,0 ,, | 13 |
| Munster | 51 58 | 5 18 E | 63 | 9,5 | 2,2 | 8,7 | 16,8 | 10,1 | 0,7 ,, | 17,4 ,, | 10 |
| Prague | 50 5 | 12 6 | 191 | 9,5 | —0,4 | 9,6 | 18,9 | 9,8 | —2,4 ,, | 20,2 ,, | 15 |
| Lausanne | 46 31 | 4 18 | 507 | 9,5 | 0,5 | 9,2 | 18,4 | 9,9 | —1,0 ,, | 18,7 Aug. | 10 |
| Zwanenburg | 52 15 | 2 0 | — | 9,6 | 2,6 | 8,4 | 16,9 | 10,6 | 1,4 ,, | 17,4 July. | 40 |
| Near London | 51 31 | 2 26 W | .. | 9,6 | 3,1 | 9,0 | 16,4 | 10,0 | 1,7 ,, | 17,3 ,, | 24 |
| Stuttgard | 48 46 | 6 51 E | 248 | 9,6 | 0,8 | 10,0 | 17,8 | 9,7 | —1,2 ,, | 18,8 ,, | 40 |
| New Bedford | 41 38 | 73 16 W | .. | 9,6 | —0,8 | 7,7 | 20,1 | 11,5 | —1,9 ,, | 21,0 ,, | 5 |
| Leyden | 52 10 | 2 9 E | — | 9,7 | 2,4 | 8,4 | 17,2 | 10,5 | 1,2 ,, | 17,9 ,, | 19 |
| Cheltenham | 41 55 | 4 24 W | .. | 9,7 | 3,8 | 9,2 | 15,8 | 10,1 | 2,7 ,, | 16,8 ,, | 13 |
| Geneva | 46 12 | 3 49 E | 396 | 9,7 | 1,2 | 9,5 | 17,9 | 10,2 | —0,4 ,, | 18,6 ,, | 40 |
| St. Jean de Morienne | 45 18 | 4 4 | 546 | 9,7 | 0,2 | 10,0 | 18,7 | 9,0 | —0,8 ,, | 19,9 ,, | 12 |
| Sympheropol | 45 0 | 31 50 | 259 | 9,7 | 0,5 | 10,6 | 19,6 | 8,0 | —0,3 ,, | 20,8 ,, | 13 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Council Bluffs........ | 41 25 | 98 3 W | 244 | 9,7 | —5,2 | 10,6 | 23,2 | 10,3 | —6,9 ,, | 23,9 ,, | 5 |
| Frankfort-on-Maine .. | 50 7 | 6 21 E | 117 | 9,8 | 1,2 | 9,9 | 18,3 | 10,0 | —0,4 ,, | 18,9 ,, | 30 |
| Strasburg........... | 48 35 | 5 25 | 146 | 9,8 | 1,1 | 10,0 | 18,1 | 10,0 | —0,4 ,, | 18,8 ,, | 32 |
| Basle................ | 47 34 | 5 15 | 253 | 9,8 | 0,4 | 9,8 | 18,4 | 9,7 | —1,0 ,, | 19,3 ,, | 11 |
| Haarlem ...... ..... | 52 23 | 2 18 | — | 10,0 | 2,8 | 9,2 | 17,0 | 11,0 | 1,0 ,, | 17,7 ,, | 18 |
| Treves .............. | 49 46 | 4 18 | 156 | 10,0 | 1,9 | 10,0 | 17,8 | 10,1 | 0,0 ,, | 18,7 ,, | 11 |
| Maestricht .......... | 50 51 | 3 21 | 49 | 10,1 | 1,9 | 10,0 | 18,0 | 11,1 | 0,0 ,, | 18,9 ,, | 16 |
| Wurzburg............ | 49 48 | 7 36 | 172 | 10,1 | 1,6 | 10,2 | 18,7 | 9,7 | —0,9 ,, | 19,6 ,, | 27 |
| Vienna .............. | 48 13 | 14 3 | 156 | 10,1 | 0,2 | 10,5 | 20,3 | 10,5 | —1,6 ,, | 20,7 ,, | 24-14 |
| Fort George.......... | 46 18 | 125 20 W | .. | 10,1 | 3,8 | 9,0 | 15,5 | 12,0 | 2,0 ,, | 16,3 Aug. | 2 |
| Fort Wolcott ........ | 41 29 | 73 40 | — | 10,1 | —0,1 | 8,4 | 20,6 | 12,2 | —1,3 ,, | 22,2 July. | 5 |
| Brussels ............ | 50 51 | 2 2 E | 58 | 10,2 | 2,5 | 10,1 | 18,2 | 10,2 | 1,2 ,, | 18,8 ,, | 36 |
| Carlsruhe............ | 49 1 | 6 5 | 113 | 10,2 | 1,1 | 10,4 | 18,9 | 10,2 | —0,5 ,, | 19,7 ,, | 38 |
| Mannheim .......... | 49 29 | 6 8 | 92 | 10,3 | 1,5 | 10,4 | 19,5 | 9,8 | 0,9 ,, | 20,2 ,, | 12 |
| Baden .............. | 47 30 | 16 43 | 156 | 10,3 | —0,6 | 10,4 | 21,1 | 10,5 | —1,9 ,, | 21,7 ,, | 27 |
| London.............. | 51 31 | 2 26 W | — | 10,4 | 4,2 | 9,5 | 17,1 | 10,7 | 3,0 ,, | 17,8 ,, | 40 |
| Lyme-Regis.......... | 50 43 | 5 16 | — | 10,4 | 5,5 | 9,2 | 15,2 | 11,6 | 4,5 ,, | 15,8 Aug. | 13 |
| Erasmus Hall........ | 40 37 | 76 18 | — | 10,7 | 0,4 | 9,3 | 21,3 | 11,8 | —0,5 Feb. | 22,8 July. | 14 |
| Paris................ | 48 50 | 0 0 | 64 | 10,8 | 3,3 | 10,3 | 18,1 | 11,2 | 1,8 Jan. | 18,9 ,, | 33 |
| Montmorency ........ | 49 0 | 0 2 | 140 | 10,9 | 2,8 | 10,6 | 18,7 | 11,4 | 0,9 ,, | 19,7? ,, | 33 |
| Gosport ............ | 50 48 | 3 26 | — | 11,0 | 5,0 | 10,1 | 17,1 | 11,9 | 3,9 ,, | 17,8 ,, | 16 |
| Plymouth............ | 50 22 | 6 28 | — | 11,1 | 6,9 | 10,1 | 16,0 | 11,7 | 5,9 ,, | 16,6 ,, | 11 |
| Penzance ............ | 50 7 | 7 53 | — | 11,1 | 6,6 | 9,9 | 16,5 | 12,1 | 5,7 ,, | 17,2 ,, | 21 |
| Fort Columbus ...... | 40 42 | 76 29 | — | 11,2 | —0,1 | 9,9 | 22,5 | 12,6 | —0,9 Feb. | 24,4 ,, | 4-5 |
| Hobart Town ........ | 42 45 S | 145 15 E | — | 11,3 | 5,6 | 11,6 | 17,3 | 10,9 | 4,5 Jan. | 17,3 ,, | 1 |
| German Town........ | 40 3 N | 77 37 W | 62 | 11,3 | 0,0 | 10,3 | 22,8 | 12,1 | —1,1 ,, | 23,8 ,, | 9 |
| Fort Vancouver ...... | 45 38 | 122 34 | .. | 11,5 | 4,2 | 11,0 | 18,2 | 12,9 | 1,7 ,, | 19,1 Aug. | 3-4 |
| Sevastopol .......... | 44 36 | 31 12 E | 49 | 11,5 | 1,8 | 10,2 | 21,7 | 12,6 | 0,6 ,, | 22,4 July. | 15 |
| La Rochelle.......... | 46 9 | 3 28 W | — | 11,6 | 4,2 | 10,6 | 19,4 | 11,5 | 2,9 Dec. | 20,2 ,, | 11 |
| Marietta ............ | 39 25 | 83 50 | 195? | 11,6 | 0,8 | 12,3 | 21,9 | 11,6 | 0,0 Jan. | 22,9 ,, | 11 |

| PLACES. | LATITUDE. | LONGITUDE from Paris. | Height above the Sea. | MEAN TEMPERATURE. | | | | | | | Number of Years of Observation. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Winter. | Spring. | Summer. | Autumn. | Coldest Month. | Hottest Month. | |
| Baltimore | 39°17′ N | 78°58′ W | .. | 11,6 | 0,4 | 10,4 | 23,1 | 12,9 | —0,6 Jan. | 24,0 July. | 8 |
| Turin | 45 4 | 5 22 E | 279 | 11,7 | 0,8 | 11,7 | 22,0 | 12,1 | —0,6 ,, | 22,9 Aug. | 30 |
| Darjiling | 27 0 | 86 4 | 2124 | 12,0 | 5,4 | 12,5 | 16,3 | 13,3 | 4,4 ,, | 16,5 ,, | 2 |
| Middletown | 40 24 | 76 33 W | .. | 12,1 | 2,2 | 11,3 | 21,1 | 13,6 | .... | .... | 3 |
| Cincinnati | 39 6 | 86 47 | 162 | 12,2 | 0,5 | 12,4 | 22,8 | 12,8 | —1,2 ,, | 23,6 July. | 9 |
| Padua | 45 24 | 9 32 E | — | 12,5 | 2,8 | 12,1 | 21,9 | 13,0 | 1,8 ,, | 22,9 ,, | 37 |
| Pavia | 45 11 | 6 49 | 88 | 12,7 | 2,2 | 12,6 | 22,8 | 13,2 | 0,7 ,, | 23,6 ,, | 12 |
| Pekin | 39 54 | 114 9 | 97 | .. | —1,0 | 14,8 | .. | .. | —2,3 ,, | .... | 1 |
| | | | | 12,7? | —3,2? | 13,5 | 28,1? | 12,4 | —4,1? ,, | 29,1? Jun. | 6 |
| Washington | 38 53 | 79 22 W | .. | 12,7 | 2,3 | 10,2 | 21,7 | 13,5 | 0,9 ,, | 25,6 July. | 6 |
| Milan | 45 28 | 6 51 E | 146 | 12,8 | 2,1 | 13,0 | 22,7 | 13,2 | 0,6 ,, | 23,7 ,, | 70 |
| Toulouse | 43 36 | 0 54 W | 152 | 12,9 | 5,2 | 11,8 | 19,9 | 13,9 | 4,1? ,, | 21,5 Aug. | 8 |
| St. Louis (Missis.) | 38 36 | 91 56 | 170 | 13,0 | 0,7 | 12,9 | 24,1 | 14,4 | —1,2 ,, | 25,7 July. | 10 |
| Trieste | 45 39 | 11 26 E | 88 | 13,2 | 4,1 | 12,1 | 21,9 | 13,7 | 3,5 ,, | 22,6 ,, | 18 |
| Sienna | 43 3 | 9 0 | 325 | 13,4 | 5,2 | 12,4 | 21,7 | 14,0 | 4,4 ,, | 22,7 ,, | 5 |
| Breschia | 45 33 | 7 54 | 152 | 13,5 | 3,7 | 13,9 | 22,4 | 14,0 | 2,4 ,, | 23,6 ,, | 17 |
| Venice | 45 26 | 10 0 | — | 13,7 | 3,3 | 12,6 | 22,8 | 13,3 | 1,8 ,, | 23,9 ,, | 19-7 |
| Constantinople | 41 0 | 26 39 | .. | 13,7 | 4,8 | 11,0 | 23,0 | 15,8 | .... | .... | 1-3 |
| Bordeaux | 44 50 | 2 55 W | — | 13,9 | 6,1 | 13,4 | 21,7 | 14,4 | 5,0 ,, | 22,9 ,, | 10 |
| Mafra | 38 56 | 11 41 | 228 | 13,9 | 9,6 | 12,7 | 18,2 | 15,1 | 9,2 ,, | 19,7 ,, | 4 |
| Otacamound | 11 55 | 74 30 E | 2241 | 13,9 | 11,4 | 16,3 | 14,1 | 13,8 | 11,1 ,, | 16,9 April. | 2-4 |
| Missouri | 30 27 | 75 42 | 1910 | 14,0 | 5,5 | 15,9 | 19,8 | 14,8 | 4,8 ,, | 20,0 June. | 2-3 |
| Montpellier | 43 36 | 1 32 | — | 14,1 | .. | .. | .. | .. | .... | .... | 14 |
| | | | | 15,3? | 6,9 | 13,8 | 24,4 | 16,1 | 5,6 ,, | 25,7 July. | 10-12 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Marseilles............ | 43 18 | | 3 2 | | 45 | 14,1 | 6,9 | 12,9 | 21,4 | 14,7 | 5,2 ,, | 22,8 ,, | 16-10 |
| Bologna ............ | 44 30 | | 9 1 | | 82 | 14,2 | 2,8 | 14,5 | 25,2 | 14,3 | 1,2 ,, | 26,4 ,, | 8-10 |
| Camajore ............ | 43 55 | | 8 0 | | .. | 14,2 | 6,7 | 13,6 | 21,9 | 14,8 | 6,0 ,, | 23,1 ,, | 41 |
| Madrid.............. | 40 25 | | 6 2 | | 663 | 14,2 | 5,6 | 14,2 | 23,4 | 13,7 | .... | .... | 2-3 |
| Avignon ............ | 43 57 | | 2 28 | | — | 14,4 | 5,8 | 13,9 | 23,1 | 14,6 | 4,8 ,, | 23,8 Aug. | 25 |
| Caserna ............ | 43 40 | | 8 10 | | .. | 14,6 | 6,8 | 13,7 | 22,5 | 15,1 | 5,4 ,, | 23,5 July. | 8 |
| Lucca .............. | 43 51 | | 8 10 | | .. | 14,9 | 4,6 | 16,1 | 23,6 | 15,3 | 4,0 ,, | 24,6 ,, | 36 |
| Santa Fé de Bogota .. | 4 36 | | 76 34 | W | 2631 | 15,0 | 15,1 | 15,3 | 15,3 | 14,5 | 14,0 Dec. | 16,1 Feb. | 1-2 |
| Toulon .............. | 43 7 | | 3 36 | E | — | 15,1 | 8,6 | 13,3 | 22,3 | 16,3 | 7,5 Jan. | 23,2 July. | 11-12 |
| Lohoughat .......... | 29 23 | | 79 56 | | 1696 | 15,2 | 7,5 | 15,4 | 21,7 | 16,3 | 7,0 ,, | 21,9 ,, | 2 |
| Florence ............ | 43 47 | | 8 55 | | 64 | 15,3 | 6,8 | 14,7 | 24,0 | 15,7 | 5,3 ,, | 25,2 ,, | 12 |
| Rome .............. | 41 54 | | 10 8 | | 53 | 15,4 | 8,1 | 14,1 | 22,9 | 16,5 | 7,2 ,, | 23,9 ,, | 30 |
| Perpignan............ | 42 42 | | 0 34 | | 53 | 15,5 | 7,2 | 14,4 | 23,9 | 16,2 | 5,5 ,, | 25,5 ,, | 6 |
| Nice ................ | 43 42 | | 4 57 | | — | 15,6 | 9,3 | 13,3 | 22,5 | 17,2 | 8,3 ,, | 23,6 Aug. | 20 |
| Quito................ | 0 14 | S | 81 5 | W | 2914 | 15,6 | 15,4 | 15,7 | 15,6 | 17,5 | 14,8 July. | 16,3 Mar. | 2-3 |
| Near Naples ........ | 40 52 | N | 11 55 | E | 150 | 15,7 | 8,7 | 14,3 | 23,5 | 16,3 | 7,9 Jan. | 24,6 Aug. | 18 |
| | | | | | | 16,0 | 8,8 | 14,7 | 23,6 | 16,8 | 7,7 ,, | 25,1 ,, | 8 |
| Chapel Hill .......... | 35 54 | | 81 19 | W | .. | 15,7 | 5,4 | 15,4 | 25,2 | 16,7 | 2,4 ,, | 25,6 July. | 3 |
| Cagliari.............. | 39 13 | | 4 6 | E | 101 | 16,3 | 10,2 | 14,0 | 22,4 | 18,3 | 8,9 ,, | 23,9 Aug. | 3 |
| Naples .............. | 40 51 | | 11 55 | | 55 | 16,7 | 9,9 | 15,6 | 23,9 | 17,3 | 9,0 ,, | 25,0 ,, | 8 |
| | | | | | | 16,4 | 9,8 | 15,2 | 23,8 | 16,8 | 9,2 ,, | 24,5 ,, | 18 |
| Lisbon .............. | 38 42 | | 11 29 | W | 72 | 16,4 | 11,3 | 15,5 | 21,7 | 17,0 | 11,2 ,, | 22,3 July. | 5 |
| Mexico .............. | 19 26 | | 101 26 | | 2271 | 16,6 | 13,0 | 18,1 | 19,1 | 16,2 | 12,3 ,, | 19,7 June. | 2 |
| Buenos Ayres ........ | 34 37 | | 60 44 | | — | 16,9 | 11,4 | 15,2 | 22,8 | 18,1 | 11,0 ,, | 23,8 Aug. | 1-4 |
| Barcelona............ | 41 22 | | 0 9 | | .. | 17,0 | 10,0 | 15,5 | 24,5 | 17,8 | 9,2 ,, | 25,5 ,, | 55 |
| Laguna (Teneriffe).... | 28 30 | | 18 39 | | 546 | 17,1 | 13,6 | 15,4 | 20,2 | 18,9 | 12,9 ,, | 21,7 ,, | 8 |
| Palermo ............ | 38 7 | | 11 1 | E | 55 | 17,2 | 11,4 | 15,0 | 23,5 | 19,0 | 10,7 Feb. | 24,6 ,, | 39 |
| Constantine.......... | 36 20 | | 4 14 | | .. | 17,2 | 10,2 | 12,3 | 26,6 | 19,7 | .... | .... | 1 |
| Kathmandou ........ | 27 42 | | 85 20 | | 1413 | 17,3 | 8,4 | 18,4 | 24,3 | 18,2 | 7,0 Jan. | 24,9 July. | 2-3 |
| Abbeville (Carolina) .. | 34 10 | | 84 46 | W | .. | 17,5 | 8,3 | 18,7 | 26,7 | 16,3 | .... | .... | 1 |

| PLACES. | LATITUDE. | LONGITUDE from Paris. | Height above the Sea. | MEAN TEMPERATURE. | | | | | | | Number of Years of Observation. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Winter. | Spring. | Summer. | Autumn. | Coldest Month. | Hottest Month. | |
| Algiers | 36°47′ N | 0°43′ W | — | 17,8 | 12,4 | 17,2 | 23,6 | 21,4 | (14,5 Mar.) | 24,7 Aug. | 4 |
| Gibraltar | 36 7 | 7 41 | .. | 17,9 | 13,8 | 17,3 | 22,7 | 17,8 | 13,7 Feb. | 23,5 July. | 2 |
| Nicolosi | 37 35 | 12 46 E | 706 | 18,0 | 10,7 | 16,6 | 25,9 | 18,7 | 10,1 ,, | 27,8 Aug. | 5-7 |
| Canea | 35 29 | 21 40 | .. | 18,0 | 12,4 | 15,6 | 25,2 | 18,9 | 11,9 Jan. | 27,5 ,, | 1-2 |
| Paramatta | 33 50 S | 148 50 | — | 18,1 | 12,5 | 19,2 | 23,3 | 18,2 | 11,7 ,, | 24,2 June. | 3 |
| Savannah | 32 5 N | 83 27 W | .. | 18,1 | 10,9 | 18,0 | 25,1 | 18,3 | .... | .... | 5 |
| Smyrna | 38 26 | 24 48 E | .. | 18,2 | 11,1 | 14,6 | 26,0 | 21,1 | .... | .... | 1 |
| Nangasaki | 32 45 | 127 32 | .. | 18,3 | 8,4 | 15,5 | 27,7 | 21,6 | .... | .... | 2 |
| Near Natchez | 31 34 | 93 45 W | 58 | 18,3 | 10,0 | 19,1 | 25,4 | 18,6 | 8,8 ,, | 26,2 July. | 9 |
| Funchal | 32 38 | 19 15 | — | 18,7 | 16,3 | 17,5 | 21,1 | 19,8 | 15,7 ,, | 22,3 Aug. | 6 |
| Messina | 38 11 | 13 14 E | — | 18,8 | 12,8 | 16,4 | 25,1 | 20,7 | 12,3 ,, | 26,2 ,, | 5-6 |
| Cape of Good Hope | 33 55 | 16 8 | — | 19,1 | 14,8 | 18,6 | 23,4 | 19,4 | 14,3 ,, | 24,1 ,, | 7-11 |
| Montevideo | 34 54 S | 58 33 W | .. | 19,3 | 14,1 | 18,1 | 25,2 | 20,0 | 13,3 Dec. | 26,7 July. | 1 |
| Smithville | 34 0 N | 80 25 | .. | 19,3 | 11,4 | 18,9 | 26,7 | 20,1 | 10,7 Feb. | 27,5 ,, | 5 |
| New Orleans | 29 58 | 92 37 | .. | 19,4 | 11,8 | 18,9 | 26,5 | 20,4 | 11,4 ,, | 26,7 ,, | 4 |
| Catania | 37 30 | 12 40 E | — | 19,6 | 12,6 | 17,5 | 26,9 | 21,4 | 11,3 Jan. | 28,4 Aug. | 4-7 |
| St. George (Bermuda) | 32 20 | 67 10 W | — | 19,7 | 15,1 | 17,6 | 24,0 | 22,2 | 14,4 ,, | 24,9 Sept. | 1 |
| Báton-Rouge | 30 26 | 93 25 | — | 19,7 | 11,7 | 20,2 | 27,0 | 19,9 | 11,2 ,, | 27,7 June. | 2 |
| Jesup. Cantonm. | 31 30 | 96 9 | 53 | 20,2 | 11,8 | 20,7 | 28,3 | 19,8 | 11,3 Feb. | 28,9 Aug. | 3 |
| Tunis | 36 48 | 7 51 E | — | 20,3 | 13,2 | 18,3 | 28,3 | 21,9 | 11,7 Jan. | 30,3 ,, | 3-4 |
| Clinch. Cant. | 30 24 | 89 34 W | .. | 20,4 | 12,0 | 21,1 | 28,8 | 20,7 | 11,0 Feb. | 28,0 July. | 3 |
| Fort St. Philip | 29 29 | 91 41 | — | 20,8 | 12,4 | 21,4 | 28,3 | 22,6 | .... | .... | 2-1 |
| Fernandina | 30 35 | 84 55 | — | 21,1 | 15,7 | 21,1 | 26,1 | 21,7 | .... | .... | 2-1 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Canton............. | 23 | 8 | N | 110 | 56 | E | — | 21,0 | 12,7 | 21,0 | 27,8 | 22,7 | 11,4 Jan. | 28,3 July. | 10 |
| | | | | | | | | 21,6 | 13,7 | 21,8 | 28,2 | 22,5 | 13,3 ,, | 28,5 June. | 3 |
| Las Palmas (Canaries) | 28 | 0 | | 17 | 51 | W | — | 21,8 | 18,0 | 19,4 | 23,8 | 26,2 | 17,8 ,, | 29,2 Oct. | 12 |
| San Croix of Teneriffe | 28 | 28 | | 18 | 36 | | — | 21,9 | 18,1 | 21,3 | 24,9 | 23,4 | 17,7 ,, | 26,1 Aug. | 2-3 |
| Fort King............ | 29 | 3 | | 84 | 30 | | .. | 22,0 | 16,5 | 21,4 | 28,1 | 21,7 | .... | .... | 1 |
| Caracas.............. | 10 | 31 | | 69 | 25 | | 887 | 22,0 | 20,9 | 21,8 | 23,4 | 22,2 | 20,0 Feb. | 24,0 July. | 1-2 |
| St. Augustine ........ | 29 | 48 | | 83 | 55 | | .. | 22,3 | 15,3 | 21,9 | 28,2 | 24,0 | .... | .... | 1 |
| Cairo................ | 30 | 2 | | 28 | 55 | E | .. | 22,4 | 14,7 | 22,0 | 29,2 | 23,5 | 13,6 Jan. | 29,6 Aug. | 3 |
| Seharanpour. ........ | 29 | 57 | | 75 | 23 | | 308 | 22,4 | 12,2 | 24,8 | 30,0 | 22,4 | 11,1 ,, | 32,2 June. | 1 |
| Cant. Brooke ........ | 27 | 57 | | 84 | 55 | W | — | 22,4 | 16,2 | 22,7 | 26,7 | 24,0 | .... | .... | 1 |
| Macao.. ............ | 22 | 11 | | 111 | 14 | E | — | 22,5 | 16,4 | 21,1 | 28,3 | 24,1 | 14,5 Feb. | 28,6 July. | 2-5 |
| Candy ............. | 7 | 18 | | 78 | 30 | | 513 | 22,7 | 22,3 | 23,5 | 22,8 | 22,4 | 21,8 Jan. | 24,2 May. | 5-6 |
| Ambala.............. | 30 | 25 | | 74 | 25 | | 331 | 22,8 | 13,2 | 25,4 | 30,1 | 22,6 | 11,7 ,, | 31,9 June. | 3-4 |
| Ubajoy .............. | 23 | | | 84 | 45 | | 94 | 23,0 | 18,3 | 21,7 | 28,4 | 23,9 | 16,8 Dec. | 28,7 July. | 4 |
| Rio Janeiro .......... | 22 | 55 | S | 45 | 36 | W | .. | 23,1 | 20,3 | 22,5 | 26,1 | 23,6 | 19,6 Jan. | 26,7 ,, | 7-9 |
| Honorourou.......... | 21 | 19 | | 160 | 21 | | .. | 23,7 | 21,6 | 23,0 | 25,5 | 24,8 | 21,3 ,, | 25,9 Aug. | 2-3 |
| Nasarabad .......... | 26 | 18 | N | 72 | 25 | E | 458 | 24,5 | 15,6 | 27,6 | 30,0 | 24,7 | 14,5 Dec. | 32,4 May. | 4 |
| St. Louis (Senegal) ... | 16 | 1 | | 18 | 53 | W | — | 24,6 | 21,1 | 21,4 | 27,6 | 28,2 | 19,9 Feb. | 30,8 Sept. | 1 |
| Key West............ | 24 | 34 | | 84 | 13 | | — | 24,7 | 21,5 | 24,2 | 27,9 | 25,5 | 20,8 Jan. | 28,1 Aug. | 6-8 |
| Port Louis .......... | 20 | 10 | S | 55 | 8 | E | — | 24,9 | 21,6 | 23,8 | 28,1 | 26,0 | 21,1 Feb. | 28,4 ,, | 10-6 |
| Pounah.............. | 18 | 30 | N | 72 | | | 546 | 24,9 | 21,5 | 26,7 | 26,1 | 25,3 | 20,8 Dec. | 27,9 May. | 4 |
| Abouscheher ......... | 28 | 15 | | 48 | 34 | | .. | 25,0 | 16,5 | 23,8 | 33,3 | 26,5 | 15,4 ,, | 34,3 July. | 1 |
| Delta of the Indus .... | 24 | 44 | | 65 | 57 | | .. | .. | 17,8 | .. | .. | .. | 17,2 Feb. | .... | 1 |
| Fouttigourh.......... | 27 | 22 | | 77 | 12 | | 181 | 25,0 | 15,3 | 28,5 | 31,7 | 24,5 | 14,1 Jan. | 35,0 June. | 2 |
| Havannah............ | 23 | 9 | | 84 | 43 | W | — | 25,0 | 22,6 | 24,6 | 27,4 | 25,6 | 21,9 ,, | 27,5 Aug. | 8 |
| St. Denis ............ | 20 | 52 | S | 53 | 10 | E | 43 | 25,0 | 22,6 | 24,9 | 26,7 | 25,6 | 22,1 ,, | 27,1 ,, | 2 |
| Vera Cruz ........... | 19 | 12 | N | 98 | 29 | W | — | 25,0 | 21,5 | 25,0 | 27,5 | 26,0 | 21,2 ,, | 27,8 May. | 13 |
| Seringapatam ........ | 12 | 45 | | 74 | 21 | E | 735 | 25,1 | 22,9 | 28,5 | 24,5 | 24,4 | 21,6 ,, | 29,4 ,, | 2 |
| Benares.............. | 25 | 19 | | 80 | 35 | | 97 | 25,4 | 16,3 | 30,0 | 29,6 | 24,1 | 15,2 Dec. | 33,4 ,, | 4 |
| Matanzas............ | 23 | 2 | | 83 | 58 | W | 35 | 25,5 | 22,5 | 25,8 | 27,6 | 26,2 | 21,5 Feb. | 27,8 July. | 3 |

| PLACES. | LATITUDE. | LONGITUDE from Paris. | Height above the Sea. | MEAN TEMPERATURE. | | | | | | | Number of Years of Observation. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Year. | Winter. | Spring. | Summer. | Autumn. | Coldest Month. | Hottest Month. | |
| Ava | 21°40′ N | 113°40′ E | 97 | 25,7 | 20,4 | 27,7 | 28,7 | 26,2 | 18,9 Jan. | 30,1 Apr. | 1 |
| Calcutta | 22 35 | 86 0 | — | 25,8 | 19,9 | 28,1 | 28,5 | 26,1 | 18,4 ,, | 29,9 May. | 17-8 |
| Bombay | 18 56 | 70 34 | — | 26,0 | 23,2 | 27,2 | 28,1 | 27,3 | 22,4 ,, | 29,3 ,, | 2 |
| Jamaica | 17 50 | 79 2 W | .. | 26,1 | 24,6 | 25,7 | 27,4 | 26,6 | 24,4 ,, | 27,6 July. | 5 |
| Tortola | 18 27 | 67 0 | 253 | 26,2 | (25,5) | (25,2) | 27,0 | 26,8 | 24,2 Mar. | 27,3 Aug. | 3 |
| Cobbe | 14 11 | 25 48 E | 487 | 26,5 | 19,9 | 28,7 | 30,0 | 27,4 | 18,8 Jan. | 30,3 July. | 2 |
| Paramaribo | 5 45 | 57 33 W | .. | 26,5 | 25,9 | 26,3 | 26,9 | 28,2 | 25,6 Feb. | 28,6 Sept. | 1-3 |
| Singapore | 1 17 | 101 30 E | .. | 26,5 | 25,9 | 26,9 | 27,1 | 26,7 | 25,6 Jan. | 27,4 June. | 6 |
| St. Bartholomew | 17 53 | 65 20 W | — | 26,6 | 26,1 | 26,6 | 27,4 | 26,4 | 25,9 Feb. | 28,5 July. | 2 |
| Batavia | 6 9 S | 104 33 E | — | 26,8 | 26,2 | 26,8 | 27,2 | 27,1 | 25,9 Jan. | 27,8 June. | 1 |
| Fort Dundas | 11 25 | 127 45 W | — | 27,0 | 24,0 | 27,5 | 28,8 | 27,8 | 22,3 ,, | 29,3 ,, | 1 |
| Anjarakandy | 11 40 N | 73 20 E | — | 27,2 | 26,9 | 29,0 | 26,1 | 26,7 | 25,7 July. | 29,8 Apr. | 10-13 |
| Christiansberg | 5 24 | 2 10 W | — | 27,2 | 27,4 | 29,0 | 25,5 | 27,0 | 24,6 Aug. | 29,2 ,, | 3-4 |
| St. Louis de Maranhâo | 2 31 S | 46 36 | — | 27,2 | 27,0 | 27,0 | 26,9 | 26,4 | 26,3 Oct. | 27,1 July. | 2-1 |
| Cumana | 10 28 N | 66 30 | — | 27,4 | 27,0 | 28,6 | 28,1 | .. | 26,9 Jan. | 29,2 May. | 1 |
| Trincomalee | 8 34 | 79 2 | — | 27,4 | 25,7 | 28,4 | 28,9 | 27,2 | 25,4 ,, | 29,2 June. | 4-3 |
| Coast of Guinea | 5 30 | 2 | — | 27,4 | 28,1 | 28,3 | 26,4 | 27,0 | 25,6 Aug. | 28,8 Feb. | 1-2 |
| Nagpour | 21 9 | 76 51 E | 273 | 27,5 | 22,7 | 32,9 | 28,2 | 26,4 | 21,9 Jan. | 35,7 May. | 3 |
| Madras | 13 5 | 77 57 | — | 27,8 | 24,8 | 28,6 | 30,2 | 27,5 | 24,1 ,, | 31,3 June. | 25 |
| Kouka | 13 10 | 12 10 | 351 | 28,2 | 23,8 | 32,6 | 29,0 | 27,2 | 20,6 Dec. | 33,7 Apr. | 1-2 |
| Karikal | 10 55 | 77 24 | .. | 28,7 | 26,4 | 30,0 | 29,9 | 28,6 | 25,5 ,, | 31,5 May. | 1 |
| Rio Hacha | 11 28 | 75 20 W | — | .. | 27,6 | 28,5 | .. | .. | 27,4 Jan. | (29,1 Jun.) | 1 |
| Maracaybo | 11 19 | 76 29 | — | 29,0 | 27,8 | 29,5 | 30,4 | 29,5 | 27,3 ,, | 30,5 Aug. | 1 |
| Masfaoua (Abyssinia) | 15 36 | 37 9 | — | (31,0) | 26,7 | 29,5 | .. | 32,0 | 25,5 ,, | (33,8 Sep.) | 1 |

**DIFFERENT TEMPERATURES IN EQUAL LATITUDES.**—The preceding table shews that the temperature of a place depends not only on its latitude, but also on its longitude. Thus Eastport, in America, and Stockholm, have a mean temperature of about 5°,5; and yet there are 14 degrees of difference in their latitudes. A mean, varying between 11° and 11°,5, is found at Germantown, Fort Columbus, Fort Vancouver, Penzance, Plymouth, and Sevastopol; that is, in 40°, 40° 42′, 45° 38′, 50° 7′, 50° 22′, and 44° 36′ N. latitude. So also in going from the west coast of North America, where it approaches nearest to the equator, the line passing through all those places whose temperature is from 11° to 11°,5, on the one hand rises towards the east coast of the new continent, where it attains the 45° of latitude; on the other hand, toward Europe, where it passes the 50th, its greatest amplitude is in 10° of latitude. On the shores of the Black Sea it descends as low as 44°; and if we knew the climate of the centre of Asia, it is probable that it would fall still lower toward the equator, in the interior of this continent. The angle under which the rays of the sun strike the earth is not, then, the only element by which temperature is determined: there are other elements which we are now about to analyse.

**PHYSICAL CAUSES OF DIFFERENCES OF TEMPERATURE.**—Winds are the most powerful cause of disturbance of equilibrium in temperature. Their action is not always immediate; but, on studying it, we are confirmed in the idea that all atmospheric phenomena are connected together, and react on each other so as alternately to play the part of cause and effect.

If the surface of the earth were perfectly smooth, and merely composed of land, or entirely enveloped with an immense ocean, we might probably find the same temperature in equal latitudes. However, on analysing the phenomena, we see that this diminution of heat does not depend simply on the lesser height of the sun above the horizon; for the trade-winds, by incessantly drawing toward the equator masses of air obtained from high latitudes, cool the intertropical regions, the climate of which is less scorching than if the atmospheric ocean were in a state of perfect repose. The upper S.W. wind, on the contrary, which comes from the equator, descends towards the earth as it advances towards the poles, and communicates to the regions that it touches a portion of the equatorial heat, and softens the rigour of their climate. The observations that we have collected confirm these facts in the most positive manner. Indeed, if we select a series of places, all situated under the same meridian, but very distant from each other in latitude, we shall find that the diminution of temperature is not proportional to the difference in latitude; and that it would be impossible to deduce the thermometric climate of any place from this element alone. The differences between calculation and observation are such, that they cannot be attributed to the employment of imperfect instruments, or to the influence of years of exceptional temperatures. Thus, for the equator, calculation gives higher temperatures than those that are found by direct observation. In more elevated latitudes, on the contrary, the numbers to which it leads are too low. These two results are very well explained by the opposing influence of the trade-winds, which warm the poles and cool the equator.

The differences between the mean temperatures of two countries situated at the same distance from the equator, are a consequence of the relative masses of earth and water with which they are surrounded. The great capacity of water for heat (p. 11), is the cause why the two great oceans that extend from pole to pole, between the two vast continents, are colder than the land in summer, and warmer in winter. Consequently, the west winds, which come from the sea, and blow more rarely in summer than in winter (p. 52), will, in this season, communicate a greater amount of heat to the west coasts of the continent. This induction is confirmed by experience. But when these winds arrive into the interior of the land, their temperature is by no means so elevated, especially if they meet near the west sides of high chains of mountains. This is the case in Scotland, and especially so in Norway. There is likewise no country on the earth which, in equal latitudes, does not enjoy a climate as mild as that of the last place we just mentioned.

Besides their elevated temperature, these S.W. winds are also distinguished by their moisture, which is such that, in winter, they are almost entirely saturated with the vapour of water; hence the atmosphere of Europe and America is almost constantly foggy during that season. These clouds oppose the cooling of the earth by radiation: in passing into the liquid state, the vapours with which they are charged set free their latent heat; and the temperature of the air is raised under this double influence. In the interior of continents, on the contrary, a serene sky favours radiation, and determines a fall in the temperature. Equilibrium is not re-established in summer; for if in this season the sky were as often clear as it is in winter, the sun would act energetically; but in the interior of the European continent, the sky being often cloudy in summer, the mean temperature of the year is much lower than on the west coasts.

It is the same with the east coasts. Kamtschatka is warmer than Siberia; New York has a higher temperature than that of the towns situated on the Mississippi. However, in high latitudes the west coasts are always colder than the east. In general, the elevation of the mean is due to the neighbourhood of the sea, its reduction to that of the continent; for the S.W. winds which, especially in winter, have passed over great continents, arrive deprived of all humidity on the east coasts, where the habitual serenity of the sky favours radiation.

The differences of temperature, such as those we have just pointed out, would exist, even though the sea were perfectly calm; but what further tends to increase them is the existence of sea-currents, which favour this unequal distribution of heat. They are principally observed on the two shores of the Atlantic, and they explain to us the mildness of the climates of the west coasts of Europe, and certain climateric peculiarities of the east regions of America.

The trade-wind that blows regularly over the Atlantic, drives toward the west a considerable mass of water. This west current continues enlarging to Cape Saint-Roch, where it divides into two branches, one of which descends toward the south, while the other ascends toward the north, along the east coast of America. This latter branch enters into the Gulf of Mexico, and then rushes into the canal of Bahama, and thence ascends toward the north, under the name of the *Gulfstream*, flowing about 80 sea miles (148 kilometres) per day. This mass of water being exposed for a long time to the rays of the tropical sun, has a temperature of more than 27°, when it leaves the Gulf of Mexico. The current expands as it ascends the American coast, and its velocity diminishes. Between Cayo Biscaino and the reef of Bahama, its width is about nine myriametres; at the parallel of Charlestown, in front of Cape Henlopen, it expands to as much as 23 myriametres; but its velocity diminishes until it does not travel more than 60 or 70 miles per day.

More northerly, the coasts of Georgia and Carolina change its direction: it turns toward the N.E., passes near Cape Hatteras, and pursues its march to the bank of St. George, on the east of Nantucket. Here, at 49° 30′ of latitude, and 67° of longitude west of Paris, it is 47 myriametres wide; under this parallel it suddenly turns to the east; so that its western boundary becomes its northern limit, and goes along the bank of Newfoundland. Its limits are dependent on the seasons. When, during the autumn, there are squalls from the north and the N.W., a considerable accumulation of water occurs between the bank of Newfoundland and the west limit of the current, which deviates it toward the east. Thence it turns toward the E.S.E., as far as the Azores, where its width is 78 myriametres or more, and its velocity 30 miles per day. It moves with less regularity along the coast of Guinea; however, its rapidity is still about 25 miles per day.

A less important branch, and one which is more dependent on the direction of the winds, separates from the principal current at about 45° or 50° of north latitude, near the bank of Bonnet-Flamand, and directs its course toward Europe. This current is more especially sensible after west winds have been blowing uninterruptedly for a long time. Every year it carries on to the coasts of Norway fruits and seeds of trees that belong to the hot parts of America. On the west coast of the Hebrides are often found the seeds of *Dolichos urens*, *Guilandina bonduc*, *G. bonducella*, *Mimosa scandens*, and other plants of Jamaica, Cuba, and the American continent. This current also brings shells of the tortoise, and casks of wine from ships wrecked on the sea of the Antillas.*

These very west winds that drive the *Gulfstream* over to the neighbourhood of Europe, produce on the coast of France a current, that **Rennell** has made known; the name of this learned geographer has been applied to it. The same winds drive the current into the Bay of Biscay, where it turns to the north, along the coasts of France, and enlarges in the neighbourhood, so as to be scarcely sensible on account of the changeableness of the winds.

The *Gulfstream*, in traversing the Atlantic, forms a very limited current, which preserves its original temperature for a long time. As early as 1780, **Franklin** and **Blagden** recommended nautical men to use the thermometer, in order to ascertain whether they were in the *Gulfstream*. According to M. **de Humboldt,** the sea, between 40° and 44° of latitude, had a temperature of 22°,5, whilst out of the current it was 17°,5. When **Sabine** went out of the current, in 36° 14′ north, and 74° west longitude, between 10 A.M. and noon, the thermometer fell in the space of two hours, from 23°,3 to 16°,9, to wit, 6°,4, without the depth of the sea having suffered any sensible change. The tem-

---

* In 1838, I found, with M. LOTTIN, at Kielvig, near the North Cape, a seed of the *Mimosa scandens* among the shingle of the bank. They are very common there, for they are seen in the possession of all the fishermen on the coast.

perature of the air above the current shares in that of the water, as all observations prove.

These currents notably elevate the temperature of the coasts that are washed by them. In low latitudes, a current of warm water passes along the Floridas, whilst a current from the north descends along the coast of Africa. So, although under the same latitude, the Floridas are warmer than the Canaries by 1° or 2°. If we examine the countries situated beyond the trade-winds, the two coasts have sensibly the same mean temperature. Differences commence at about 30° of north latitude. On the east coast of America the temperature falls much more rapidly than on the coast of Europe, as we leave the equator. This fall is especially sensible in the places where this *Gulfstream* is at a distance from the new continent. If we collect the latitudes under which the mean temperatures of 25°, 20°, 15°, 10°, 5°, and 0°, are found, we obtain the following relations:—

LATITUDE OF PLACES OF EQUAL MEAN TEMPERATURE, ON THE COASTS OF EUROPE AND AMERICA.

| TEMPERATURE. | COAST OF AMERICA. | COAST OF EUROPE. | NORWAY. |
|---|---|---|---|
| 25° | 24° 21′ | 18° 49′ | „ |
| 20 | 32 20 | 31 27 | „ |
| 15 | 38 24 | 41 33 | „ |
| 10 | 41 30 | 52 3 | „ |
| 5 | 44 51 | 60 7 | 63° 23′ |
| 0 | 51 57 | 66 48 | 70 56 |

The S.W. winds which prevail in high latitudes are warmed by the *Gulfstream*, and raises the temperature of west Europe, so that the isothermal of zero cuts the coast of Norway 20° more northerly than it does that of America, namely, at a latitude where we find on the east coast of America temperatures of —10° and —15° in the interior of the land.

Although generally warmer than the east coast of the two continents, the west coast of America has not, however, a temperature comparable with that of the west coast of Europe; this is due to the direction of the marine currents. When it inclines to the west, the equatorial current has a greater width; but the islands, that are so numerous in the

Pacific Ocean, turn it out of its course, and, between New Holland and the Philippines, there are currents dependent on the monsoons; it is only on the coast of Japan that a current flowing to the N.E. is found, which is comparable in its extent and rapidity with the *Gulfstream* of the Atlantic. The S.W. winds always drive considerable masses of water toward America; for, on the coasts of California, and near Alaschka, are found the remains of Japanese junks: but this current never attains the temperature of the *Gulfstream;* the winds, also, that heat Kamtschatka and the west coast of America, are not to be compared in temperature with those that pass over the *Gulfstream.*

**TEMPERATURE OF THE EQUATOR.**—If we choose places situated between the tropics, from their mean temperature, that of the equator may be deduced; and we may obtain a result that will not be far from the truth. Indeed, within these limits the differences of latitude have much less influence over the climate than when we approach nearer to the arctic zone. This is due to the little variation in the height of the sun in the different seasons, and to the difference of the constant sea and aërial currents that prevail in these regions. For, as we have seen, the east coast of America is heated by an equatorial current, and the west coast by a current from the north. In India, the very powerful influence of monsoons is found; but on the west coast of South America the temperature appears to decrease very rapidly: however, observations are still very few in number for these countries, and we cannot rigorously deduce the law of this decrease.

M. **de Humboldt** fixed the heat of the equator approximately at 27°,5; and, indeed, if we examine the temperature of the different places situated near the line, we shall find the following numbers:—

| | | |
|---|---|---|
| West coast of Africa. | North hemisphere | 27°,85 |
| East coast of America. | N. and S. hemisphere | 27 ,74 |
| Hindostan and Ceylon | | 27 ,29 |
| East coast of Asia | | 27 ,66 |
| Great Ocean | | 27 ,27 |
| East coast of America | | 27 ,40 |

The mean is 27°,53, which singularly confirms the result found by M. **de Humboldt.** However, this is only true of the coasts; in the interior of Africa and America the temperature is higher than at the sea-shore. A distinguished traveller, M. **Boussingault,** has published observations made in different parts of the Andes. Although these places are often situated at more than 3000 metres above the level of the sea, we can yet determine approximatively the temperature which they would have if they were at the level of the ocean. Now, on deducing the decrease of temperature from these observations themselves, I find more than 28°; but here is clearly shewn the influence exercised by exterior circumstances over the mean temperature; for, at equal latitudes and heights, barren and dry countries have a temperature a degree higher than those that are covered with forests, and, consequently, watered by frequent rains. For to the absence of vegetation must be attributed the burning climate of the interior of Africa. The few observations we possess seem to assign it a temperature of 29°,2; and yet these places are situated at even more than 300 metres above the level of the sea.

The preceding facts prove the opposing influence of the earth and the sea; but they do not decide the question of knowing if, under each meridian, the hottest points are at the intersection of this meridian with the equator. It is probable that the violent rains caused by ascending aërial currents in the neighbourhood of the equator must give rise to differences of several degrees.

M. **Berghaus** has given, in the second part of his *Physical Atlas*, a chart, in which he has collected all the places, the temperature of which is a *maximum*. This curve, which is named the *equator of heat*, very nearly follows the equator of the earth, and presents inflections, the cause of which is not manifest; for the want of observations, and the little reliance to be placed on those which have been made, do not as yet authorise us to trace accurately the curve in question.

**ISOTHERMALS.** — On connecting by lines all the points whose mean temperature is the same, we obtain the curves that M. **de Humboldt** was the first to trace on charts, and which he has named *Isothermals* (ἴσος, *equal*; θερμὸς, *heat*). But, as this temperature varies with the height above the sea, these temperatures must be reduced to that level,—a reduction of which I shall speak presently. This work is one of the few that form an epoch in Meteorology; it has served to establish the great laws of the distribution of heat on the surface of the globe. Since its publication, observations have been multiplied; and, in 1831, I endeavoured to trace out a new series of isothermal lines, which differ in only a few points from those of M. **de Humboldt**. I have further modified this work, since we have possessed observations made in the interior of continents, and in the polar regions. The following are the principal results of these researches:—

1st. The point of each meridian that possesses the highest temperature does not always coincide with the intersection of the meridian and the equator.

2d. The equator of the earth, on the borders of the sea, has a temperature of 27°,5; on the west coasts of the two continents this heat appears to be a little less, because the currents of cold water which come from the poles depress the temperature of these points. In the interior of the two continents, the temperature of the equator is higher than on the coasts; the rains are less abundant, the sky more serene, and consequently the influence of the sun is more energetic. In Africa, especially, where the air is strongly heated by vast sandy deserts, this difference is notable. In America, the least increase of the continent in longitude tends to diminish it considerably. The temperature of the equator rises in Africa to 29°, and even more.

3d. The isothermal of 25° (*vide* pl. VI.) cuts the west coast of America, a little north of Acapulco; then it passes by Vera Cruz, and a little to the north of Havannah (temp. 25°). At the east of the meridian of this city it forms a slight convexity towards the north, and falls on the west coast of Africa, which it cuts between Cape Blanc and the mouth of the Senegal, about 18° or 19° of north latitude. Hence it rises abruptly toward the north, passes by the north of the Red Sea, then by Abuscheher, on the Persian Gulf (lat. 28° 15′, temp. 25°), and probably attains here its most northerly point. Then, at the east, it descends toward the south, cuts the group of the Philippines in the north part of the isle Luçon, in 16° or 17° of north latitude. (Manilla, lat. 14° 36′, temp. 25°,6.)

4th. The isothermal of 20° (pl. VI.) cuts the west of America, in the middle of California, at 28° or 29° of north latitude. It rises a little toward the north; it then goes parallel to the equator until it reaches the west coast of America, in South Carolina, at 32° north latitude (Fort Johnston, lat. 34°, temp. 19°,2; cantonment Jessup, lat. 31° 30′, temp. 20°,2). It falls a little toward the south, leaves the Bermudas (lat. 32° 20′, temp. 19°,7) to the north, and passes between Madeira and Teueriffe (Funchal, temp. 18°,7; Sainte-Croix-de-Teneriffe, 21°,9). In Africa, it ascends abruptly towards the north, passes near Tunis and Algiers; it then seems to follow the direction of the coast, which runs from north to south, and passes between the isle of Candia (lat. 35° 29′, temp 17°,9) and Cairo (lat. 30° 2′, temp. 22°,4). It is probable that, in the interior of Asia, it rises anew toward the north, to fall again toward the west coast, which it cuts in the neighbourhood of Formosa.

5th. The isothermal of 15° (pl. VI.) cuts the west coast of America near Port San-Francisco, in New California; it proceeds straight to the east, and in the State of Delaware attains a latitude of 37° to 38° (Fort Savern, lat. 38° 58′, temp. 13°,9; Chapel Hill, lat. 35° 54′, temp. 15°,7; Nashville, lat. 36° 5′, temp. 15°,4). Thence it rises toward the north, and reaches the west coast of Europe, at the limit of Spain and Portugal (Lisbon, lat. 38° 43′, temp. 16°,4); it then passes to the north of Rome (temp. 15°,4), and traverses the north part of Turkey. This line attains the east coast of Asia in the south part of the Corea, and Japan (Nangasaki, lat. 32° 45′, temp. 16°).

6th. The isothermal of 10° (pl. VI.) cuts the west coast of America at the mouth of the Columbus (Fort George, lat. 46° 18′, temp. 10°,1; Fort Vancouver, lat. 45° 36′ N. temp. 11°,5); descends toward the south, traverses the north part of the State of Ohio, and reaches near New York the shores of the Atlantic (Kingston, New York, lat. 41° 55′, temp. 10°; North Salem, lat. 41° 20′, temp. 8°,9). Here the isothermal presents a great convexity towards the equator; then it rises abruptly toward the north, passes in the neighbourhood of London (lat. 51° 31′, temp. 10°,4; Dublin, lat. 53° 21′, temp. 9°,5). This is the highest latitude that this isothermal attains; for it then falls toward the south, passes through Bohemia (Prague, lat. 50° 5′, height above the sea, 195 metres, temp. 9°,5; Dresden, lat. 51° 3′, height, 117 metres, temp. 8°,5), the north part of the Black Sea (Nicolaïeffe, lat. 46° 58′, temp. 9°,3; Sevastopol, lat. 44°,35, temp. 11°,5). This isothermal probably cuts the east coast of Asia, at the north of the isle of Nipon.

7th. The isothermal of 5° (pl. VI.) cuts the west coast of America at the north of New Archangel, on the isle Sitcha (lat. 57°, temp. 7°,1). Yet it seems to come from the south; for Iloulouk, on the isle Ounalaschka, and in lat. 53° 53′, appears to have a temperature of only 4°. It then descends toward the south, cuts Lake Michigan (Fort Brady, lat. 46° 39′, height, 180 metres, temp. 4°,9), and the west coast of America, in the State of Maine (Eastport, lat. 44° 54′, temp. 5°,4; Halifax, lat. 44° 44′, temp. 6°,2). It then traverses the south part of Newfoundland, passes the north of the Feroe Isles, cuts the Norwegian coast as high up as Drontheim (lat. 63° 26′, temp. 4°,5). As soon as it has traversed the Scandinavian Alps, it descends toward S.E., passes to the north of Christiania (temp. 5°,4) and Stockholm (temp. 5°,6), to the south of Kasan and Moscow, and reaches the coast of Asia in the midst of the chain of the Kuriles.

8th. Parting from the west coast of America, the isothermal of zero (pl. VI.) directs its course toward the S.E., passes by the south part of the lake Winipeg, and cuts the S.E. angle of Labrador. Thence it rises abruptly toward the N.E., touches the North Cape of Norway (North Cape, lat. 71° 10′, temp. 0°,1), descends abruptly toward the south, in the interior of Lapland, parallel to the Scandinavian chain; traverses the north extremity of the Gulf of Bothnia (Uleaborg, lat. 65°, temp. 0°,7), passes to the north of Kasan, Slatoust (lat. 55° 8′, height, 360 metres, temp. —0°,7) and Bernaul (lat. 53° 20′, height, 118 metres, temp. 1°,7); rises on the east coast of Asia, toward the N.E., and cuts it toward the 56th parallel, in the middle of Kamtschatka (Petropaulowsk, lat. 53°, temp. 2°,04).

The isothermals that we have hitherto mentioned might have been traced on a chart on **Mercator's** projection; but the following cannot be followed throughout their course except on a terrestrial globe, or on a chart with a polar projection, such as that of pl. VI.; for they no longer make the tour of the earth, but they form in each continent two systems of concentric curves. We will give an idea of their arrangement, which is as yet little known.

9th. The isothermal of —5° (pl. VI.) probably commences toward the mouth of the river Mackenzie, penetrates into the interior of the American continent, and attains about 92° of west longitude, and 52° north latitude, at its most southern point. Then, directing itself toward the N.E., it passes by the north parts of Labrador (Nain, lat. 57° 30′, temp. —3°,6; Okak, lat. 57°, temp. —3°,6), and cuts the west coast of Greenland at the height of the polar circle. In our continent this line occurs between the White Sea and Nova Zembla; it passes several degrees to the north of Tobolsk, attains its most southern point under the meridian of Irkutsk; it then rises again toward the N.E., and traverses the east coast of Asia in the countries of the Jakoutes.

The isothermal of —10° (pl. VI.) cuts the south part of Bear Lake, it then passes into the neighbourhood of Fort Reliance (lat. 62° 46′, temp. —10°,2), and rises again at the north. The curve of the old continent traverses Nova Zembla (Felsenbai, lat. 70° 37′, temp. —9°,4), Matotschkin-Schar, lat. 73° 15′, temp. —8°,4), passes into the neighbourhood of Jakoutsk (lat. 62° 2′, height 115 metres, temp. —9°,7); then, rising towards the N.E., it reaches Nischni-Kolymsk (lat. 68° 18′, temp. —10°).

10th. The isothermal of —15° passes to the south of

Melville Island, by Port Elizabeth, in the isle of Boothia (lat. 65° 59′, temp. —15°,7), then rises to the north of the isle of Igloolik (lat. 69° 20′, temp. —16°,6), on the north coast of Siberia. This line appears to cut the coast several degrees to the west of Cape Taimura; it also passes perhaps by Ustjansk.

**TEMPERATURE OF THE NORTH POLE.**—Philosophers have been much occupied upon this problem, which probably can never be resolved by direct observation. The greater majority of ancient authors have assigned to it a very elevated temperature. M. **Arago**[*] distinguishes the case in which the solid earth would extend to the pole, from that where it would be surrounded by water. In the former case, he thinks that a temperature of —32° may be assigned to it; in the latter, a temperature of —18°. **Mayer's** calculations assign to it a temperature of 0°, which is evidently too high, but that which M. **Arago** attributes to it appears to me a little too low.

More recent voyages render it very probable that seas extend to the pole. If this is the case, its mean temperature must be about —8°; a figure which cannot be far from the truth, since the observations made on the west coast of America, on the east coast of Asia, and on the west coast of Europe, lead equally to this result. In studying the temperature of the two seas, we deduce the relation existing between this temperature and latitude; and this relation leads us to adopt —5°,7 as the temperature of the sea at the north pole, a temperature a little higher than that of the air. This difference arises from the land-winds blowing at the pole, which lower the temperature of the air.[†]

---

[*] Vide *Annuaire du Bureau des Longitudes* for 1825, p. 186.

[†] In the second voyage of *La Recherche* to Spitzbergen, in July and August 1839, I found, by means of several of WALFERDIN's inverting thermometers, corrected for pressure, and employed simultaneously in each experiment, the following temperatures at the surface of the earth, and at different depths:—

| POINTS. | | DEPTH in Metres. | TEMPERATURE at this Depth. | TEMPERATURE at the Surface. |
|---|---|---|---|---|
| Latitude. | Longitude. | | | |
| 70° 40′ N. | 21° 5′E. | $195^{m}$ | 3°,91 | 5°,0 |
| 71 1 | 21 3 | 240 | 3 ,85 | 7 ,5 |
| 72 29 | 17 34 | 390 | 3 ,63 | 7 ,1 |
| 73 36 | 18 32 | 870 | 0 ,10 | 5 ,7 |
| 73 52 | 14 3 | 308 | 2 ,42 | 5 ,5 |
| 74 52 | 10 37 | 487 | 0 ,82 | 5 ,8 |
| 75 55 | 6 56 | 730 | 0 ,42 | 3 ,4 |
| 76 13 | 10 28 | 641 | 0 ,17 | 5 ,4 |
| 76 57 | 11 9 | 317 | 1 ,56 | 2 ,4 |
| 77 43 | 9 51 | 121 | 1 ,30 | ,, ,, |
| 79 33 | 8 34 | 65 | 1 ,27 | 2 ,8 |

**POLES OF COLD.**—On comparing the mean temperature of the pole with that of a great many places on the earth, and on considering the curves described by the isothermals, we are led to admit that the poles of cold do not coincide with the geographical poles (*vide* pl. VI.). **Brewster** was the first to maintain that these two poles were in the north of either continent; he thought that they were situated under the 80th parallel, and in 93° of east longitude, and 182° of west longitude from Paris. In my *Treatise on Meteorology*, I have shewn that one of these points is at the north of Barrow's Strait, in America; the other near Cape Taimura, in Siberia. **Berghaus**, in his Atlas, transfers the American cold pole to 78° of north latitude, and 92° of west longitude, and assigns to it a temperature of —19°,7. He places the Asiatic cold pole under 79° 30′ north latitude, and 118° east longitude, and gives it a temperature of—17°,2. We shall probably never be able to fix exactly the position of these two points, nor to determine rigorously their temperature. However, taking advantage of the few observations that we possess on the climate of North Asia, I find that the isothermal of —5° passes through the following points:—

COURSE OF THE ISOTHERMAL OF —5°.

| | | | | |
|---|---|---|---|---|
| Longitude | 60° E. | Latitude | 65° | 20′N. |
| „ | 70 | „ | 64 | 32 |
| „ | 110 | „ | 57 | 41 |
| „ | 120 | „ | 58 | 21 |

(*Vide* pl. VI.)

Thus it descends towards the south at 110° of east longitude, and rises again towards the north; it is, therefore, between the 70th and the 110th degree of longitude that it attains its most southern point: aud between these meridians we may expect to find the pole of cold.

**TEMPERATURE OF THE SOUTHERN HEMISPHERE.**—Almost all meteorological series have been made at places situated in the northern hemisphere. Science is in possession of but very few observations on the other hemisphere, and it is only with hesitation that we can employ the means that have been deduced. However, we possess some data on the high latitudes of the east coast of America. The following have come to my knowledge:—

MEAN TEMPERATURES OF THE SOUTHERN HEMISPHERE.

| PLACES. | S. LATITUDE. | TEMPERATURE. |
|---|---|---|
| Maranham . . | 2° 29′ | 27°,40 |
| Rio Janeiro . . | 22 56 | 23 ,42 |
| Buenos Ayres . | 34 36 | 17 ,00 |
| Falkland Isles . | 51 0 | 8 ,46 |
| Port Famine . . | 53 44 | 5 ,04 |

According to this, the isothermal of 5° probably cuts the south extremity of America; it is in this latitude, also, of 55° that the same isothermal cuts the west coast of North America. We may hence conclude that the distribution of heat is nearly the same in the two continents as far as 50°; but the temperature of the south pole, deduced from that of the places situated near the equator, is a little lower than that of the north pole. The temperature of the Southern Ocean is also colder in equal latitudes than that of the North Sea. Travellers have put forth very exaggerated ideas on the difference of the temperature of the two hemispheres; this is due to the small number of stationary observers that have dwelt there. **Kirwan, Legentil,** and **de Humboldt,** have long ago remarked that the cold summers alluded to by travellers decide nothing with regard to the mean, because the very large mass of water that is found in this hemisphere must greatly mitigate the rigour of the winters. The following facts prove that the difference is not so great as it has been described.

In his second voyage, **Cook** could scarcely pass beyond the polar circle; but more recently, **Weddel** found the sea free to the 74th degree of south latitude.* **Forster's** account appears exaggerated: he thus speaks:—"In the middle of summer the mountains and the coast of New Georgia are covered with snow, even to the edge of the sea; it is only on certain spots more exposed to the sun that this bed is able to melt, and leave the earth bare. On the spot where we landed we found only two plants, the *Ancistrum decumbens*, and the

---

* The ice-bank by which navigators are stopped occupies every year a different place, and presents very variable solutions of continuity. Thus, in his two attempts to advance towards the south pole, DUMONT-DURVILLE was stopped each time near the polar circle, although he tried several times to penetrate into the ice. Since his time, Mr. JAMES ROSS found the sea navigable as far as 78° 4′ of south latitude.

*Dactylis glomerata.*" It would, undoubtedly, be a very extraordinary climate in 54° 30′, to produce only two phanerogamic plants, and where the earth should be thus covered with snow all the summer: but **Cook's** account shews that glaciers descend from elevated mountains; and the stay of the voyagers was much too short to induce me to believe that they had collected all the flowers of the island. **Cook** mentions a moss, of which **Forster** does not speak;[*] **Weddel,** who visited the island more recently, says that the grass is six decimetres high, and that he found a large quantity of antiscorbutic plants. South Nova Scotia, which is situated several degrees farther south, produces also a grass and a lichen.

The description that **Forster** gives of Terra del Fuego is not more flattering. "The west coast," says he, "is a chain of naked rocks, the summits of which are covered with snow. In a large harbour, situated at the north-west of Cape Horn, where we passed several days, we did not find the least trace of vegetation, except a moss which covered marshy places; and in ravines, and certain valleys, a shrub and a few thinly scattered trees." **Cook,** on the contrary, speaks of the same spot as being very rich in wood and in herbaceous plants; and, more southerly, **Weddel** was able to make planks from the trees with which he met. **Banks** was more fortunate than **Forster;** in the Bay of St. Vincent, near the Strait of **Lemaire,** he found, in the space of four hours, a hundred species of new plants, herbaceous and woody. The birch (*Betula antarctica*), of which the woods consist, had a trunk nine or ten metres high, and six or eight decimetres in circumference; and yet, as these trees were near the sea, we must admit that they did not attain their full developement. One degree further to the north, near Port Famine (mean temp. 5°), **Byron, Fitzroy,** and **Dumont-Durville,** found the shores of the Straits of Magellan covered with forests of most magnificent antarctic beech-trees, called *Fagus antarctica.* Some of the trees were 2,4 metres in diameter; the woods were tenanted by

---

[*] FORSTER has greatly exaggerated the poverty of the flora of this country. For a long time, also, on the faith of MARTENS of Hamburg, PHIPPS, SCORESBY, PARRY, and SABINE, it has been thought that the number of plants at Spitzbergen did not exceed a hundred. Since the voyage of KEILHAU, and those of the Commission of the North, the total number of the plants found in this isle amounts to 210. (Vide *Flora*, 1842, No. 31.) At Magdalena Bay, in 79° 28′ north latitude, in a very limited space, exposed to all the violences of the sea-breezes, I collected twenty-four phanerogamic plants. A list of them is found in my *Observations on the Glaciers of Spitzbergen* (*Bibliothèque Universelle*, July, 1840).—M.

parrots, and the natives were quite naked—a proof that the winter is not very rigorous.

**Barrow's** reports, on the expedition of the ships *Adventure* and *Beagle*, agree with these relations. According to him the east part of Terra del Fuego is the best of all the countries which are situated south of 45° of south latitude. The woody mountains of the west are reduced to the rank of hills, or plains, covered with trees. The climate is a mean between that of East Patagonia and West Terra del Fuego, which is penetrated by a deep bay, with islands studded with mountains, rising to about 600 metres. The weather is cloudy, rainy, and unsettled, throughout the year. The west part of Patagonia is formed of a great number of islands, the interiors of which are covered with impenetrable forests; the rain is continual, and the earth is never dry.

These gales and incessant rains render the summer of these countries very disagreeable, but the winters are very mild; and although at Port Famine the thermometer does not rise above 9°,8, it does not fall so low as the freezing point during the winter. This climate is, therefore, very analogous to that of West Norway, where the rain refreshes the summers, and keeps the winters warm.*

Attempts have been made to explain this lower temperature of the southern hemisphere; it has been said that the summer is some days longer in the northern hemisphere than in the other; but this difference is of trifling importance, and is, moreover, compensated in a great measure by the lesser distance of the earth from the sun during its south declination.

Others have spoken of the great mass of water that is found in the southern hemisphere; the water reflects one part of the rays, and the other penetrates into its interior, and does not contribute toward heating its surface. But it must be allowed that, in the course of ages, the heating of the interior strata must long ago have attained its limit. It would be the same if we wished to instance the greater calorific capacity of water compared with that of the earth; this circumstance must have an influence over the extent of the diurnal variations, but not over the annual mean. We may even deduce from it the opposite consequence: which

---

* The mildness of these climates is also due to a current of warm water that ascends along the west coast of South America, and traverses the Straits of Magellan. I obtain this information from Captain Duperrey, who has voyaged in these latitudes.—M.

is, that the southern hemisphere ought to be hotter than the other, on account of the greater mass of water that covers it; for, as the surface of the earth itself evaporates less than the water, the vapours come from the west seas; and, as the atmosphere that covers them is drier than that of the west seas of our hemisphere, the latter ought to be colder, on account of the more active evaporation, and the greater quantity of heat that becomes latent, in consequence of this evaporation.

I think it is to the particular configuration of the south continent that must be attributed its low temperature in high latitudes. In the northern hemisphere the equatorial currents are urged toward the high latitudes by the prevailing S.W. winds; in the other hemisphere, on the contrary, the current of the Indian sea turns to the north, or the west coast of Africa. It could not, therefore, heat the countries that surround the south pole. It appears, also, that there are no currents going from Cape Horn to the south pole; if, as modern travels seem to prove,* there exist extensive territories in the neighbourhood of this pole, they ought to turn back the equatorial currents; and, their climate being very severe, they would also cool the current of air by which they are traversed.†

**TEMPERATURE OF THE GROUND.**—If a spherical body, that is a bad conductor of heat, be exposed in the open air, having in its centre the bulb of a thermometer, the scale of which is visible exteriorly, the diurnal variations of this thermometer would be less than those of an instrument suspended freely in the air; their amplitudes will be the less, the more solid the body is, or the more its substance is a bad conductor of heat. The temperature of a body of this nature will be never very far away from the

---

* See especially those of BISCOE, WEDDEL, BALENY, DUMONT-DURVILLE, and JAMES ROSS.

† Perhaps, in explaining the unequal temperature of the two hemispheres, we ought to include the radiation of the ground toward celestial space,—a radiation, the intensity of which may vary according to the different regions of space, as M. POUILLET points out. Infinite space, peopled with the myriads of stars that surround us, with regard to its thermic effects, may be ideally represented by an immense hollow sphere, the surface of which is retained at a certain constant temperature, that might vary from one point of the surface to another. It is not impossible that the mean temperature of the south polar regions of this hollow sphere would be notably lower than that of the regions near the north pole of the said sphere, and the inequality of the temperatures of the two hemispheres, which are separated by the plane of the celestial equator, might induce a corresponding inequality in the two hemispheres of the earth. This thought is susceptible of verification; and properly conducted *actinometric* experiments may one day decide this delicate question.—M.

mean of the day on which the observation is made—a mean that may be deduced from a single or from two daily observations.

The terrestrial globe is a body of this kind. Thermometers furnished with long tubes are buried in the ground, and their indications are noted every day. In Germany, at six decimetres deep, the diurnal variation disappears. If the bulb is buried still deeper, the hours have no influence; and the indications do not change in the course of the day. Finally, between six and ten metres the instrument indicates throughout the day a temperature which is very nearly that of the annual mean. The depth at which this constant temperature is found depends on the conductibility of the soil,* and especially on the difference between the means of winter and those of summer. In tropical America, where this difference amounts to only a few degrees, we have merely to plunge the thermometer to a depth of five or six decimetres in order to obtain this mean.†

---

* Mr. Forbes made some comparative experiments near Edinburgh, on the variations of temperature at different depths in the trap of Calton Hill, in a homogeneous bed of sand, and in the coal-sandstone of Craigleith.

MAXIMUM AMPLITUDE OF THE ANNUAL VARIATION.

| ROCKS. | DEPTH IN METRES. | | | | TIMES OF THE MAXIMA OF TEMPERATURE. | | | |
|---|---|---|---|---|---|---|---|---|
| | m.<br>1,0 | m.<br>1,9 | m.<br>3,9 | m.<br>7,8 | m.<br>1,0 | m.<br>1,9 | m.<br>3,9 | m.<br>7,8 |
| Trap . . | 10°,53 | 6°,61 | 3°, 5 | 0°,80 | 6 Aug. | 2 Sep. | 17 Oct. | 8 Jan. |
| Sand . . | 11 ,23 | 8 ,30 | 4 ,19 | 1 ,16 | 31 July | 24 Aug. | 7 Oct. | 30 Dec. |
| Sandstone | 9 ,58 | 7 ,72 | 5 ,22 | 2 ,28 | 5 Aug. | 19 Aug. | 11 Sep. | 11 Nov. |

These results are corrected for the expansion and contraction of the part of the thermometric rods that is buried, and of that which is exposed (*Comptes rendus de l'Académie des Sciences*, t. viii. p. 85. 1839).—M.

† We are indebted to M. Boussingault for this result, which he obtained by a great number of observations. Thus, at the village of Vega de Zupia, in the Cordilleras, elevated 1225 metres above the sea, long series of thermometric observations made in the open air, in 1825, 1826, and 1829, have enabled us to fix the mean temperature at 21°,5. At three decimetres below the surface, in a closed hole roofed over, a thermometer, in August and September, marked 21°,5, or 21°,6, but more frequently 21°,5. The same results were obtained in the mines of Marmato, at 1426 metres above the sea; at the village of Purace, 2651 metres; at Popayan, elevated 1808 metres; and at Quito, which is 2914 metres above the sea.

M. Boussingault has given, p. 244–7, *Annales de Chimie et de Physique*, t. liii. 1833, the mean temperatures of 128 points situated between 11° north latitude, and 5° south latitude.

This rule is not at all applicable to our hemisphere, where very different laws prevail as we approach the pole. At Jakoutsk, in Siberia, in 62° of latitude, and at a mean temperature of —9°,7 (*vide* the sketch, p. 476), If thermometers, buried at different depths, are placed near each other, not only will their variations be reduced, but their ranges will differ considerably from that of the temperature of the air. The days when these thermometers will attain their *maxima* and *minima* will occur sooner or later after those on which the thermometer in the open air will indicate these extreme temperatures. If the bulb of the thermometer is buried, for example, $1^m,3$, in the ground, the *minimum* will take place in March, the *maximum* in September, that is to say, two months after the *minimum* and *maximum* in the air. In fact, when, during summer, the temperature of the air and of the surface of the ground is raised, the heat penetrates slowly through this badly conducting body; and some time elapses before the thermometer is influenced by these changes.*

M. ERMAN, and after him, M. SCHERGIN, took the temperature of the ground in a pit dug for the purpose of finding water. The following results were obtained :—

| DEPTH. | TEMPERATURE. |
|---|---|
| $15,2^m$ | $-7°,5$ |
| 23,5 | $-6,9$ |
| 36,3 | $-5,0$ |
| 116,5 | $-0,6$ |

(Vide *Comptes rendus de l'Académie des Sciences*, t. vi. p. 501. 1838).—M.

[*] M. QUETELET, director of the Observatory of Brussels, made, from 1834 to 1839, a series of observations on the range of thermometers buried in the ground at depths of $0^m,19$; $0^m,45$; $0^m,75$; $1^m,00$; $1^m,95$; $3^m,90$; and $7^m,80$. The results to which he arrived, and their mathematical discussion, form the subject of two long memoirs, inserted in the tenth and thirteenth volumes of the *Memoirs of the Brussels Academy*. In this place I can only give the general consequences that he has deduced from his observations.

1st. The mean rate of the transmission of heat from the surface of the ground was $7^m,80$, in 144 days, which gives three decimetres, traversed in six days.

2d. On comparing the observations of Paris, Strasbourg, Zurich, and Brussels, he finds that the annual variations are null at a depth of twenty-four metres. The amplitudes observed at Brussels, from 1834 to 1837, were—

| DEPTH. | ANNUAL VARIATIONS. |
|---|---|
| $0,19^m$ | 13°,28 |
| 0,45 | 12 ,44 |
| 0,75 | 11 ,35 |
| 1,00 | 10 ,58 |
| 1,95 | 7 ,59 |
| 3,90 | 4 ,49 |
| 7,80 | 1 ,13 |

3d. The rapidity with which the diurnal variations of temperatures are transmitted to the interior of the earth is about three hours for a bed of earth one decimetre thick.

4th. Diurnal variations may be considered as almost nothing at the depth of $1^m.3$, that is to say, at a depth nineteen times less than that to which these annual variations extend in a like degree. At $8^m,5$ deep, M. BRAVAIS observed at Bosekop a variation not exceeding one degree.

The mean temperature of the year is deduced from those of the ground, by having recourse to one of the three following methods :—

**TEMPERATURE OF SPRINGS.**—Springs and fountains owe their origin to rain-waters, which penetrate by the clefts and fissures of the soil, collect into reservoirs, and run out when they find an issue. Hence it is observed in all countries that, after long drought, the springs dry up; whilst they become more abundant after continued rains. During rainy years miners have much difficulty in protecting themselves from infiltrations; but the narrowness of the channels in which the water circulates is such, that it is not until several days, or even several weeks, after a heavy rain, that these infiltrations become more abundant.

The water being thus for a long time in contact with the different beds of which the soil is composed, the equilibrium of temperature is established between them: according as the rain-water is hotter or colder than the terrestrial strata, it cools or warms them. If it is collected in a subterranean reservoir, sufficiently deep that the diurnal variations have no longer any power to act on it, it will acquire a certain degree of temperature. In passing out by any channel, its temperature will be modified by the sides of this conduit; it will, therefore, be reduced in winter and elevated in summer, especially if we think of the great capacity of water for heat.

Abundant springs, which come from a great depth, have almost invariably the same temperature throughout the year. It is not, however, identical with that of the soil, although for a long time we have thought we could admit this. If mountains rise abruptly above the plain, the fountains that play at the foot of the mass will be colder than those that appear in the plain at a little distance. The water which penetrates the soil at the summit of the mountain is very cold, especially when it arises from the melting of snows: it then cools the strata through which it passes, so that mountain-springs have generally a very low temperature.

Springs, whose temperature is constant throughout the course of the year, are very suited for determining the

---

1st. By a single observation, taking the temperature of the earth, at twenty metres deep, and correcting it for the rise of temperature, in proportion to this depth, which may be estimated at one degree for each thirty or thirty-five metres;

2d. By the observations of two separate months of a half-year, taking the temperature at a few yards deep only;

3d. By the observations of four months equally distributed, reading thermometers placed in the open air, or on the surface of the earth.

The question of the temperature of the globe has been treated with the fullest details in the work by Professor G. BISCHOFF, entitled, *Die Waermelehre der innern unsers Erdkærpers*; Leipsic, 1837.—M.

mean temperature of the year, because two or three observations are sufficient for knowing this mean temperature. However, we should not forget a remark first made by **Wahlenberg**. Having observed in the neighbourhood of Upsal a great number of springs, some of which preserved a constant temperature, whilst that of others was variable, he found that, at a mean, the constant springs had a higher temperature than the others. This is, because they come from a great depth. Experiments made on Artesian wells shew, in the most evident manner, that temperature increases with depth. The water of some of these wells, and of almost all mineral springs that are not thermals, gives a higher degree of temperature than that which corresponds to the depth of their reservoir: hence, it is often very difficult to decide whether a spring may be made use of in meteorological researches.[*]

**Roebuck** was probably the first to advise the observation of springs in order to obtain the mean temperature of a place. He observed that those of London and Edinburgh have a temperature that very closely approaches that of the annual mean. After him, **John Hunter** again directed attention to this subject. But it is principally the observations of MM. **de Humboldt, Wahlenberg, de Buch, Erman**, and **Kupffer**, made in almost all parts of the world, which have demonstrated the interest of researches of this kind.

---

[*] The experiments of M. WALFERDIN, in the Artesian wells of the Paris basin, are contrary to the opinion of M. KAEMTZ, who insists that the temperature of the waters playing from an Artesian well are higher than that which they ought to have in respect to the depth of the reservoir. M. WALFERDIN made use of his inverting thermometer. These instruments, of which a description and figure are given in M. POUILLET's *Eléments de Physique*, t. ii. p. 507, and *fig*. 366, were protected from pressure; and the author always employed several simultaneously. Their agreement, which is often marvellous, is a guarantee to the correctness of the results. The following are instances:—

| ARTESIAN WELLS. | DEPTH. | TEMPERATURE. | INCREASE OF 1° FOR |
|---|---|---|---|
| Military School... | 137$^{m}$ | 16°,40 | 30$^{m}$,85 |
| St. André (Eure) . | 253 | 17 ,95 | 30 ,95 |
| Grenelle ...... | 400 | 23 ,50 | 31 ,50 |
| | 400 | 23 ,75 | 30 ,87 |
| | 505 | 26 ,43 | 32 ,30 |

To deduce the law of the increase of temperature in proportion to the depth, the constant temperature of 11°,7, which is that of a thermometer placed 28 metres deep, in the cellars of the Observatory, has been taken as a

The differences that are found between the temperature of springs and the mean of the years are due to the climacteric conditions peculiar to each locality. In Western Europe there is an equality; in Western Norway, on the contrary, the springs appear to be a little colder than the air. In proportion as we recede from the sea-shore, in that part of Europe which is on the north of the chain of the Alps, the springs are hotter than the air; and the difference is greater as we penetrate more deeply into the interior of the Continent. In almost all Italy, and between the tropics, the springs are colder than the mean of the air.

**M. de Buch** was the first to explain these apparent anomalies, by attending to the mode of the formation of springs. If it never rained, the soil would have, at a certain depth, the mean temperature of the air; if the same quantity of rain fell every month, and if we admit that this rain is at the temperature of the air, the mean of the springs would be equal to that of the air. This is the case in England, where as much rain falls in winter as in summer. In countries, on the contrary, where the summer rains exceed those of the winter, the mean temperature of the water that falls is higher than that of the air, and the springs are in the same condition. So, also, in Sweden and Germany, the springs are many degrees warmer than the annual mean. The contrary occurs in countries where it rains much in winter, as Norway and Italy. In tropical countries, the temperature falls rapidly at the commencement of the rainy season; but, in the localities where it rains in intervals throughout the year, there is an identity between the heat of the springs and that of the air.

**DECREASE OF TEMPERATURE WITH THE HEIGHT.**—In proportion as we ascend a mountain, it is

---

starting point. Thus it is proved that in the *chalk* strata, which forms the lower part of the Paris basin, the temperature increases 1° for every 31 or 32 metres. The last of these numbers, obtained by MM. ARAGO and WALFERDIN, in experiments made by them at the well of Grenelle with most minute carefulness, has yet been disputed by philosophers; but it was easy to shew its accuracy, since the water flows to the surface of the soil. We know, indeed, that it comes from a depth of 548 metres. If the notation of 26°,43 established for 505 metres, and the law of 1° of increase for every 32,3 metres, which has been deduced from it, be correct, we must find, from this latter datum for 43 metres, the difference between the depth of 505 and 548 metres, 1°,33, which, when added to 26°,43, obtained for 505 metres, makes 27°,76. Now, the water that comes to the surface has a temperature of from 27°,65 to 27°,70, and this minimum difference corresponds, as M. WALFERDIN was assured of by experiments of another kind, to the diminution of temperature that flowing water experiences in ascending from a depth of 548 metres, to the upper orifice of the well.

We see that it was difficult to find a more striking agreement between the latter temperatures obtained before the starting forth and those of the water that now runs on the surface of the soil.—M.

found that the temperature falls. Cases may undoubtedly occur in which this fall is nothing, or in which it is even warmer above than below; but these exceptions are rare, and are to be traced to the direction of the winds and to the season. Sometimes, indeed, warm south winds prevail above whilst the north wind blows on the plain. To know the laws of the decrease of temperature with the height, we must take the mean of a great many observations. The law according to which temperature decreases, as to the limits of the atmosphere, is yet unknown; however, within the limits that have hitherto been examined, we commit no great error in admitting that the same differences of level correspond to the same differences of temperature. If, then, we know the first of these quantities we shall divide it by the second, and the quotient will indicate the number of metres that we must ascend in order that the temperature may fall one degree.

Long series of correspondent observations, made at great differences of level, shew that this decrease varies with the season and with the hour of the day. The observations that **de Saussure** continued for seventeen days, on the Col du Géant, 3428 metres above the sea, whilst simultaneous observations were being made at Geneva (407 metres), and at Chamouni (1044 metres), have made the horal influence evident. According to the observations of **de Saussure,** and those which I made on the Rigi (1810 metres), while observations were being made at Basle, at Berne (548 metres), at Geneva, and at Zurich (459 metres), the following are the heights in metres which we must ascend in order to obtain a decrease of one degree:—

DIFFERENCE OF LEVEL, CORRESPONDING TO A FALL OF 1° OF THE THERMOMETER, AT ALL HOURS OF THE DAY.

| HOURS. | COL DU GÉANT. | RIGI. | HOURS. | COL DU GÉANT. | RIGI. |
|---|---|---|---|---|---|
| | m. | m. | | m. | m. |
| Noon. | 147,93 | 129,81 | Midnight | 170,93 | 163,91 |
| 1 | „ | 131,75 | 13 | „ | 168,40 |
| 2 | 139,94 | 128,83 | 14 | 189,06 | 174,63 |
| 3 | „ | 127,08 | 15 | „ | 180,68 |
| 4 | 141,89 | 124,35 | 16 | 209,91 | 185,16 |
| 5 | „ | 121,81 | 17 | „ | 186,33 |
| 6 | 140,92 | 122,01 | 18 | 194,90 | 178,92 |
| 7 | „ | 127,86 | 19 | „ | 168,01 |
| 8 | 143,06 | 135,65 | 20 | 179,90 | 153,19 |
| 9 | „ | 144,42 | 21 | „ | 144,42 |
| 10 | 156,90 | 152,02 | 22 | 160,02 | 139,36 |
| 11 | „ | 158,46 | 23 | „ | 121,95 |
| Mean .. | Col du Géant . 164,69<br>Rigi . . . . 149,10 | | | | |

(*Vide* Appendix, *fig.* 19.)

**De Saussure** made observations during the night; being alone, I could not read the barometer longer than from five in the morning till ten in the evening, and the laws of nocturnal decrease are deduced from those of the day. Although these tables present a few anomalies, yet they render the diurnal period clearly evident. About five in the evening is the time when the decrease of temperature is most rapid, and towards sunrise it is slowest. The difference that corresponds to these two times, deduced from observations, is equal to about the third of the mean height that we must ascend in order to obtain a fall of one degree. The difference of the two means, $164^{m},7$ and $149^{m},1$, is derived from the differences that the meteorological phenomena presented in the course of the two series.*

---

* If the diurnal variation of the thermometer followed the same laws on mountains and on plains, the two thermometers would rise and fall simultaneously; and their ranges, remaining parallel, the difference of their indications would be constant. The decrease of temperature would not vary according to the hours of the day. But, if the two diurnal curves of the temperature of the two stations are constructed graphically (taking the time as the abscissa), we immediately recognise the want of parallelism. In the following table M. Bravais has chosen for his lower station the mean of corresponding observations made at Milan, Geneva, and Zurich. The upper

The annual period is not less marked in our climates; the simultaneous meteorological series made at Geneva and on

---

station was on the summit of the Faulhorn, 2673 metres, in the canton of Berne. The observations lasted forty-four days; their mean epoch corresponds to August 12, 1841.

DECREASE OF TEMPERATURE BETWEEN MILAN, GENEVA, ZURICH, AND THE FAULHORN.

| HOURS. | STATIONS. | | DIFFERENCE. | DECREASE OF 1° FOR |
|---|---|---|---|---|
| | LOWER. | HIGHER. | | |
| 0 | 21°,45 | 6°,30 | 15°,15 | 155ᵐ |
| 3 | 22 ,28 | 5 ,71 | 16 ,57 | 139 |
| 6 | 20 ,91 | 4 ,09 | 16 ,82 | 139 |
| 9 | 17 ,85 | 3 ,10 | 14 ,75 | 159 |
| 12 | 14 ,67 | 2 ,95 | 11 ,72 | 200 |
| 15 | . . . | 2 ,65 | . . . | 200 ? |
| 18 | 14 ,88 | 2 ,53 | 12 ,35 | 190 |
| 21 | 18 ,85 | 4 ,21 | 14 ,64 | 160 |
| | | | Mean . . . . | 170ᵐ |

(*Vide* Appendix, *fig.* 20.)

During winter the results appear to be somewhat different. In January 1827, M. ESCHMANN remained for eleven days on the Rigi, while HORNER was making observations 1370 metres lower. The following are the hourly means:—

DECREASE OF TEMPERATURE BETWEEN ZURICH AND THE RIGI, IN WINTER.

| HOURS. | STATIONS. | | DIFFERENCE. | DECREASE OF 1° FOR |
|---|---|---|---|---|
| | HIGHER. | LOWER. | | |
| 0 | −0°,50 | −2°, 6 | −2°, 2 | 627ᵐ |
| 1 | −0 ,60 | −2 , 5 | −1 , 9 | 719 |
| 2 | −0 ,40 | −2 , 4 | −2 , 0 | 685 |
| 3 | −0 ,90 | −3 , 0 | −2 , 1 | 651 |
| 4 | −1 ,50 | −4 , 1 | −2 , 6 | 527 |
| 5 | −2 ,00 | −5 , 0 | −3 , 0 | 457 |
| 6 | −2 ,40 | −5 , 5 | −3 , 1 | 442 |
| 7 | −2 ,50 | −5 ,75 | −3 ,25 | 420 |
| 8 | −2 ,75 | −5 , 9 | −3 ,15 | 435 |
| 9 | −2 ,70 | −6 ,25 | −3 ,55 | 385 |
| 10 | −2 ,75 | −6 ,25 | −3 , 5 | 389 |
| . . | . . . | . . . | . . . | . . . |
| 19 | −4 , 6 | −6 , 9 | −2 , 3 | 596 |
| 20 | −4 , 4 | −6 , 5 | −2 , 1 | 651 |
| 21 | −3 , 6 | −5 , 5 | −1 , 9 | 719 |
| 22 | −2 , 9 | −4 , 4 | −1 , 5 | 913 |
| 23 | −2 , 0 | −2 ,75 | −0 ,75 | 1828 |

The differences of temperature are more feeble during the night than by day, which is precisely the reverse of what happens in summer. The habitually hazy state of the lower strata during winter may account for this difference. Moreover, the different terms, the means of which are represented by the figures in the column marked *difference*, are very irregular; the thermic state

St. Bernard enable us to calculate the laws. I have also compared places whose difference of level does not rise to more than 100 or 150 metres. The temperature of a place depends on its latitude, its longitude, and on its elevation above the level of the sea. Although we do not well know the mathematical relation existing between temperature and these three elements, yet we may find it for a surface of small extent, and have regard, in the developement of the formula, to the three co-ordinates of which we have spoken. I have therefore chosen thirty points, situated on the south and on the north of the Alps, between 45° and 50° of latitude, and between the meridians of Vienna and Paris, and I have deduced the laws of the distribution of heat in this surface. I have thus obtained the height in metres to which we must ascend in order to have a fall of 1° in the thermometer. The following table contains the results furnished by comparing Geneva and St. Bernard, and those to which the calculation of which I have just spoken has led me:—

DIFFERENCE OF LEVEL, CORRESPONDING TO A FALL OF 1° OF THE THERMOMETER, IN THE DIFFERENT MONTHS OF THE YEAR.

| MONTHS. | GENEVA AND ST. BERNARD. | S. GERMANY AND N. ITALY. |
|---|---|---|
| | m. | m. |
| January | 270,53 | 257,27 |
| February | 222,58 | 193,54 |
| March | 182,43 | 159,63 |
| April | 176,00 | 160,60 |
| May | 178,14 | 157,87 |
| June | 176,19 | 148,32 |
| July | 181,07 | 148,71 |
| August | 196,85 | 145,98 |
| September | 196,85 | 161,96 |
| October | 195,88 | 177,75 |
| November | 241,88 | 195,49 |
| December | 217,90 | 233,49 |
| Year | 202,12 | 172,68 |

(*Vide* Appendix, *fig.* 21.)

---

of the atmosphere is much more variable than in summer. In winter, and in winter alone, those remarkable interversions of temperature occur, that are accidentally found, even by day, higher on the mountain than on the plain.

The two series equally prove that in summer the thermometer falls much faster, in proportion as we ascend, than it does in winter. However, the figures present very notable differences—I think I can place greater reliance on those in the third column; for the hill on which the hospice of St. Bernard is situated is exposed to south winds, which may have some influence over the thermometer. These local disturbances vanish when we compare long series made in different localities, as is the case in the last column.*

It follows, from this unequal decrease, that the difference between the winter and the summer means is less the higher we go into the mountains. In the plains of Switzerland, at the height of about 400 metres, it is 19°. On St. Gothard, 2091 metres, it is 14°,9, and on St. Bernard, 2493 metres, 13°,5. **De Saussure**, who was the first to make this important remark, thought that the differences between the seasons would disappear at the height of 12000 or 13000 metres.†

The decrease of temperature has also been studied in South America by **de Humboldt**; he found that it was 1° for every 191 metres in the mountains, and 243,5 metres on the plains. A series of places in South India gave 177 metres; in the north of Indostan, on the contrary, 226,6 metres; a number which is near to that observed by M. **de Humboldt** in America, for the plains. Every where analogous differences of level are attained; 247 metres in West Siberia, a number that changes to 243,5, if the comparison includes the

---

So that we ought to possess a very much greater number of observations in order to know exactly the daily hibernal range of the differences of temperature between two stations very distant from each other in respect to elevation.

With regard to the summer range it may be considered as well known. Besides M. Kaemtz's observations on the Rigi, and the Faulhorn, in 1832 and 1833, and those of de Saussure on the Col du Géant, we have also the observations that I made with M. Bravais on the Faulhorn in 1841; and the twenty days of observations by MM. Bravais and Peltier on the same mountain in 1842; and finally, forty days of observation on the Brocken in 1820, by MM. Œsfeld and Hænel. All agree in indicating an almost parallel march for the decrease at the different hours of the day.—M.

* M. Schouw has studied the decrease of temperature on the north declivity of the Alps. On comparing the long series made on St. Gothard (2110 metres), and on St. Bernard (2493 metres), with that of Turin and Milan, a decrease of 1° is found for 168 metres (*Climat d'Italie*, p. 80).—M.

† On Mont Venteux, a rugged and isolated mountain of Provence, latitude, 44° 10′ N., longitude, 2° 56′, height, 1911 metres above the Mediterranean, I found by nineteen observations, made in different years and in different seasons, a decrease of 1° for 188 metres in winter, 129 metres in summer, 148 at a mean. Ramond's observations (*Recherches sur la formule Barométrique*, p. 189), comprised between the 43d and 49th degrees of latitude, give us a mean of 1° for every 148 metres. (Vide *Annales des Sciences Naturelles*, 2d series, t. x. p. 129. 1838).—M.

elevated places of North India. In the United States we find 222,2 metres.*

I do not think that these differences arise from the mean temperature that I have used, not referring to the same year; the configuration of the countries appears to be the most important element. If the land is slightly elevated, or the country is composed of successive steps, the decrease of temperature is much more slow than on the side of abrupt mountains. In the former case, a difference of 235 metres may be taken for 1°, and in the latter a difference of only 195. This difference proves to us how difficult it is to reduce to the sea level the mean of places situated at a certain elevation above. When the height is considerable, great errors may be committed; but, if we possess many observations in a country, these may be avoided, by deducing the decrease from the longitude, latitude, and height.†

---

* While at the equator the law of decrease is very nearly the same in all seasons; the polar regions, on the contrary, offer the greatest differences between summer and winter. From a series of four days of observations, made every half hour, the members of the Commission of the North found at Spitzbergen (latitude 77°. 30′ N.), and in the month of August, 1838, a mean decrease of 1° for every 172 metres. This result, calculated by M. Bravais, coincides with the decreases observed in the temperate zones. The difference in the height of the stations was 560 metres.

In winter the temperature goes on increasing with the height, up to a certain limit, which is variable according to the different atmospheric circumstances, the influence of which is not yet very exactly known. The hour of the day appears to be indifferent, since there exists no thermometric diurnal variation in the strata of the surface. The mean of thirty-six experiments, made with kites or with captive balloons, at Bosekop, latitude 69° 58′ N. has given a mean rate of increase of 1°,6 for the first 100 metres. Beyond this limit, and even beyond the first 60 or 80 metres, the temperature again becomes decreasing, at first very slowly, but afterwards the decrease is accelerated. The observations that have been made on the flanks or on the summits of mountains, during the same expedition, entirely confirm these results. The cooling influence of a soil, that radiates its own heat for several weeks, without receiving any thing on the part of the sun, in compensation of its losses, the influence of counter-currents from above, coming from the west and the south-west with a high temperature, account for this anomaly, which, in winter, represents the normal state of the most northern parts of the European continent.

M. Fournet has collected a great number of examples of the interchange of temperatures, observed by himself and others in France and in Switzerland, during severe winters. Thus, during the winter of 1838-9, M. Bravais, sen. observed that the *maxima* of cold were distributed in the following manner, in the neighbourhood of Annonay, where he lived:—

| PLACES. | HEIGHT ABOVE THE SEA. | MAXIMUM OF COLD. |
|---|---|---|
| Andancette . . . . . . . | 125m | −20° |
| Annonay . . . . . . . . | 900 | −17 |
| Saint-Agrève . . . . . . . | 1250 | −12 |

*Vide*, on the interversion of atmospheric temperature in rigorous winters, *Annales de Chimie et de Physique*, t. lxxii. p. 319. 1839.—M.

† Among the observations made to determine the decrease, those collected in aërostatic voyages present a very particular interest; the temperatures are there less affected by local circumstances, such as the heating

The results that I have cited are deduced from long series of observations. Isolated experiments have been made by travellers and aëronauts; but they are worthy of little reliance, although they agree generally with the preceding results.*

---

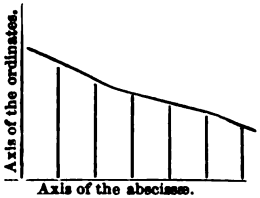
of the soil, ascending or descending currents, &c.; and the series presented by such temperatures are more susceptible of being contrasted with the series of the decreasing temperatures of the higher regions of the atmosphere.

M. Bravais collected his results into the following table:—

DECREASES OF TEMPERATURE OBSERVED IN AEROSTATIC VOYAGES.

| OBSERVERS. | LIMITS of the Stratum of Air. | DECREASE OF 1° FOR |
|---|---|---|
| | m. m. | m. |
| Gay-Lussac | 0–3800 | 188,5 |
| | 3800–5700 | 185,8 |
| | 5700–6900 | 161,2 |
| Zeune and Jungius | 0–3900 | 189,0 |
| Graham and Beaufoy | 0–3800 | 185,0 |
| Sacharoff | 0–2600 | 224,0 |
| Clayton (two voyages) | 0–2800 | 135,0 |
| | 2800–4800 | 291,0 |
| | 4800–5450 | 255,0 |

These observations are still not sufficiently numerous to enable us to deduce from them any general consequences, on account of the eminently variable nature of the decreases. It seems, however, that the decrease, at first very rapid near the surface, goes on diminishing to a certain height, perhaps about 3000 or 4000 metres, and thence accelerates more and more; so that, if we take the vertical elevations as abscissæ, and the temperatures, increased by 100° (in order to render them all positive), as ordinates, the curve of the temperatures will first turn its convexity toward the axis of the abscissæ; it will then undergo an inflexion, and will finish by turning its concavity toward the same axis.



This is the most probable form of the curve, indicating the length of the barometric column, at different heights in the atmosphere. The recent researches of M. Biot, on the same question, prove also that at great elevations in the atmosphere this curve finishes by being concave toward the axis of the abscissæ; and even if the law, of which he has recognised the existence, be prolonged to the limits of the atmosphere, the distance we must ascend, in order to obtain a decrease of 1°, would continually diminish in proportion to the corresponding density of the air.—M.

* M. Maedler compared the climate of the Brocken (1140 metres) with

The decrease of temperature with the height, appears opposed to certain observations that every body has had the opportunity of making. Indeed, when we climb a mountain on a calm and serene summer's day, we experience overpowering heat. If we suspend two thermometers, one in the shade and the other in the sun, their difference will be greater than on the plain; the actinometer and the heliothermometer (p. 149) shew this difference still more evidently. As the rays of the sun act with greater energy on account of the thinner stratum of air that they have to traverse, it would seem that the temperature ought to be higher. Experience shews the contrary, and reason agrees with it.

If the air were not an elastic fluid, if throughout its entire height its density were the same as at the level of the sea, the limits of the atmosphere would be very contracted; and beyond would be found an absolute vacuum of a very low temperature. The cold would be communicated to the higher stratum, and would gradually be propagated toward the ground; but the diminution of temperature with height would be of very little note; for liquids, and gases especially, are bad conductors of heat.

The differences between luminous and dark heat (p. 148) in their passage through bodies, are still more important. When the solar rays penetrate into the atmosphere they lose at each moment a certain quantity of heat, which they give up to the molecules of air through which they pass. However, the greater portion of them reach the ground, and heat it. If the ground did not radiate, and if the density of the air were uniform throughout its height, the temperature of the upper strata would be higher than that of the lower strata, because the solar rays that they receive are less weakened. But the radiation of heat subverts the phenomenon; for the calorific rays emitted by the earth not being luminous, are absorbed by the lower strata of the atmosphere, which becomes more highly heated.

The density of the air is not uniform, as we have assumed it; it diminishes from below upward. Not only do the lower strata, for equal volumes, absorb more than the

that of Berlin (40 metres) during the period comprised between September, 1837, and December, 1838. The general result is that the *maxima* diurnal temperatures, namely, those of 2 o'clock, differ much less in winter than in summer. The curves of the means of 6 A.M. are almost parallel. In *all* seasons, the temperature is higher on the Brocken on a serene than on a cloudy day; and in the month of January the serene days were warmer than at Berlin. The number of cloudy days was 133 in Berlin in 1838, and only 96 on the Brocken. (For further details, *vide* SCHUMACHER's *Jahrbuch Für*, 1839.)—M.

upper, but it is they which first receive the radiations emitted by the ground. Each constituent molecule of the atmosphere radiates in all directions, like the earth itself. The rays directed downward, are received by the lower strata, and by the earth, whilst those directed upward are partly lost in celestial space.

All these circumstances explain to us the influence of the seasons, of day, and of atmospheric variations, on the phenomena that we are analysing. When the weather is serene, and the sun high, the ground is much more heated than during cloudy weather, or when the sun is at a very small height above the horizon; so that radiation is much more active. But as this radiation heats the lower strata chiefly, we may imagine that in summer the temperature decreases with extreme rapidity. If we ascend to a table-land, instead of climb a mountain, the great surface of the former heating the air in contact with it, the decrease of temperature is not so rapid.

We also commonly regard the change of volume in the same mass of air as one of the most influential causes of the decrease of temperature. For if a piston is moved with friction in a glass or metal cylinder, and is suddenly thrust down, amadou placed in the cylinder is immediately kindled. An apparatus of this kind is called a pneumatic tinder-box. Reciprocally, if the air is rarefied beneath the receiver of an air-pump, there is a reduction of temperature. It follows from these facts, that the calorific capacity of the air increases in proportion as it is rarefied; a greater quantity of heat is therefore necessary in order to elevate its temperature the same number of degrees; and it borrows this heat from all neighbouring bodies, and from the thermometer, which falls rapidly.

When, therefore, the luminous and calorific rays of the sun traverse the rarefied strata of the atmosphere, the thermometer does not rise so much as it does in the neighbourhood of the ground, even when a cubic metre of this rarefied air has not absorbed more heat than a cubic metre of denser air; like as a kilogramme of water is only elevated in temperature 4° under the influence of a source of heat that would raise the temperature of a kilogramme of iron 36° (p. 11).

By combining all these elements, we can perfectly understand the decrease of temperature with the height. The influence of ascending and descending currents does not appear to me so great. Indeed, in proportion as the heated air ascends, the pressure to which it is subjected diminishes:

it expands, and consequently becomes cool: other aërial masses descend, contract, and are heated. However, these displacements can contribute to the production of the phenomenon only in an adventitious manner.

**VEGETATION OF MOUNTAINS.**—The fall of temperature, according to the height, has the greatest influence over the life of organised beings in mountains; and although these details enter into physical geography, I think they cannot be read without interest.

In the plains of Switzerland, at the foot of the Alps, we admire the very beautiful vegetation, the orchards, the corn-fields and the meadows destined to support, during the winter, the cattle that feed on the mountains during the summer. The plants of the high Alps are found there, springing from seeds brought thither by the torrents, and which are entirely wanting in France and Germany. Examples: *Pyrethrum alpinum*, *Lepidium alpinum*, *Linaria alpina*. At the foot of the mountains are beautiful forests of beech, fir, and sometimes pine.

If we ascend five or six hundred metres we find the bear's ear (*Primula auricula*), which covers the rocks with its bright yellow flowers; the stalkless gentian (*Gentiana acaulis*), the large petals of which, of an ultra-marine blue, incline toward the earth; the wolf's bane (*Aconitum napellus*), the ranunculus with monk's-hood leaves (*Ranunculus aconitifolius*), the *Trollius europæus*, &c. &c. At the height of 1000 metres, the soldanelle (*Soldanella alpina*), grows in the hollows watered by melting snow, which it frames in a violet border. The *Crocus vernus* is found in the same localities, and passes away as quickly as the soldanelle. The declivities are covered with rhododendrons (*Rhododendron ferrugineum* and *R. hirsutum*), shrubs covered with red flowers producing the most beautiful effect, and often ornamenting large surfaces.

At the height of 2000 metres the greater part of the vegetation of the plain has disappeared, and cannot be propagated. In North Switzerland, the vine does not rise higher than about 550 metres; on the south declivity of the Alps, and in Valois, it attains 650 metres; and in some favourable localities, such as Val-Sesia, at the foot of Monte Rosa, it is found even at the height of 1000 metres.* It is the same with the cereals; the more we ascend, the later is the harvest. In July, 1832, the harvest was over on the plains of Switzerland; but it was yet in hand in the Haut-

---

* Antel (Val Tornanche), 1042; south side of St. Bernard, 1040; Val d'Aoste, below Courmayeur, 1024.—M.

Valois, in the neighbourhood of Munster and Obergestlen. In elevated villages they are often obliged to suspend the sheaves to poles, in order to ripen the grain artificially. A particular means is also employed to make the snow disappear: they cover it with black earth, which, as it absorbs the heat, hastens its melting. **De Saussure** has seen this means employed in the valley of Chamouni. In the north of Switzerland the cereals may rise as high as 1100 metres, but they do not calculate on a sure harvest beyond about 900 metres. Maize ripens even at 870$^{m}$.* The localities have in this case a great influence; thus, in the valley of Lugnetz (canton of the Grisons), cereals are found near Vin, at 1510 metres. On the north side of Monte Rosa, barley ceases at the height of 1300 metres; on the south

---

* More frequently cultivation is pushed by the inhabitants as high as possible on the slopes of the mountains. The peasant of France, Switzerland, Piedmont, or Savoy, does not fear to carry the hoe, wherever he has a reasonable hope of a harvest. Cultivated fields, therefore, cease where they can no longer recompense the cultivator for his labours; but the estimation of the value of products, compared with the labour that they demand, varies with different people and different individuals. Thus, in the limit of cultivated fields, is a function of political and moral elements; and not the simple result of the change of climate, like the limits of a wild plant that is independent of man. The following is a proof:—It is an almost general law that all vegetables rise higher on the south than on the north declivity of mountains; and yet if, under this point of view, we compare the limits of cultivated fields in the Pennine Alps, which I obtained by exact barometric measurements, it is rarely so. On examining the relative heights of permanent habitations on the two sides, we obtain a result which confirms the preceding.

COMPARATIVE TABLE OF THE HEIGHT OF THE MOST ELEVATED VILLAGES, AND THE ALTITUDINAL LIMIT OF CULTIVATED FIELDS ON THE TWO SIDES OF THE PENNINE ALPS.

| DEFILES OR PASSAGES. | MOST ELEVATED VILLAGES. | | | | END OF CULTIVATED FIELDS. | |
|---|---|---|---|---|---|---|
| | North Side. | | South Side. | | North Side. | South Side. |
| | | m | | m | m | m |
| Col du Bonhomme | Nant-Bourant . | 1423 | Chapiu . . . | 1078 | ,, | ,, |
| Saint-Bernard . | Saint-Pierre | 1637 | Saint-Remy . | 1618 | 1687 | 1620 |
| Col de la Fenêtre | Lourtier . . | 1066 | Lomond . . | 1049 | 1145 | 1675 |
| Mont-Cervin . | Zermatt . . | 1614 | Val Tornanche | 1542 | 1984 | 1673 |
| Col Macugnaga | Saas . . . . | 1601 | Macugnaga . | 1300 | 1750 | 1300 |
| Simplon . . . | Baerensaal . . | 1554 | Simplon . . | 1504 | 1047 | 1000 |
| Means : . . . | | 1482 | | 1349 | 1553 | 1454 |

The influence of exposure is explained on the contrary in the most evident manner, by the differences of level that are observed between the limit of a wild plant on the south and on the north side of an isolated mountain. Mount Ventoux, in Provence, which I have studied with this object in view, side, it ascends in certain points, to 1950. It is the same with fruit-trees. In North Switzerland, none exist above 880 metres; only in certain favourable localities, near Disentis, for example, are they found at 1070. Cherry-trees ascend higher; the latter, which are found as standards on the Riga, are at *Unter-Daechli* (953$^{m}$). It is with much difficulty that the Capuchins of the convent of Marie-à-la-Neige (*Maria zum Schnee*) can occasionally ripen them in espaliers at 1310$^{m}$ above the level of the sea. Walnut-trees (*Juglans regia*), which in the plains are magnificent trees, disappear at about 800$^{m}$;* the chestnut (*Castanea vesca*) does not exist beyond 780$^{m}$.† 877 metres may therefore be regarded as the mean limit of cultivation.

It is useless to insist on the local circumstances by which this limit may be modified; and on its fall, in proportion as we approach the north. In Lapland it is 100 metres above the level of the sea. In South America, maize rises to 2270 metres, but it is only abundant between 1000 and 2000; from 2000 to 3000, the cereals of Europe are found; wheat, in the lower zones, rye and barley in the higher regions; from 3000 to 4000, nothing but the potatoe is cultivated.

In Switzerland, man has carried the hoe as high as possible, and he has profited by every portion of cultivatable earth. However, at a certain elevation, the woods become predominant, and finish by occupying all the surface of the soil; but even the physiognomy of the trees changes with the height. The pointed fir (*Abies excelsa*) is transformed

---

is a remarkable example. The following are the highest limits of several plants on the two sides:—

LIMITS OF DIFFERENT TREES ON THE TWO SIDES OF MOUNT VENTOUX.

| TREES. | South Side. | North Side. |
|---|---|---|
| | m | m |
| Aleppo Pine (*Pinus alepensis*) | 430 | ,, |
| Holm Oak (*Quercus ilex*) . . | 538 | 618 |
| Walnut (*Juglans regia*) . . . | ,, | 800 |
| Beech (*Fagus silvatica*) . . . | 1660 | 1380 |
| Pitch Tree (*Abies excelsa*) . | ,, | 1720 |
| Pine Mugho (*Pinus uncinata*) | 1810 | |
| Summit . . . . | 1911 | |

(*Vide* Botanic Topography of Mount Ventoux, *Annales des Sciences Naturelles*, t. x. pp. 129, 228. 1838.)—M.

* In the Pennine Alps the walnut-tree rises to the mean height of 1005 metres; that is, 1060 in the south, and 950 in the north.

† On the south side of the Pennine Alps its mean limit is 875 metres.

into a pyramid; its lower branches, of which the base is formed, rest on the ground: the structure of the wood also varies; the annual layers are thinner, and the wood harder. On a branch of pine twenty-seven millimetres in diameter, I counted sixty annual layers.[*] The trees finally disappear altogether. In the north of Switzerland, the beech does not rise above 1300 metres; the fir stops at 1800. On the south side of Monte Rosa, trees ascend as high as 2270; these are the larch (*Larix europæa*), the cembro (*Pinus cembra*), the alder (*Almus viridis*), and the birch (*Betula alba*). In the north, green trees do not pass beyond 2000 metres. The latter also vary much; on the north side of the Alps the firs attain the highest elevation;[†] on the south side it is the larch; on Ararat, the birch ceases at 2530 metres; in the Caucasus, at 2360. On the south side of the Pyrenees, the firs (*Abies pectinata*) cease at 2570; in the north, the pines (*Pines sylvestris*) cease at 2420. In Lap-

---

[*] In our researches on the increase of wood-fir in the north of Europe, inserted in Vol. 15 of the *Mémoires de l'Académie de Bruxelles*, M. Bravais and myself have shewn that the mean thickness of the annual ligneous layers of the wood pine increases as we go from north to south. The following table clearly shews the powerful influence of climate :—

MEAN THICKNESS OF THE ANNUAL LAYERS OF THE WOOD-PINE AT DIFFERENT LATITUDES.

| PLACES. | N. LATITUDE. | E. LONGITUDE. | MEAN THICKNESS. |
|---|---|---|---|
| | | | mm. |
| Kaaflord . | 69° 57′ | 20° 40′ | 0,65 |
| Pello . . | 66 48 | 21 40 | 0,88 |
| Geffle . . | 60 40 | 14 50 | 1,11 |
| Halle . . | 51 30 | 9 40 | 2,24 |

M.

[†] On the Grimsel, in Switzerland, is an exception to this rule; and the succession of large vegetation on its north side, recals to mind the succession of the same vegetation along the coasts of Scandinavia. The following is the table:—

LIMITS OF TREES ON THE NORTH SIDE OF THE GRIMSEL.

| TREES. | ALTITUDINAL LIMITS. |
|---|---|
| | m. |
| Hard oak (*Quercus robur*) . . . . . . . . | 808 |
| Beech (*Fagus silvatica*) . . . . . . . . . | 985 |
| Cherry (*Cerasus vulgaris*) . . . . . . .<br>Hazel (*Corylus avellana*) . . . . . . . | 1060 |
| Fir (*Abies excelsa*) . . . . . . . . . . . | 1545 |
| Service (*Sorbus aucuparia*) . . . . . . . . | 1620 |
| Mugho pine (*Pinus silvestris, V. montana*) . | 1810 |
| White birch (*Betula alba*) . . . . . . . . | 1975 |
| Cembro pine (*Pinus cembra*) . . . . . . . | 2100 |

(For further details, vide *Annales des Sciences Naturelles*, Oct. 1842.)—M.

land, the dwarf birch (*Betula nana*) is the last tree; it ceases to grow at 585 metres.

Above the region of forests, we find in the Alps the region of stunted pines (*Krummholz*, *Pinus mugho*), of rhododendrons, of herbaceous willows (*Salix herbacea*, *S. reticulata*, *S. serpillifolia*, &c.) of alders (*Alnus viridis*), and junipers (*Juniperus communis*). In the Carpathians it is the mugho pine, and on Ararat a juniper (*Juniperus oxycedrus*) and the *Cotoneaster uniflora*, that are the last to disappear.

This region of forests and that which immediately follows, constitute the productive part of the high Alps. During summer it nourishes numerous flocks, which ascend as the snow disappears. It is the same in the Scandinavian Alps, where the nomade Laplander wanders with his immense herds of reindeer.

The mugho pine disappears in the Alps at the height of 2270 metres; pasturage extends to 2600 metres, and even higher; dwarf willows and herbaceous plants cover the soil. We observe there the androsace (*Androsace alpina*, *A. helvetica*, *A. pennina*, &c.), the *Silene acaulis*, saxifrage, (*Saxifraga muscoïdes*, *S. bryoïdes*, *S. aizoïdes*, *S. stellaris*, &c.), gentians, (*Gentiana verna*, *G. bavarica*, *G. glacialis*, *G. nivalis*); besides these social plants, the *Cerastium latifolium*, lady's mantle (*Alchemilla alpina*, *A. pentaphylla*), and the ranunculus (*Ranunculus glacialis*, *R. pyrenæus*) live more isolated.

The higher we ascend, the more does the number of the phanerogams diminish in proportion to the cryptogams. On Mont-Blanc, the last cryptogam found by **de Saussure** was the *Silene acaulis*, at 3469 metres;[*] **M. de Welden** gathered on Monte Rosa stunted *Pyrethrum alpinum* and *Phyteuma pauciflorum*, in the middle of the glacier of Lys, at the place called Le Nez, at 3683 metres. Higher up, nothing is found but lichens,[†] which cover the bare rock. I shall not give the complete enumeration of the particular plants of these vegetable regions; I content myself with naming the most characteristic, and the most apparent. I may simply add a few remarks on their *habitats*.

Few plants ascend from the plain to the summit of the

---

[*] M. BRAVAIS saw the same plant at 900 metres above the sea, in the neighbourhood of Bosekop, lat. 69° 58′, where it is also found vegetating on the sea-shore, shaded by the last wood pines of Europe.

[†] At the summit of the Jungfrau, at 4175 metres, M. AGASSIZ, in 1841, found on the gneiss rock, by which it is terminated, five species of lichens; namely, *Lecidea conglomerata*, ACH.; *L. confluens*, *Parmelia elegans*, *α miniata*, SCHÆRER; *Umbilicaria atropruinosa*, *γ reticulata*, SCHÆRER; and *U. virginis*, SCHÆRER.—M.

highest mountains. Those which are in this condition are singularly modified as they ascend. Some plants resist these influences: thus **Raymond** has observed that the spring gentian (*Gentiana verna*), has the same *habitat* at all heights in the Pyrenees. But these are only exceptions; a plant is generally stunted in proportion as it ascends. Thus the pale primrose (*Primula farinosa*) sometimes attains a length of ten or fifteen centimetres in the plains of Switzerland, and its leaves are straight. On the Rigi, the plant is not higher than eight or ten centimetres; the leaves are spread out, and the flowers have a deeper colour. On the Faulhorn (2683 metres), the entire plant scarcely attains two centimetres in height; the rosette is extended on the ground, and the umbel appears sessile.

Anatomical changes correspond to these exterior modifications. The leaves that are spread out on the ground become smaller, and less fleshy; they are covered with hair, and their roots are very strong. The flower alone preserves the same dimensions, but it appears larger, because the plant is smaller, and the colour of the corella deeper. All travellers are struck with the intense blue assumed by the flowers of the stunted *Myosotis silvestris*, which is frequently described under the name of *Myosotis nana*.

Another difference resides in the duration of the plants; as we ascend the number of annuals and biennials diminishes, whilst that of perennials goes on increasing proportionately. In the high regions, annual plants are almost entirely wanting; and in the mean regions they are only found in the neighbourhood of cottages, whither they have been brought by man. Indeed, the seeds of these plants do not every year arrive at maturity in so rigorous a climate; and the species entirely disappears. It is not so with perennial vegetables, which can remain without ripening their fruits, or even bearing flowers; their stem either resists the colds of winter, or else, if it perishes, new suckers arise from the root. Add to this, that the bent branches of alpine vegetation, and willows in particular, send forth roots, and may then be separated from the parent plant. Hence arise those thick and tufted surfaces, where the closely interlaced stalks scarcely permit us to isolate any perfect specimens. The *Silene acaulis* is a striking example of this, and it is unfortunate; for, according to **Raymond's** observation, no idea can be obtained of the beauty of this plant, unless we have seen it on the snowy summits, which it embellishes with its thick tufts covered with flowers (*vide* Note C).

**LIMIT OF ETERNAL SNOWS.**—Even in the midst of summer, when abundant rains fall on the plains, the mountains continue whitened by snow or sleet. Thus, I have often seen on the Rigi showers of sleet: but at 300 or 400 metres lower there was none; and, in the plain, there was rain. I have also experienced heavy showers of rain in the plain, but, as soon as the clouds were gone, the mountains were seen to be covered with newly fallen snow. M. de Charpentier, who lived at Bex, in the centre of the high Alps, assures us that this phenomenon is constant after all rain-storms.

These masses of snow that fall in summer, melt very quickly under the influence of the sun and rain; but on very elevated summits they never disappear, for there is situated the region of eternal snow. The limit, above which the snow never melts, is pretty well determined on each mountain, and is called *the limit of eternal snow*. But before pointing out its height in the different chains of mountains that cover the globe, I must point out the distinction between snows and glaciers.

If, from an elevated point, such as the Rigi or Weissenstein, we contemplate the Alps, it is easy to distinguish below the region of cultivation, higher up that of forests, still higher that of meadows, and finally the region of eternal snows. Its lower limit is a straight line, sensibly horizontal; and it is only in certain spots that white trains are seen to descend to the plains; these lines, which occupy the bottom of valleys, are the *glaciers*.

In looking at a glacier more closely, we find that it is composed of ice and not of snow, and that it is frequently surrounded with cultivated fields. The ice is not composed of continuous transparent masses like that of ponds and rivers, but of separated fragments. A block breaks into a multitude of transparent pieces, separated from each other by capillary intervals. This ice, being thus composed of fragments, is not slippery, so that we can walk firmly on it. Lower down, these fragments have very nearly the size of a nut; but in proportion as they are higher up, they become less, and at the height of 2700 metres they are not larger than a pea. The surface of the glacier is composed of separate roundish grains, in which we tread as in sand; they are called *névé* (*Firn*). In the higher regions snow is found.

The névé is a transformation of snow, which I was able clearly to follow out in 1833. At the end of August and the beginning of September, enormous masses of snow fell on the Faulhorn. In certain places, near the inn, it was two metres deep: the snow was composed of regular crystals or radiating needles. A series of fine days succeeded bad weather. Although the thermometer in the shade was not many degrees above the freezing point, the sun melted the surface of the snow, which, at the end of the first day, was penetrated with water to the depth of two centimetres. The next morning it was covered with a brilliant and irregular bed of ice. Scarcely had the rays of the sun fallen on it for a few moments, when this bed, instead of being continuous, was found composed of little grains of ice of the size of millet-seeds. This phenomenon is renewed for several days, and the bed of ice becomes so strong that it is able to support the foot of man; the bed of grains of névé is already nearly a decimetre in thickness. At the surface, they attain the size of small peas; and below, they were smaller. It was impossible for me to follow these transformations for any length of time, because new masses of snow were added to the first, and again produced the phenomena that I had previously observed.

This transformation of snow into névé is analogous to certain artificial crystallisations. Take a salt that is much more soluble in hot than in cold water, nitrate of potash, for example; pour on it some water, and heat it, at the same time stirring it, until its temperature is some degrees higher than that of the room in which you are operating. After having maintained it for some hours at this temperature, pour it into an open plate; as it cools, a great number of unequal crystals are formed, which extend from the circumference to the centre, in the form of needles. When the temperature of the liquid is *in equilibrio* with that of the room, raise it a few degrees; the water being able to dissolve more salt, you will see the little crystals disappear, and the larger ones become smaller. When the water is again cold, the little crystals appear again, but they attach themselves to the larger. If the experiment is several times repeated, the number of crystals continues diminishing, but their dimensions increase.

It is the same with the formation of the névé and the ice of the glaciers. Let us imagine two mountains, 3000 metres high, separated by a deep valley. During winter, considerable masses of snow are accumulated there by the winds, or precipitated in the form of avalanches. In the spring, the sun's heat becomes sufficiently strong to be able to melt the snow; the water produced from this fusion penetrates between the crystals, and partly fills them with bubbles of air. If it freezes on the following night, which happens every night in these high regions, the water combines with the flakes of snow, and the latter are transformed into transparent grains of ice. The bubbles of air prevent the glaciers from being transformed into a compact mass. The following day the sun again acts; the crust is softened; the grains, especially the smaller, melt in the water: they then unite themselves on the following night to the larger, which thus increase successively. If the accumulated mass of snow has great power, and the summer has been without heat, it does not entirely melt, but is transformed into névé. If the fusion and successive coagulations of a mass of snow are renewed for several years, a new glacier is formed, as is frequently observed in the Alps. The size of the fragments increases; and although they are separated by air and water, still in a liquid state, yet their union is sufficiently intimate to form a compact mass.

A glacier is not a motionless mass; it is unceasingly descending towards the plain. This progression is due to different causes; the water that results from the melting of the surrounding snows filters into the mass, melts it partially, and separates it from the ground. Superficial and deep channels are formed, in which the water flows abundantly. If the plain on which the glacier rests is very inclined, its weight tends to make it descend. Crevices and cracks are formed. When the temperature of the air falls below zero, the water contained in the capillary intervals congeals, expands, and the mass limited above and on its sides by mountains, elongates in the only direction where it finds no obstacle, that is to say, parallel to its great axis, and from above downwards. Every thing then conspires to make the glacier descend into the plains, where its presence, in the midst of forests and cultivated fields, is a subject of astonishment to all travellers. These glaciers descend lower as the mountains whence they arise are higher,* because the masses of snow that accumulate on their summit are greater, and repair the losses that the lower extremity of the glacier undergoes by melting. So that the ice of the lower extremity of the glaciers, which, during many years, has undergone successive thaws and congelations, is composed of very bulky fragments, as compared with the granules of névé (*vide* Note D).

---

* The mean height of the lower extremity of the four lowest glaciers of the Swiss Alps is 1230 metres above the level of the sea. These are those of Bossons and de la Bresva, which descend from the sides of Mont-Blanc; of Grindelwald and Aletsch, which come from Finsteraarhorn and the Jungfrau.—M.

The glaciers being only local phenomena, dependent on the height of the mountains, and on the configuration of the land, should be completely neglected when we are determining the limit of eternal snows. The height at which fields of snow are found on plain surfaces, or on surfaces rather inclined, throughout the year, is that of eternal snows. This limit varies according to the quantity of snow that falls during the winter, the heat of the summers, the locality, and a host of circumstances that escape us; thus the mean must be gathered from a great many observations. M. **Hugi** affirmed, although incorrectly, that the line which separates the glaciers from the névés was more constant than that of the perpetual snows. The following table, borrowed from the clever work of M. **de Humboldt**, on Central Asia, entitled *Researches on the Mountain Chains, and on Comparative Climatology*, vol. iii. p. 359, gives the height and the limit of eternal snows at different latitudes:—

HEIGHT OF THE LIMIT OF PERPETUAL SNOWS IN THE TWO HEMISPHERES, DETERMINED BY DIRECT MEASUREMENTS.

| CHAINS OF MOUNTAINS. | LATITUDES. | Lower Limit of Perpetual Snows. | Mean Temperatures of the Plains in the same Latitudes. | |
|---|---|---|---|---|
| | | | Entire Year. | Summer. |
| I. *Northern Hemisphere.* | | | | |
| Coast of Norway, Isle Mageroe . | 71° 15′ N. | 720$^m$ | 0°,2 | 6°,4 |
| Inner Norway . | 70°–70 15 | 1072 | 3 ,0 | 11 ,2 |
| Inner Norway . | 66 –67 30 | 1266 | „ | „ |
| Iceland, Oosterjoekull . . . | 65 | 936 | 4 ,5 | 12 ,0 |
| Inner Norway . | 60 62 | 1560 | 4 ,2 | 16 ,3 |
| Siberia, Chain of Aldan . . . | 60 55 | 1364 | „ | „ |
| North Ourals . | 59 40 | 1460 | 1 ,2 | 16 ,7 |
| Kamtschatka, Volcano of Chevelutch . . . | 56 40 | 1600 | 2 ,0 | 12 ,6 |
| Ounalaschka . | 53 44 | 1070 | 4 ,1 | 10 ,5 |
| Altaï . . . . | 49° 15′–51° | 2144 | 2 ,8 | 17 ,8 |
| Alps . . . . | 45 45–46 | 2708 | 11 ,2 | 18 ,4 |

| CHAINS OF MOUNTAINS. | LATITUDES. | Lower Limit of Perpetual Snows. | Mean Temperatures of the Plains in the same Latitudes. | |
|---|---|---|---|---|
| | | | Entire Year. | Summer. |
| Caucasus, Elbrouz | 43°21′ N. | 3372$^{\text{m}}$ | 13 ,8 | 21 ,6 |
| Caucasus, Kasbek | " | 3235 | " | " |
| Pyrenees . . . | 42°30′–43° | 2728 | 15°,7 | 24°,0 |
| Ararat . . . . | 39°42′ | 4318? | 17 ,4 | 25 ,6 |
| Asia Minor, Mont Argæus . . | 38 33 | 3262 | " | " |
| Bolor . . . . | 37 30 | 5185 | " | " |
| Sicily, Ætna . . | 37 30 | 2905 | 18 ,8 | 25 ,1 |
| Spain, Sierra-Nevada of Grenada | 37 10 | 3410? | " | " |
| Hindou-Kho . | 34 30 | 3956 | " | " |
| Himalaya, N. side | 30°15′–31° | 5067 | " | " |
| " S. side | " | 3956 | 20 ,2 | 25 ,7 |
| Mexico . . . | 19°–19°15′ | 4500 | 25 ,0 | 27 ,8 |
| Abyssinia . . . | 13 10 | 4287 | " | " |
| S. America, Sierra Nevada de Merida . . . . | 8 5 | 4550 | 27 ,2 | 28 ,3 |
| S. America, Volcano of Tolima | 4 46 | 4670 | " | " |
| S. America, Volcano of Puracé | 2 18 | 4688 | " | " |
| II. *Equator.* | | | | |
| Quito . . . . | 0 0 | 4818 | 27 ,7 | 28 ,6 |
| III. *Southern Hemisphere.* | | | | |
| Andes of Quito . | 1° – 1°30′ S. | 4812 | " | " |
| Chili . . . . | 14°30′–18° | " | " | " |
| E. Cordilleras . | " | 4853 | " | " |
| W. Cordilleras . | " | 5646 | " | " |
| Chili, Portillo and Volcano of Peuquenes . . . | 33 | 4483 | " | " |
| Chili, Andes along the Coast . . | 41°–44° | 1832 | " | " |
| Straits of Magellan . . . . | 53°–54° | 1130 | " | " |

The line of eternal snow is seen, generally, to fall from the equator toward the pole. However, there are numerous exceptions to this rule: we must analyse them attentively.

The limit of eternal snows being determined by the height at which the snow that falls during the winter does not melt, the manner in which snow behaves with respect to heat is here one of the most important elements. When a solid body passes into the liquid state, the heat becomes latent, as in the case when a liquid evaporates. Let a tub of snow be placed in a warm room, and a thermometer be plunged in; the latter will very rapidly fall to the freezing point. For a long time it will remain stationary; although the snow melts rapidly, it is not until the whole is melted that it again rises, continuing to rise until the temperature of the water is *in equilibrio* with that of the room; yet, the walls and every object in this room radiate heat towards the vessel; but this heat disappears and becomes latent during the act of fusion.

To prove this truth, take a kilogramme of water at zero, and a kilogramme of water at 75°; the mixture will be of the temperature of 37°,5. Take, on the contrary, a kilogramme of ice or snow, and throw it into a kilogramme of water at 75°: the ice or snow will melt, but the temperature of the mixture will remain at zero. Thus the 75° of heat from the water have disappeared during the melting of the snow or of the ice, by which they have been absorbed.*

In considering the anomalies presented by the height of the limit of eternal snows, we ought never to forget this latent heat. Imagine a room that is not warmed during the winter, so that its temperature falls several degrees below zero; place in it several tubs filled with snow, and then warm this room; the temperature of the walls and of the air will rise several degrees above zero, but the temperature of the snow will remain at zero. The temperature of the room and the quantity of snow are here the influential elements; and it often happens that a small quantity of snow will melt faster in a room moderately heated than a considerable mass in the same room immoderately heated.

The height of the snow-line being a function of the quantity that falls in winter and of the heat of the summers, it is clear that, in equal latitudes, it must be higher in the interior of continents, where less snow falls, and where the summers are warmer, than on the coasts. Thus it is 650

---

* According to the very recent experiments of MM. DE LA PROVOSTAYE and PAUL DESAINS, this number should be modified, and the latent heat of ice would be 75°,1.—(Vide *Comptes rendus de l'Institut*, April 1843, p. 837.)

metres higher in the Caucasus than in the Pyrenees. In the mountains of Lapland, **Wahlenberg** found the limit of eternal snows at 1005 metres on the Norway coast, and at 1255 on the Swedish side; **Schouw** and **Smith** made the same remark in the district of Bergen.

This difference is very marked on the two sides of the Himalaya. On the south side, M. **de Humboldt** formerly fixed the line of eternal snows at 3700 metres; since his account, the English traveller, **Webb**, found, near Kedarnath, at 3655 metres, and **Mllem**, at 3610 metres, trees and rhododendrons; and a luxuriant vegetation at 3870. The line of eternal snows, therefore, rises above 3900 metres. On the north side of the Himalaya it is still higher, and even exceeds that of eternal snows on the equator. The very few facts that we possess enable us to fix it approximately at 5070 metres, thus, at 1170 metres higher than on the other side.

This great difference is due to the changes of the monsoons; in the north of the Himalaya extends a vast plain, covered with sand and rounded flints—a very desert. The contrast between the temperature of the air above this plain and above the one situated to the south, gives rise to monsoons. So, on the north of the Himalaya, there will be hot land-wind; on the south, fresh sea-breezes. The fall of the snow-line on the south is further favoured by the direction of these winds. During summer, they blow from the S.W. and bring vapours that condense on the chain of mountains and form a band of cloud and fog, which prevent the action of the sun on the snow, while at the north the sky must be almost always serene. Add to this, that less snow falls during the winter on the north, or continental side, and that, consequently, this must disappear up to a greater height.

## V.

# WEIGHT OF THE ATMOSPHERE.

**WEIGHT OF THE AIR.**—**Aristotle** was the first to suspect that the air was heavy; to assure himself of this, he took a leathern bottle, weighed it first, when empty, and then again, after having filled it with air; for, said he, if the air is heavy, the bottle must be heavier in the latter than in the former case. These anticipations not having been confirmed by experiment, he concluded that the air was not heavy. However, several philosophers of antiquity admitted the materiality of the air as a fact. Thus the school of **Epicurus** compared the effects of winds to those of air in motion, and regarded the elements of the air as invisible bodies, called by **Epicurus**, *Corpora Cæca.*

However, during the reign of the philosophy of **Aristotle**, it was admitted that the air was not heavy, and there were but very few philosophers who did not share in this error. About 1640, **Toricelli** and **Otto de Guericke** made about the same time some experiments by which the weight of the air was proved. **Otto de Guericke's** experiments with the air-pump were the most conclusive.

Take a glass globe furnished with a stop-cock, of the capacity of thirty cubic decimetres; weigh it by a good balance; then screw it on the plate of the air-pump, and exhaust it. On again weighing the ball, you will find that its weight has diminished; if the stop-cock is opened, the air rushes into the ball with a hissing noise, and the equilibrium is restored.

So that, by repeating judiciously **Aristotle's** experiments, **Otto de Guericke** convinced himself that the air is heavy. If **Aristotle** found the contrary, it is duc to the change of volume of the leathern bottle in the two essays; for every body, when weighed in a fluid, loses in weight a quantity equal to the weight of the fluid displaced. Take a piece of iron: weigh it carefully in the air; then suspend it with a wire beneath the scale-pan, so that it plunges into a vessel filled with water; its weight will then not be more than 0,86 or 0,88 of what it was in the air. A closer examination shews that the loss in weight is equal to the weight of the water displaced by the iron. Fill a stoppered bottle with water, and, after having wiped it, place it on the balance beside the piece of iron, and weigh it with care; then place the piece of iron in the bottle; it will evidently expel an equal volume of water; and if you again weigh the bottle, after having wiped it, the weight will be diminished by that of the water expelled from it. Moreover, this diminution will be exactly equal to the loss of weight which the piece of iron undergoes, when weighed in the water.

The experiments of **Otto de Guericke** having proved that the air is heavy, every body that is weighed in air must lose in weight a quantity equal to the volume of air it displaces. The bottle employed by **Aristotle** would have been heavier if weighed *in vacuo*. Suppose that about thirty cubic decimetres of air were introduced by being blown in, its weight would have increased about four grammes, but the bottle would at the same time have expanded; its volume is increased by thirty cubic decimetres and displaces a volume of air equal in weight, so that its loss in weight is four grammes. So that its weight remains the same; but in **Otto de Guericke's** experiment the vessel retained the same capacity whether it were empty or full; and its loss in weight by the air displaced being in both cases the same, we should expect to find a difference that would shew the weight of the air.

**OF THE BAROMETER.**—Before **Otto de Guericke**, **Toricelli** had made an experiment, which also proved the weight of the air, although in a less direct manner. Take a glass tube a metre long, and closed at one of its extremities, fill it with mercury, and plunge it by its open end into a cup filled with the same metal; the column will fall in the tube to the height of about seventy-six centimetres (about thirty English inches) on the sea shore. If the tube is inclined the length of the column will increase, but its vertical height above the mercury bath will always remain the same. If made with water, this experiment would have given us a column 10,2 metres high (33½ft. English), and consequently 13,5 times longer than the column of mercury; but as this metal is 13,5 times denser than water, the experiment proves that the lengths of the columns are inversely proportioned to the densities of the liquids.

When **Toricelli** had discovered this relation, he concluded that the weight of the air opposed the escape of the mercury by the lower orifice of the tube, and he gave the name of barometer to his instrument, from the Greek, *βάρος*, weight, and *μίτρον*, measure. The height of the mercurial column above the surface of the metal is named the *height of the barometer*. He relied on the well-known phenomena of communicating tubes. If a tolerably large barometric tube is bent so as to form two parallel branches, and water is poured into one of them, it will be at a level in both branches. The same thing is observed whatever be the liquid employed, or the relative diameter of the two tubes; if we first pour mercury into one branch and water into the other, the surface of the mercury will be lower in the branch containing mercury than in the other; but, if we guide the horizontal plane through the line separating the mercury and the water, and seek the elevation above this plane of the opposite mercurial column, we shall find it 13,5 times less than that of the water. On repeating the experiment with other liquids which do not combine chemically, we arrive at this general result, that the heights of columns above the surface of contact of the two liquids are inversely proportional to their densities.

Let us now admit that the air is a heavy body; it follows that the strata of air superposed, even to the limits of the atmosphere, exercise a pressure on all bodies placed on the surface of the earth. If, therefore, we fill with mercury a bent tube open at its two extremities, and the branches of which are parallel, the mercury will tend toward the same level in both, because the air will press equally on their surface. But if one of the branches is closed, and the apparatus filled with mercury, it will stand higher in the branch that is deprived of air and closed, where there will be nothing but the weight of the mercury; while, in the other, there will be the weight of the mercury, and then that of the atmosphere, which in this case fills the place of the water that we poured on the mercury in the former experiment. Thus, then, the difference of level between the two columns will indicate to us the weight of the atmosphere.

If this hypothesis is true, it follows, as **Paschal** was the first to observe, that the mercurial column must be larger at the foot than at the summit of a mountain. For then none of that portion of the column of air that is beneath the observer presses upon the mercurial column contained in the open tube. Experiment confirms this anticipation; so that barometers may be employed to measure the height of mountains. Two observers place themselves, one at the summit, the other at the foot; they make simultaneous observations, and from the difference of the length of the mercurial columns they deduce the level of the two stations. With a barometer, provided with a scale properly divided, even the differences between one story and another of a house are observed.*

**ELASTICITY OF THE AIR.**—By elasticity we understand that property which certain bodies possess of occupying less space under the influence of certain forces, and of returning to their original volume as soon as these forces cease to act. Take a tumbler, invert it, and plunge it into water; in proportion as the liquid rises in the vessel the imprisoned air occupies a space, which is less as the glass is plunged deeper. If we raise it so that the brim comes in contact with the surface of the water, the air again fills the whole glass. In the latter case the air is merely subjected to atmospheric pressure; when the glass is plunged in the

---

* Two kinds of barometers may be employed for meteorological and hypsometric observations; the basin barometer, or FORTIN'S, and the syphon barometer. These two kinds of instruments have been infinitely modified. Among all these varieties, an instrument, which the experience of several years and many voyages has induced me to consider the most perfect, is FORTIN'S barometer, modified by M. DELCROS, of which a general view is given in plate II. *fig.* 5, and the details in *figs.* 6 and 7.

The first modification of FORTIN'S barometer, realised by M. DELCROS, consists in this:—that the summit of the ivory point, plate II. *fig.* 7, $d$, is level with the summit of the annular meniscus $f'\ c''$ of the reservoir. FORTIN placed this point so that its lower extremity was tangent to the convex arc, by which the surface of the annular meniscus is united with the sides of the reservoir. The point of contact was situated at such a distance from the axis that the depression, *corresponding to this point*, exactly compensated the depression of the summit of the meniscus. Experiment has shewn that this compensation, which is possible in theory, is very rarely realised in practice. By means of the table that we give page 245, it is easy to calculate exactly this depression.

The object of M. DELCROS'S second modification was to render the mercury of the attached thermometer, plate II. *fig.* 5, $t\ t'$, as little sensible to the variations of temperature in the circumambient medium, as was that of the barometric column itself. The bulb of this thermometer is cylindrical, and a metal envelope, of thickness equal to that of the copper mounting, protects it against external thermometric influences.

Finally, the moving screw of the vernier is suppressed. The slide, plate II. *fig.* 6, $b\ b'\ b''\ b'''$, is retained by gentle friction; and a small metal button $c$ is attached to it, so that it may be moved up or down by a series of repeated taps. A penknife, a key, even the pencil of the observer, are sufficient to produce the slightest displacements. *Vide*, for further details on these instruments, the barometric comparisons made in the north of Europe by A. BRAVAIS and CH. MARTINS, *Mém. de l'Acad. de Bruxelles*, t. xiv. 1841; and the description of the barometer with constant level, by M. DELCROS, *Bulletin de la Société Géologique de France*, t. xii. 1841.—M.

water it is subject in addition to the pressure of the water. Mercury is preferable for researches of this kind; for we are able, in small apparatus, to obtain greater pressures than with water; and the experiments are not complicated by the formation of vapours. Exact experiments shew that the volume of a given mass of air is in inverse proportion to the pressure; this is called **Mariotte's** law, from its discoverer. Suppose we fill a vessel with eighty cubic centimetres of air under a barometric pressure of seventy-six centimetres, this air will be merely subject to atmospheric pressure; but if we further weigh upon it a column of mercury seventy-six centimetres high, the pressure will be doubled; that is to say, 152 centimetres: this mass of air will then only occupy a space of forty cubic centimetres; if the pressure were seventy-one instead of seventy-six the space occupied would be,

$$\frac{80 \times 76}{71} = 85 \text{ cubic centimetres.}$$

These facts lead us to admit, that between the molecules of air there exists a repulsive force, by virtue of which they tend to separate from each other; the following experiment proves this in a direct manner. Take a soft flattened bladder: place it under the receiver of an air-pump; it will swell out as the vacuum is being made, but shrink up again as the air is allowed to return into the receiver. The particles of air, therefore, tend to separate by virtue of their elasticity, and to occupy the greatest possible space; but the pressure of the atmosphere, acting on the sides of the bladder, confines them, and presses them close together: as soon as it ceases, the molecules separate in all directions.

If our atmosphere were not retained by the force of gravity, it would be dissipated into space. It follows that the density of the air diminishes as we ascend from the surface of the earth, because the higher strata are not pressed upon by the lower. Experiment, moreover, proves this directly: the higher we ascend the more does the weight of a cubic decimetre of air diminish.

We may observe throughout nature analogous effects to those of the expansion of a bladder, under the receiver of an air-pump. In many coal-pits there is an escape of hydrogen, a gas easily obtained by acting on zinc by sulphuric acid diluted with water. This gas is very inflammable, when mixed with air it detonates; now in certain galleries this gas is so abundant that they are obliged to be abandoned; but, more frequently, it is developed in holes and caverns, communicating with the gallery by narrow fissures. While the gas is in small quantities its presence is not indicated, but there is frequently a detonation at the time of a storm. This coincidence is easily explained,—the storm is indeed generally preceded by a sudden fall in the barometer; the pressure becoming less, the hydrogen escapes from the fissures, and fills the gallery; and if any one is so unfortunate as to enter with a light an explosion instantly occurs.*

A similar phenomenon occurs in springs containing carbonic acid. It is probable that these waters are charged with this gas in cavities where the atmospheric pressure is much greater than on the surface of the earth; but when the spring arrives at the surface, the gas is liberated in the form of bubbles, especially if the barometer is low.

**METHODS FOR DETERMINING THE WEIGHT OF THE AIR.**—The two properties of the air, namely, its weight and its elasticity, may serve to measure the weight of the atmosphere. As every body loses in air a weight equal to that of the air it displaces, of which we may convince ourselves by various experiments, a hollow sphere of glass or metal is suspended to the beam of a balance, whilst a dense body, of small bulk, is suspended on the other side. If the oscillations of the balance-beam can be given on graduated scales, we shall observe that the sphere falls when the weight of the air diminishes, just as if it became heavier, whilst it ascends if the pressure increases. This is easily explained; indeed, as the sphere and the body each displace a mass of air equal to their volume, they weigh less than *in vacuo;* but the loss in weight of the sphere is greater than that of the body. If, then, the pressure diminishes, the weight of the two bodies *in equilibrio* diminishes also; but that of the sphere diminishes less than that of the body; it will, therefore, be heavier, and will descend. This apparatus, which has been employed by some observers, is always incorrect, however perfect may be the balance employed.

---

* Mr. John Buddle relates that, in a gallery of a coal-mine at Wallsend, an explosion of *fire-damp*, or carburetted hydrogen, killed fifty-two persons, on October 21, 1821; the barometer stood at only 731 millimetres.

Mr. Combes remarks, that the pressure under which the gas is liberated is not the same in all mines; thus, in the coal-mine of Latour, near Firmini, hydrogen was abundantly liberated through a mass of water, twelve metres deep, and consequently under a pressure of about two atmospheres. He observes, as did Mr. Buddle, that an escape occurred principally in the neighbourhood of spots where the strata lose their regularity, either by a fault or an elevation. Thus on April 10, 1824, there was an explosion in the coal-mine of Ronchamp (Haute-Saône), by which twenty workmen were killed. The gas had previously been rarely seen in this mine, or only in small quantities; however, an escape had taken place before the accident, in the neighbourhood of a fault.—(*Comptes rendus de l'Acad. des Sciences*, t. ii. pp. 323, 509. 1836). M.

We may also measure the variations of atmospheric pressure by considering the volume, which the same mass of air occupies under different circumstances. Thus, let a certain volume of dry air be closed up in a glass tube, of a known capacity, and separated from the surrounding air by a column of mercury. If, while the temperature remains the same, the pressure diminishes, this air will expand, and from the space it occupies may be deduced the change of pressure; as heat also dilates the air, we must attach to the apparatus a correct thermometer, in order to appreciate variations of temperature.

The barometer is the instrument which best indicates changes in atmospheric pressure; but, in order to make an exact instrument, we must not neglect any of the following precautions.

**BOILING THE MERCURY IN THE BAROMETER.**—As the length of liquid columns *in equilibrio* with the atmosphere are inversely proportional to their density, it is indispensable to employ perfectly pure mercury; if it is amalgamated with zinc or lead, its density is no longer the same, and the length of the column differs from that of a barometer filled with perfectly pure mercury. The most simple process consists in washing the mercury with acetic or dilute sulphuric acid; other more perfect processes are difficult of execution.

The mercury, being properly purified, is poured into the tube, but then the air remains imprisoned at the bottom of the tube, and the metal itself is mixed with bubbles of air. To drive these away, the tube is first filled to about one-third; it is then brought near to a charcoal fire, or a strong spirit-lamp, and is turned on its axis so as to expose to the fire the whole surface of the cylinder in succession, until the mercury begins to boil; it is then allowed to become *completely* cold, and mercury is added so as to fill two-thirds of the tube. Boiling is again commenced, beginning from below; and we continue thus until the tube is filled and all the mercury has boiled. In order to learn whether a barometer has been well boiled, it is gently inclined, the striking of the mercury against the end produces a dry and metallic sound; it is, on the contrary, dull and heavy if a bubble of air remains. We may also discover, by means of a lens, if any bubble of air remains at the end of the tube.*

**SCALE OF THE BAROMETER.**—It must be of brass,

---

* It is essential that the boiling be not carried on too long, otherwise the column of mercury remains adhering to the top of the tube, or else it is terminated by a plane or even a concave surface, instead of a convex meniscus.—M.

provided with a vernier, so as to give at least the tenths of a millimetre. In France, the scale is in millimetres; in England, in English inches divided into tenths;[9] in Germany, in French inches and lines; the vernier generally indicates the tenth of a line. The Germans indicate inches by putting two accents after the number; lines, by putting three accents; 27'' 3''', 85, means 27 inches, 3 lines, 85 hundredths of a line; more frequently they give the height in lines, and the preceding number becomes 327, 85'''.

**CORRECTION RELATING TO TEMPERATURE.**—In order to admit of comparison, barometric measurements require a correction, because heat expands the mercury. If we compare two barometric columns, having the same length at different temperatures, these columns would not have the same actual length at the same temperature. Thus, then, we must make a correction, in order that the lengths of the barometric columns may be such as they would have been found if the barometers had been suspended in the same room; so that a thermometer is attached to each barometer, and so placed that its temperature indicates, as nearly as possible, that of the mercury of the barometric column. Measurements carefully made, prove that if we represent by 1 the length of the barometric column at freezing point, this length becomes 1,0156 at the temperature of boiling water. The dilatation of mercury being uniform between the freezing and boiling point, the dilation for one centigrade degree may be considered 0,0018; if, then, a barometer, with the air at zero, is at $760^{mm}$, and it is brought into a room at 20°, its height will be $762{,}44^{mm}$, without the atmospheric pressure having undergone the slightest change. The reverse takes place in like manner; if, in a chamber at 32°, the barometer indicates 763,90, it will only be 758,03 in the air at —16°.

By means of tables we may thus reduce the temperature of the mercurial column to any other temperature whatever,* but it is generally reduced to that of melting ice.

The graduated scale that accompanies the barometric tube also changes in length, according to the temperature: it is longer in high temperatures than in low; and then the

[9] *Vide* Note *h*, Appendix, No. II.

* Tables for the reduction of the barometer to zero, are found in the *Annuaires*, published by M. SCHUMACHER, within the limits comprised between 700 and 778, and the temperatures of – 17 to + 32. That of the metric barometer is found in the *Annuaire* of 1838; those of French inches and lines in that of 1839; that of the English barometer in the *Annuaire* of 1837.

measure of an interval is expressed by a smaller number than during cold. Thus, then, while heat elongates the mercurial column, the scale, by expanding, partly destroys this effect; if mercury and copper dilated equally, these two effects would reciprocally destroy each other, and the correction would be nothing; but it is not so. When the scale is of brass, as is generally the case, its expansion is only 0,1 of that of the mercury. On the other hand, if we are at liberty to reduce the mercurial column to any temperature, it is not the same with the scale; for, in all countries, the division of scales is always brought to a certain temperature. Thus, in France, the millimetres of the scale are not strictly millimetres, except at the temperature of zero; French feet and inches are not feet and inches, except at a temperature of 13° Réaumur. We here give a table for reducing to the temperature of zero a barometric column provided with a brass scale, the metrical divisions of which represent centimetres and millimetres at the temperature of zero.*

---

* For M. Kaemtz's table, which only extended from 540 to 778 metres, I have substituted the much more extensive and perfect table lately calculated by M. Delcros. Its use is very simple. Suppose that the barometer is at 745 millimetres, and the attached thermometer indicates 9°. We must *subtract* $1^{mm},082$, and we shall have the height of the barometer reduced to $743^{mm},918$ at zero. Another example: If the barometer indicates $758^{mm},62$, and the thermometer 15°,6, the quantity to be subtracted will be first that which corresponds to 10°, which will be found in the column headed 1°, namely, $1^{mm},22$, increased by that corresponding to 5°, namely, $0^{mm},61$. Finally, to this sum we add the correction corresponding to 0°,6, namely, $0^{mm},07$. The total correction will therefore be:

$$1^{mm},22 + 0^{mm},61 + 0^{mm},07 = 1^{mm},90.$$

As the correction undergoes very little change in every five millimetres of the barometric column, and the thermometric indications only give approximately the temperature of the barometric column, it would be pretending to an imaginary exactness to make rigorous interpolations.

If the thermometer that is attached to the barometer marks degrees *below* zero, we then take the corresponding positive degrees in the table, and the correction becomes *additive*. Thus, in a general manner, if $h$ is the height of the barometer, $n$ the number of positive or negative degrees marked by the thermometer, the formula of the reduction to zero is $= h.\,n.\,0{,}0001614$.—M.

# TABLE
## OF THE DILATATIONS OF THE MERCURIAL COLUMN.

| HEIGHT of the Barometer. | DILATATIONS OF THE MERCURIAL COLUMN. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1° | 2° | 3° | 4° | 5° | 6° | 7° | 8° | 9° |
| mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| 400 | 0,065 | 0,129 | 0,194 | 0,258 | 0,323 | 0,387 | 0,452 | 0,516 | 0,581 |
| 05 | 0,065 | 0,131 | 0,196 | 0,261 | 0,327 | 0,392 | 0,457 | 0,523 | 0,588 |
| 10 | 0,066 | 0,132 | 0,198 | 0,265 | 0,331 | 0,397 | 0,463 | 0,529 | 0,596 |
| 15 | 0,067 | 0,134 | 0,201 | 0,268 | 0,335 | 0,402 | 0,469 | 0,536 | 0,603 |
| 20 | 0,068 | 0,136 | 0,203 | 0,271 | 0,339 | 0,407 | 0,474 | 0,542 | 0,610 |
| 25 | 0,068 | 0,137 | 0,206 | 0,274 | 0,343 | 0,411 | 0,480 | 0,549 | 0,617 |
| 30 | 0,069 | 0,139 | 0,208 | 0,278 | 0,347 | 0,416 | 0,486 | 0,555 | 0,625 |
| 35 | 0,070 | 0,140 | 0,211 | 0,281 | 0,351 | 0,421 | 0,491 | 0,562 | 0,632 |
| 40 | 0,071 | 0,142 | 0,213 | 0,284 | 0,355 | 0,426 | 0,497 | 0,568 | 0,639 |
| 45 | 0,072 | 0,144 | 0,215 | 0,287 | 0,359 | 0,431 | 0,503 | 0,574 | 0,646 |
| 50 | 0,073 | 0,145 | 0,218 | 0,290 | 0,363 | 0,436 | 0,508 | 0,581 | 0,654 |
| 55 | 0,073 | 0,147 | 0,220 | 0,294 | 0,367 | 0,441 | 0,514 | 0,587 | 0,661 |
| 60 | 0,074 | 0,148 | 0,223 | 0,297 | 0,371 | 0,445 | 0,520 | 0,594 | 0,668 |
| 65 | 0,075 | 0,150 | 0,225 | 0,300 | 0,375 | 0,450 | 0,525 | 0,600 | 0,675 |
| 70 | 0,076 | 0,152 | 0,228 | 0,303 | 0,379 | 0,455 | 0,531 | 0,607 | 0,683 |
| 75 | 0,077 | 0,153 | 0,230 | 0,307 | 0,383 | 0,460 | 0,537 | 0,613 | 0,690 |
| 80 | 0,077 | 0,155 | 0,232 | 0,310 | 0,387 | 0,465 | 0,542 | 0,620 | 0,697 |
| 85 | 0,078 | 0,156 | 0,235 | 0,313 | 0,391 | 0,470 | 0,548 | 0,626 | 0,704 |
| 90 | 0,079 | 0,158 | 0,237 | 0,316 | 0,395 | 0,474 | 0,554 | 0,633 | 0,712 |
| 95 | 0,080 | 0,160 | 0,240 | 0,319 | 0,399 | 0,479 | 0,559 | 0,639 | 0,719 |
| 500 | 0,081 | 0,161 | 0,242 | 0,323 | 0,403 | 0,484 | 0,565 | 0,646 | 0,726 |
| 05 | 0,081 | 0,163 | 0,244 | 0,326 | 0,407 | 0.489 | 0,570 | 0,652 | 0,734 |
| 10 | 0,082 | 0,165 | 0,247 | 0,329 | 0,412 | 0,494 | 0,576 | 0,658 | 0,741 |
| 15 | 0,083 | 0,166 | 0,249 | 0,332 | 0,416 | 0,499 | 0,582 | 0,665 | 0,748 |
| 20 | 0,084 | 0,168 | 0,252 | 0,336 | 0,420 | 0,504 | 0,587 | 0,671 | 0,755 |
| 25 | 0,085 | 0,169 | 0,254 | 0,339 | 0,424 | 0,508 | 0,593 | 0,678 | 0,763 |
| 30 | 0,085 | 0,171 | 0,257 | 0,342 | 0,428 | 0,513 | 0,599 | 0,684 | 0,770 |
| 35 | 0,086 | 0,173 | 0,259 | 0,345 | 0,432 | 0,518 | 0,604 | 0,691 | 0,777 |
| 40 | 0,087 | 0,174 | 0,261 | 0,349 | 0,436 | 0,523 | 0,610 | 0,697 | 0,784 |
| 45 | 0,088 | 0,176 | 0,264 | 0,352 | 0,440 | 0,528 | 0,616 | 0,704 | 0,792 |
| 50 | 0,089 | 0,177 | 0,266 | 0,355 | 0,444 | 0,533 | 0,621 | 0,710 | 0,799 |
| 55 | 0,090 | 0,179 | 0,269 | 0,358 | 0,448 | 0,537 | 0,627 | 0,717 | 0,806 |
| 60 | 0,090 | 0,181 | 0,271 | 0,361 | 0,452 | 0.542 | 0,633 | 0,723 | 0,813 |
| 65 | 0,091 | 0,182 | 0,274 | 0,365 | 0,456 | 0,547 | 0,638 | 0,730 | 0,821 |
| 70 | 0,092 | 0,184 | 0,276 | 0,368 | 0,460 | 0,552 | 0,644 | 0,736 | 0.828 |
| 75 | 0,093 | 0,186 | 0,278 | 0,371 | 0,464 | 0,557 | 0,650 | 0,742 | 0,835 |
| 80 | 0,094 | 0,187 | 0,281 | 0,374 | 0,468 | 0,562 | 0,655 | 0,749 | 0,842 |
| 85 | 0,094 | 0,189 | 0,283 | 0,378 | 0,472 | 0,566 | 0,661 | 0,755 | 0,850 |
| 90 | 0,095 | 0,190 | 0,286 | 0,381 | 0,476 | 0,571 | 0,667 | 0,762 | 0,857 |
| 595 | 0,096 | 0,192 | 0,288 | 0,384 | 0,480 | 0,776 | 0,672 | 0,768 | 0,864 |

| HEIGHT of the Barometer. | DILATATIONS OF THE MERCURIAL COLUMN. | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1° | 2° | 3° | 4° | 5° | 6° | 7° | 8° | 9° |
| mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| 600 | 0,097 | 0,194 | 0,290 | 0,387 | 0,484 | 0,581 | 0,678 | 0,775 | 0,872 |
| 05 | 0,098 | 0,195 | 0,293 | 0,391 | 0,488 | 0,586 | 0,683 | 0,781 | 0,879 |
| 10 | 0,098 | 0,197 | 0,295 | 0,394 | 0,492 | 0,591 | 0,689 | 0,788 | 0,886 |
| 15 | 0,099 | 0,198 | 0,298 | 0,397 | 0,496 | 0,596 | 0,695 | 0,794 | 0,893 |
| 20 | 0,100 | 0,200 | 0,300 | 0,400 | 0,500 | 0,600 | 0,700 | 0,800 | 0,901 |
| 25 | 0,101 | 0,202 | 0,303 | 0,403 | 0,504 | 0,605 | 0,706 | 0,807 | 0,908 |
| 30 | 0,102 | 0,203 | 0,305 | 0,407 | 0,508 | 0,610 | 0,712 | 0,813 | 0,915 |
| 35 | 0,102 | 0,205 | 0,307 | 0,410 | 0,512 | 0,615 | 0,717 | 0,820 | 0,922 |
| 40 | 0,103 | 0,207 | 0,310 | 0,413 | 0,516 | 0,620 | 0,723 | 0,826 | 0,930 |
| 45 | 0,104 | 0,208 | 0,312 | 0,416 | 0,520 | 0,625 | 0,729 | 0,833 | 0,937 |
| 50 | 0,105 | 0,210 | 0,315 | 0,420 | 0,524 | 0,629 | 0,734 | 0,839 | 0,944 |
| 55 | 0,106 | 0,211 | 0,317 | 0,423 | 0,529 | 0,634 | 0,740 | 0,846 | 0,951 |
| 660 | 0,106 | 0,213 | 0,320 | 0,426 | 0,533 | 0,639 | 0,746 | 0,852 | 0,959 |
| 65 | 0,107 | 0,215 | 0,322 | 0,429 | 0,537 | 0,644 | 0,751 | 0,859 | 0,966 |
| 70 | 0,108 | 0,216 | 0,324 | 0,433 | 0,541 | 0,649 | 0,757 | 0,865 | 0,973 |
| 75 | 0,109 | 0,218 | 0,327 | 0,436 | 0,545 | 0,654 | 0,763 | 0,871 | 0,980 |
| 80 | 0,110 | 0,219 | 0,329 | 0,439 | 0,549 | 0,658 | 0,768 | 0,878 | 0,988 |
| 85 | 0,111 | 0,221 | 0,332 | 0,442 | 0,553 | 0,663 | 0,774 | 0,884 | 0,995 |
| 90 | 0,111 | 0,223 | 0,334 | 0,445 | 0,557 | 0,668 | 0,780 | 0,891 | 1,002 |
| 95 | 0,112 | 0,223 | 0,336 | 0,449 | 0,561 | 0,673 | 0,785 | 0,897 | 1,010 |
| 700 | 0,113 | 0,226 | 0,339 | 0,452 | 0,565 | 0,678 | 0,791 | 0,904 | 1,017 |
| 05 | 0,113 | 0,228 | 0,341 | 0,455 | 0,569 | 0,683 | 0,797 | 0,910 | 1,024 |
| 10 | 0,115 | 0,229 | 0,344 | 0,458 | 0,573 | 0,688 | 0,802 | 0,917 | 1,031 |
| 15 | 0,115 | 0,231 | 0,346 | 0,462 | 0,577 | 0,691 | 0,808 | 0,923 | 1,039 |
| 20 | 0,116 | 0,232 | 0,349 | 0,465 | 0,581 | 0,697 | 0,813 | 0,930 | 1,046 |
| 25 | 0,117 | 0,234 | 0,351 | 0,468 | 0,585 | 0,702 | 0,819 | 0,936 | 1,053 |
| 30 | 0,118 | 0,236 | 0,353 | 0,471 | 0,589 | 0,707 | 0,825 | 0,943 | 1,060 |
| 35 | 0,119 | 0,237 | 0,356 | 0,474 | 0,593 | 0,712 | 0,830 | 0,949 | 1,068 |
| 40 | 0,119 | 0,239 | 0,358 | 0,478 | 0,597 | 0,717 | 0,836 | 0,955 | 1,075 |
| 45 | 0,120 | 0,240 | 0,361 | 0,481 | 0,601 | 0,721 | 0,842 | 0,962 | 1,082 |
| 50 | 0,121 | 0,242 | 0,363 | 0,484 | 0,605 | 0,726 | 0,847 | 0,968 | 1,089 |
| 55 | 0,121 | 0,244 | 0,365 | 0,487 | 0,609 | 0,731 | 0,853 | 0,975 | 1,097 |
| 60 | 0,123 | 0,245 | 0,368 | 0,491 | 0,613 | 0,736 | 0,859 | 0,981 | 1,104 |
| 65 | 0,124 | 0,247 | 0,370 | 0,494 | 0,617 | 0,741 | 0,864 | 0,988 | 1,111 |
| 70 | 0,124 | 0,249 | 0,373 | 0,497 | 0,621 | 0,746 | 0,870 | 0,994 | 1,118 |
| 75 | 0,125 | 0,250 | 0,375 | 0,500 | 0,625 | 0,750 | 0,876 | 1,001 | 1,126 |
| 80 | 0,126 | 0,252 | 0,378 | 0,504 | 0,629 | 0,755 | 0,881 | 1,007 | 1,133 |
| 85 | 0,127 | 0,253 | 0,380 | 0,507 | 0,633 | 0,760 | 0,888 | 1,014 | 1,140 |
| 90 | 0,127 | 0,255 | 0,382 | 0,510 | 0,637 | 0,765 | 0,893 | 1,020 | 1,148 |
| 95 | 0,128 | 0,257 | 0,385 | 0,513 | 0,641 | 0,770 | 0,898 | 1,026 | 1,155 |
| 800 | 0,129 | 0,258 | 0,387 | 0,516 | 0,646 | 0,775 | 0,904 | 1,033 | 1,162 |

Before abandoning this subject, we must shew by some examples the indispensable necessity of these reductions; formerly, they were neglected; and it is only within about ten years that the majority of observers have taken them into account. However, in some countries, and particularly in England, there are philosophers who do not appear to have appreciated their necessity: for their meteorological journals merely contain the uncorrected heights of the barometer. Indications of this kind teach us plainly, in general terms, whether the barometer is high or low; but there are a great number of researches for which they could not be employed. Do we wish, for example, to compare the barometric height in the different seasons? The reduction is indispensable. Indeed, suppose that during the winter the barometer was placed in a room not warmed, the mean temperature of which was —5°; and that, in summer, the same mean was 20°; suppose also that, in the two seasons, the *uncorrected* height was $756^{mm}$. We should commit a great error were we to conclude that the atmospheric pressure was the same in both seasons; for, on reducing the barometers to zero, we should find that, in winter, the mean height of the barometer is $756^{mm},24$, and in summer, $753^{mm},56$; so that it is $2^{mm},68$ less in summer than in winter. There are other researches in which small differences in temperature may occasion great errors; we shall presently see that the barometer is lower at 4 P.M. than at 10 A.M. In our mean latitudes this difference is about $0^{mm},6$. Suppose that the barometers are not brought to the same temperature, and that the thermometer rises 3°, from 10 A.M. to 4 P.M., a difference that is observed almost every day throughout the year; it follows that the barometer is higher by $0^{mm},4$ than if the temperature had not changed: for, if the barometer falls $0^{mm},6$, in consequence of diminution of pressure, it rises $0^{mm},4$ in consequence of increase of temperature, and the corrected difference is $0^{mm},6 - 0^{mm},4 = 0^{mm},2$; on the contrary, without these corrections, it is $0^{mm},6 - 0^{mm},2 = 0^{mm},4$: thus the error would be $0^{mm},2$. Consequently, the most faithful observations, and those made with the best instruments, are valueless unless the temperature of the barometric column be known.

**CORRECTION FOR CAPILLARITY.**[*]—In all reservoir barometers, where the point is adjusted to the summit of the meniscus, and in that of **Fortin**, as modified by M. **Delcros**, in particular, another correction is necessary; it

---

[*] The paragraph and the table have been added by M. Martins.

is that for capillarity. In consequence of this force, the barometric column is shorter than it ought to be; and, consequently, it does not measure exactly the weight of the atmospheric column. In order to make this correction, we must know two elements: 1st, the interior diameter of the tube; 2d, the length of the versed-sine (*flèche*) of the meniscus. If the maker has not taken care to measure the interior diameter directly, it may be deduced from the exterior diameter; the exterior diameter is first measured by callipers, and, by deducting from this diameter $2^{mm},3$ for tubes eight or ten millimetres in external diameter, and $2^{mm},5$ for those ten or twelve millimetres in external diameter, we have an approximation to the interior diameter of the tube.

To know the length of the versed-sine of the meniscus, the slide $b\ b'\ b''\ b'''$ (pl. II. *fig.* 6) is so placed, that the edge $n\ m$ is tangent to the summit of the meniscus; the point of the scale corresponding to this is noticed; the slide is then lowered until the edge $n\ m$ coincides with the base of the meniscus; this point of the scale is also noticed. By repeating this operation ten or twenty times in succession, we obtain for the length of the versed-sine a mean value, which is quite exact enough.

Knowing the radius of the tubes and the length of the versed-sine of the meniscus, it is easy to know what is the corresponding capillary depression by making use of the following table. Thus:—suppose the radius of the tube is equal to four millimetres, and the versed-sine of the meniscus $0^{mm},8$. I look for 4,0 in the first column, and 0,8 in the first horizontal line. At the point where the vertical column, corresponding to the radius of the tubes, meets the horizontal line corresponding to the versed-sine, the number 0,45 is found. This must be added to the barometric column, in order to correct the error for capillary depression, and to have exactly the weight of the atmospheric column.*

---

* M. BRAVAIS has shewn that capillary depression may be calculated as a function of the angle of incidence of the meniscus on the glass, and of the radius of the barometric tube. The table constructed by him with his formula differs very little from the following, which M. DELCROS has calculated, by help of the formulæ of M. SCHLEIERMACHER (Vide *Annales de Chim. et de Phys.*, 3d series, t. v. 1842).

## TABLE OF DEPRESSIONS DUE TO CAPILLARY ACTION IN BAROMETRIC TUBES.

| RADIUS of the tube in millimetres. | HEIGHT OF THE VERSED-SINE OF THE MENISCUS IN MILLIMETRES. | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0,2 | 0,3 | 0,4 | 0,5 | 0,6 | 0,7 | 0,8 | 0,9 | 1,0 | 1,1 | 1,2 | 1,3 | 1,4 | 1,5 | 1,6 | 1,7 |
| 2,0 | 0,60 | 0,89 | 1,16 | 1,41 | 1,65 | 1,86 | 2,05 | 2,21 | 2,35 | ,, | ,, | ,, | ,, | ,, | ,, | ,, |
| 2,2 | 0,49 | 0,72 | 0,95 | 1,16 | 1,36 | 1,54 | 1,71 | 1,85 | 1,98 | 2,09 | ,, | ,, | ,, | ,, | ,, | ,, |
| 2,4 | 0,40 | 0,60 | 0,79 | 0,97 | 1,14 | 1,29 | 1,44 | 1,57 | 1,68 | 1,78 | 1,87 | ,, | ,, | ,, | ,, | ,, |
| 2,6 | 0,34 | 0,50 | 0,66 | 0,81 | 0,96 | 1,09 | 1,22 | 1,33 | 1,44 | 1,53 | 1,61 | 1,68 | ,, | ,, | ,, | ,, |
| 2,8 | 0,29 | 0,43 | 0,56 | 0,69 | 0,82 | 0,93 | 1,04 | 1,14 | 1,24 | 1,32 | 1,39 | 1,46 | 1,51 | ,, | ,, | ,, |
| 3,0 | 0,24 | 0,36 | 0,48 | 0,59 | 0,70 | 0,80 | 0,90 | 0,99 | 1,07 | 1,14 | 1,21 | 1,27 | 1,32 | 1,37 | ,, | ,, |
| 3,2 | 0,21 | 0,31 | 0,41 | 0,51 | 0,60 | 0,69 | 0,78 | 0,86 | 0,93 | 1,00 | 1,06 | 1,11 | 1,16 | 1,20 | 1,24 | ,, |
| 3,4 | 0,18 | 0,27 | 0,36 | 0,44 | 0,52 | 0,60 | 0,68 | 0,75 | 0,81 | 0,87 | 0,93 | 0,98 | 1,02 | 1,06 | 1,10 | ,, |
| 3,6 | 0,16 | 0,23 | 0,31 | 0,38 | 0,46 | 0,52 | 0,59 | 0,65 | 0,71 | 0,76 | 0,81 | 0,86 | 0,90 | 0,94 | 0,97 | ,, |
| 3,8 | 0,14 | 0,21 | 0,27 | 0,34 | 0,40 | 0,46 | 0,52 | 0,57 | 0,62 | 0,67 | 0,72 | 0,76 | 0,80 | 0,83 | 0,86 | 0,89 |
| 4,0 | 0,12 | 0,18 | 0,24 | 0,30 | 0,35 | 0,40 | 0,46 | 0,50 | 0,55 | 0,59 | 0,64 | 0,67 | 0,71 | 0,74 | 0,77 | 0,79 |
| 4,2 | 0,11 | 0,16 | 0,21 | 0,26 | 0,31 | 0,36 | 0,40 | 0,45 | 0,49 | 0,53 | 0,56 | 0,60 | 0,63 | 0,66 | 0,68 | 0,71 |
| 4,4 | 0,09 | 0,14 | 0,19 | 0,23 | 0,27 | 0,32 | 0,36 | 0,40 | 0,45 | 0,47 | 0,50 | 0,53 | 0,56 | 0,59 | 0,61 | 0,63 |
| 4,6 | 0,08 | 0,12 | 0,16 | 0,20 | 0,24 | 0,28 | 0,32 | 0,35 | 0,38 | 0,42 | 0,45 | 0,47 | 0,50 | 0,52 | 0,54 | 0,56 |
| 4,8 | 0,07 | 0,11 | 0,15 | 0,18 | 0,22 | 0,25 | 0,28 | 0,31 | 0,34 | 0,37 | 0,40 | 0,42 | 0,45 | 0,47 | 0,49 | 0,50 |
| 5,0 | 0,07 | 0,10 | 0,13 | 0,16 | 0,19 | 0,22 | 0,25 | 0,28 | 0,31 | 0,33 | 0,35 | 0,38 | 0,40 | 0,42 | 0,44 | 0,45 |
| 5,2 | 0,06 | 0,09 | 0,12 | 0,14 | 0,17 | 0,20 | 0,22 | 0,25 | 0,27 | 0,30 | 0,32 | 0,34 | 0,36 | 0,37 | 0,39 | 0,41 |
| 5,4 | 0,05 | 0,08 | 0,10 | 0,13 | 0,15 | 0,18 | 0,20 | 0,22 | 0,24 | 0,26 | 0,28 | 0,30 | 0,32 | 0,34 | 0,35 | 0,36 |
| 5,6 | 0,05 | 0,07 | 0,09 | 0,12 | 0,14 | 0,16 | 0,18 | 0,20 | 0,22 | 0,24 | 0,26 | 0,27 | 0,29 | 0,30 | 0,32 | 0,33 |
| 5,8 | 0,04 | 0,06 | 0,08 | 0,10 | 0,12 | 0,14 | 0,16 | 0,18 | 0,20 | 0,21 | 0,23 | 0,24 | 0,26 | 0,27 | 0,28 | 0,29 |
| 6,0 | 0,04 | 0,06 | 0,07 | 0,09 | 0,11 | 0,13 | 0,14 | 0,16 | 0,18 | 0,19 | 0,21 | 0,22 | 0,23 | 0,24 | 0,25 | 0,26 |
| 6,2 | 0,03 | 0,05 | 0,07 | 0,08 | 0,10 | 0,11 | 0,13 | 0,14 | 0,16 | 0,17 | 0,19 | 0,20 | 0,21 | 0,22 | 0,23 | 0,24 |
| 6,4 | 0,03 | 0,05 | 0,06 | 0,07 | 0,09 | 0,10 | 0,12 | 0,13 | 0,14 | 0,15 | 0,17 | 0,18 | 0,19 | 0,20 | 0,21 | 0,21 |
| 6,6 | 0,03 | 0,04 | 0,05 | 0,07 | 0,08 | 0,09 | 0,11 | 0,12 | 0,13 | 0,14 | 0,15 | 0,16 | 0,17 | 0,18 | 0,19 | 0,19 |
| 6,8 | 0,02 | 0,04 | 0,05 | 0,06 | 0,07 | 0,08 | 0,10 | 0,11 | 0,12 | 0,13 | 0,14 | 0,14 | 0,15 | 0,16 | 0,17 | 0,17 |
| 7,0 | 0,02 | 0,03 | 0,04 | 0,06 | 0,07 | 0,08 | 0,09 | 0,10 | 0,11 | 0,11 | 0,12 | 0,13 | 0,14 | 0,15 | 0,15 | 0,16 |

**DIURNAL VARIATIONS OF THE BAROMETER.**—We are aware that in our climates the barometric column is incessantly oscillating. These irregular oscillations, which, beyond the tropics, are connected with the state of the atmosphere, depend on the geographical position of the place; they are more marked as we recede further from the equator. Within the tropics the state of the atmosphere has very little influence over the barometer. If, therefore, we observe the instrument hourly for one, or for several days, we shall remark regular oscillations, that is to say, the mercury will fall at certain hours to rise again at other hours.

A dissertation by **Beale**, published in 1666, shews that even then he suspected the existence of this phenomenon; for he affirms that the barometer is higher in the evening and in the morning than it is at mid-day. Analogous indications are found in voyages to equinoctial countries. An unknown observer, who dwelt at Surinam in 1722, was the first to give positive notions on this phenomenon; he says, that the barometer has two diurnal *minima* and two *maxima*; and he indicated very exactly the hours of these extremes, which we will term tropical hours. Father **Boudier** studied the daily oscillations at Chandernagor, in India, during the year 1740: more recently, this phenomenon has been remarked by a great number of travellers; but M. **de Humboldt** was the first who made very exact observations, and who drew the attention of philosophers to this variation. It was important to know whether this phenomenon exists also in other countries. **Ciminello** made an uninterrupted series of observations at Padua, from 1778 to 1780; but his work fell into oblivion. The observations of **van Swinden** in Holland, and of **Hemmer** and **Planer** in Germany, left much to be desired; **Ramond**, therefore, undertook a continued series; and other meteorologists imitated him: unfortunately, they contented themselves with observing the barometer only three or four times a-day. **Yelin**, of Munich, made a long succession of observations; but, although they clearly shew the law of diurnal oscillations, we cannot conclude any thing concerning the extent of these oscillations, because he did not notice the temperature of the mercury. The series made by **Hallstroem**, at Abo, in Finland, is infinitely more satisfactory: at Halle, from the commencement of 1827, I have almost always observed the barometer hourly from 6 A.M. to 10 P.M. **Neuber**, at Apenrade, **Lohrmann**, at Dresden, **Koller**, at Kremsmunster, and the astronomers of the Milan Observatory, are now making, or have made, some long series. The most northern point, for which we possess several years of observations, is Petersburg, where the state of the instruments is observed every two hours. The observations made by the English, in their voyages to the pole, unfortunately leave much to be desired.

The diurnal oscillations depend on the geographical position of the place where the observations are made. Near the equator the differences between the *maximum* and the *minimum* are very great; and a single day's observations are sufficient to establish the existence of these oscillations. It is not the same in the high latitudes; not only is the diurnal variation less, but it is also marked by irregular oscillations. However, if we follow the barometer for a month, the mean of the observations enables us to recognise the law; it is even appreciable in a period of ten days. Once, in the course of my observations, I was unable to recognise it; it was during the first eighteen days of the month of December, 1833, which was so remarkable for disturbances of every kind. One year of observations, therefore, is sufficient to establish the laws of diurnal variation; but the difference of seasons is not easily recognised even in a series of twelve years.

In almost all the series that we possess, observations have not been made at night; however, the hourly changes are so regular, that the range of the barometer by night may be deduced from that which it follows during the day. The following table presents the mean height of the barometer for all hours of the day, and at different latitudes:—

## MEAN HEIGHT OF THE BAROMETER, EXPRESSED IN MILLIMETRES, FOR ALL HOURS, AND IN DIFFERENT PLACES.

| PLACES. | G. OCEAN. | CUMANA. | LA GUYARA. | CALCUTTA | PADUA. | HALLE. | ABO. | PETERSBURG. | PLACES. |
|---|---|---|---|---|---|---|---|---|---|
| Latitude. | 0° 0′ | 10° 28′ N. | 10° 36′ N. | 22° 35′ N. | 45° 24′ N. | 54° 29′ N. | 60° 57′ N. | 59° 66′ N. | Latitude. |
| Observers. | Horner. | Humboldt. | Boussingault. | Balfour. | Ciminello. | Kaemtz. | Hallstroem | Kupffer. | Observers. |
| Noon. | 752,35 | 756,57 | 759,41 | 759,61 | 757,02 | 753,29 | 759,31 | 759,47 | Noon. |
| 1 | 751,87 | 755,99 | 758,91 | 759,22 | 756,85 | 753,11 | 759,29 | ,, | 1 |
| 2 | 751,55 | 755,47 | 758,41 | 758,39 | 756,67 | 752,99 | 759,27 | 759,38 | 2 |
| 3 | 751,15 | 755,14 | 758,12 | 758,12 | 756,54 | 752,89 | 759,25 | ,, | 3 |
| 4 | 751,02 | 754,96 | 758,05 | 757,91 | 756,47 | 752,84 | 759,25 | 759,32 | 4 |
| 5 | 751,31 | 755,14 | 758,10 | 757,93 | 756,46 | 752,86 | 759,27 | ,, | 5 |
| 6 | 751,71 | 755,41 | 758,40 | 758,01 | 756,50 | 752,91 | 759,29 | 759,31 | 6 |
| 7 | 751,93 | 755,81 | 758,90 | 758,02 | 756,63 | 753,02 | 759,34 | ,, | 7 |
| 8 | 752,35 | 756,21 | 759,19 | 758,54 | 756,79 | 753,14 | 759,39 | 759,32 | 8 |
| 9 | 752,74 | 756,59 | 759,69 | 759,24 | 756,92 | 753,24 | 759,44 | ,, | 9 |
| 10 | 752,85 | 756,87 | 759,93 | 759,33 | 757,02 | 753,31 | 759,47 | 759,36 | 10 |
| 11 | 752,86 | 757,15 | 759,98 | 759,09 | 757,02 | 753,29 | 759,47 | ,, | 11 |
| Midnight. | 752,47 | 756,86 | 759,64 | 758,80 | 757,01 | 753,23 | 759,41 | 759,35 | Midnight. |
| 13 | 752,20 | 756,53 | 759,34 | 758,62 | 756,90 | 753,14 | 759,33 | ,, | 13 |
| 14 | 751,77 | 756,21 | 759,05 | 758,57 | 756,84 | 753,05 | 759,24 | 759,32 | 14 |
| 15 | 751,63 | 755,89 | 758,81 | 758,49 | 756,78 | 752,99 | 759,14 | ,, | 15 |
| 16 | 751,32 | 755,66 | 758,68 | 758,47 | 756,74 | 752,99 | 759,07 | 759,32 | 16 |
| 17 | 751,65 | 755,79 | 758,85 | 758,44 | 756,75 | 753,34 | 759,03 | ,, | 17 |
| 18 | 751,95 | 756,18 | 759,32 | 758,68 | 756,79 | 753,12 | 759,04 | 759,39 | 18 |
| 19 | 752,48 | 756,58 | 759,94 | 759,16 | 756,89 | 753,24 | 759,08 | ,, | 19 |
| 20 | 752,95 | 756,98 | 760,50 | 759,88 | 757,01 | 753,37 | 759,15 | 759,49 | 20 |
| 21 | 753,16 | 757,31 | 759,63 | 760,11 | 757,08 | 753,44 | 759,21 | ,, | 21 |
| 22 | 753,15 | 757,32 | 760,50 | 750,19 | 757,14 | 753,46 | 759,29 | 759,51 | 22 |
| 23 | 752,80 | 757,01 | 759,99 | 750,09 | 757,07 | 753,40 | 759,32 | ,, | 23 |

(*Vide* Appendix, *fig.* 22.)

From among the great number of places, for which I possess barometric series, I have chosen those that have seemed to me suited to shew the law which these oscillations follow; they are comprised between the equator and the 60th degree of north latitude. These numbers very well shew the laws of the diurnal barometric variation. From mid-day, the barometer falls until 3 or 5 P.M.,—the moment when it attains its *minimum*; it then rises, and its *maximum* occurs between nine and eleven in the evening. It falls again, and a second *minimum* is observed, about four in the morning, and a second *maximum* about 10 A.M.*

The tropical hours are not the same in all countries; but this difference perhaps only depends on the want of length in certain series, which prevents the influence of anomalies from entirely disappearing. The general means are as follows:—

---

* The *bihorary* barometric observations made at Bosekop, latitude 66° 58′, by the hybernating members of the Commission of the North, gave M. BRAVAIS the following results, as hourly means:—

HOURLY BAROMETRIC MEANS AT BOSEKOP.

| HOURS. | HEIGHT of the Barometer. | HOURS. | HEIGHT of the Barometer. |
|---|---|---|---|
|  | mm. |  | mm. |
| Noon. | 755,01 | Midnight. | 754,90 |
| 2 | 754,96 | 14 | 754,79 |
| 4 | 754,82 | 16 | 754,70 |
| 6 | 754,87 | 18 | 754,68 |
| 8 | 754,89 | 20 | 754,75 |
| 10 | 754,92 | 22 | 754,96 |

In order to obtain these numbers, the curve of diurnal variation is determined separately for the equinoxes and the solstices, and the mean between the equinoctial and the solstitial curve is taken.

If we deduce from this table the barometric mean for the hours 4 and 16, and if we subtract it from the mean of the barometric heights at the hours 10 and 22, we shall have what M. KAEMTZ has termed the *mean diurnal oscillation of the barometer:* its value is equal to $0^{mm},18$. The observations at Koningsberg, Petersburg, and Kasan, gave about the same amplitude. Moreover, the increments and decrements of these numbers prove that, in the regions situated at the north of the polar circle, the hours of the arrival of the *maxima* and *minima* are behind the hours of the arrival which are peculiar to the temperate zones; but this retardation is not sufficiently great to subvert the direction of the undulation: in order that this subversion may take place, the delay should be, at least, three hours; and our observations prove that it is scarcely equal to one hour and a half under the 70th degree of latitude.—M.

### TROPICAL HOURS OF DIURNAL BAROMETRIC VARIATION IN THE NORTHERN HEMISPHERE.

| | | |
|---|---|---|
| *Minimum* of the evening . . . | $4^h$ | $5^m$ |
| *Maximum* of „ . . . | 10 | 11 |
| *Minimum* of the morning . . . | 15 | 45 |
| *Maximum* of „ . . . | 21 | 37 |

If, therefore, an observer wishes to know the *maxima* and *minima* of atmospheric pressure, he should make his observations at 4 A.M. and at 10 P.M. The choice of these hours is the more to be recommended, as they are those, the thermometric mean of which is equal to the diurnal thermometric mean.

**TROPICAL HOURS IN THE DIFFERENT SEASONS.**—If the geographic position appears without influence over the tropical hours, the seasons have a very sensible influence, which was found in **Ciminello's** series, and was pointed out in a very positive manner by **Ramond**; my series at Halle gives for the tropical instants the following moments in true time, and in the decimal parts of an hour.

### TROPICAL HOURS OF DIURNAL BAROMETRIC VARIATION AT HALLE.

| MONTHS. | MINIMUM. | MAXIMUM. | MINIMUM. | MAXIMUM. |
|---|---|---|---|---|
| January . | $2^h$,81 | $9^h$,17 | $16^h$,91 | $21^h$,91 |
| February . | 3 ,43 | 9 ,46 | 15 ,86 | 21 ,66 |
| March . . | 3 ,82 | 9 ,80 | 15 ,87 | 22 ,10 |
| April . . | 4 ,46 | 10 ,27 | 15 ,53 | 21 ,53 |
| May . . . | 5 ,43 | 10 ,93 | 15 ,03 | 21 ,13 |
| June . . | 5 ,20 | 10 ,93 | 14 ,83 | 20 ,73 |
| July . . | 5 ,21 | 11 ,04 | 15 ,04 | 20 ,48 |
| August . . | 4 ,86 | 10 ,66 | 15 ,06 | 20 ,96 |
| September . | 4 ,55 | 10 ,45 | 15 ,45 | 21 ,71 |
| October . . | 4 ,17 | 10 ,24 | 15 ,97 | 22 ,07 |
| November . | 3 ,52 | 9 ,85 | 16 ,68 | 22 ,08 |
| December . | 3 ,15 | 9 ,11 | 16 ,91 | 22 ,18 |

(*Vide* Appendix, *fig.* 23.)

This table, however, possesses several anomalies, and proves that a series of observations, comprising ten years, is not sufficient in our latitudes to determine rigorously the tropical instants. The influence of the seasons is very marked: in winter the barometer attains its lowest point about three o'clock, but in summer it falls until five o'clock at least. On the whole, during winter, the tropical moments are nearer mid-day, by about two hours; they arrive later in the morning and sooner in the evening.

**AMPLITUDE OF THE DIURNAL OSCILLATIONS.**—The influence of latitude over this amplitude is very evident. Let us look, for example, for the difference between the height of the barometer at 10 A.M. and at 4 P.M.; we shall find $2^{mm},39$, as the mean at Cumana and La Guayra; and at Petersburg and Abo, $0^{mm},113$, that is about $\frac{1}{20}$th the extent of the oscillations near the equator. The opinions of meteorologists on the manner in which these comparisons ought to be established are divided: M. **de Humboldt** takes the difference of the two extremes of morning and evening, and neglects the others; others consider the four extremes, and take the difference between the highest *maximum* and the lowest *minimum*. These two methods appear to me incorrect; and I have perceived that, by thus neglecting the two extremes, the accidental variations are not sufficiently eliminated. Suppose, for instance, that the barometer falls rapidly between 10 A.M. and 4 P.M. The difference between the two observed extremes will be too great; but, for the very reason that it has fallen rapidly during the day, it will fall less during the night; and, by subtracting the mean of the *minima* from that of the *maxima*, we shall find a quantity that will approach much nearer to the truth: we will name this difference the *diurnal oscillation*.

Before examining the extent of the mean diurnal oscillation in different regions, I must mention certain important points, which we must not lose sight of, in comparing these quantities with each other. In our climates, the season has an influence over the diurnal oscillation, and even within the tropics it is less during the rainy season; at least, such seems to be the result of the few observations that have been made in India. **Ramond** was the first to point out this fact, which has since been established by a great many observers; but, in order to obtain exact numbers, we must calculate series comprising a great number of years. For, if it is very certain that in winter the diurnal oscillation arrives at its *minimum*, there is some doubt remaining as to the season at which it reaches its *maximum*; some place it in summer, others in autumn, some even in spring. As my observations comprise a long series, I have reduced them to three years of the Milan Observatory. It is much to be regretted that **Hallstroem** has not yet published the series that he made at Abo and at Helsingfors; they would lead to important conclusions.

MEAN DIURNAL OSCILLATION OF THE BAROMETER.

| MONTHS. | HALLE. | MILAN. |
|---|---|---|
| | mm. | mm. |
| January . . . | 0,393 | 0,738 |
| February . . . | 0,476 | 0,718 |
| March . . . . | 0,488 | 0,871 |
| April . . . . | 0,569 | 0,871 |
| May . . . . | 0,546 | 0,801 |
| June . . . . | 0,557 | 0,961 |
| July . . . . | 0,566 | 0,952 |
| August . . . | 0,569 | 0,812 |
| September . . | 0,546 | 0,817 |
| October . . . | 0,566 | 0,745 |
| November . . | 0,426 | 0,727 |
| December . . | 0,363 | 0,700 |

(*Vide* Appendix, *fig*. 24.)

The influence of season becomes evident in this table: in winter, the diurnal oscillation attains its *minimum*; it continues augmenting till summer, when it attains its *maximum*. Halle and Milan follow the same law; but the anomalies that we observed, on calculating the mean oscillation for these two towns, prove that even decennial series are too short.

In order to know the mean diurnal oscillation of the barometer, the observations must embrace at least one year; the height above the level of the sea has also a great influence. **Daniell** was the first to remark that the barometer of the great St. Bernard was often higher in the afternoon than in the morning, whilst the contrary was the case at Geneva. A series of corresponding observations made by M. **Eschmann** on the Rigi, and M. **Horner** at Zurich, lead to the same result. I here give a series of horary observations corresponding to those of Zurich, and made by myself on the Rigi, and on the Faulhorn; the observations of the hours 10 and 17 were found by interpolation.*

---

* The observations made in 1841 and 1842 by MM. Bravais, Wachsmuth, Peltier, and myself, on the Faulhorn, assign to the barometric variation a diurnal range, differing in many respects from that obtained by the author on the same mountain. In order that the reader may compare, at a glance, these several series of observations, we will give the table of them, as constructed by M. Bravais. The numbers followed by two points (:) were obtained by interpolation.

DIURNAL VARIATION OF THE BAROMETER ON THE FAULHORN.

| Hours. | KAEMTZ. 1832. | KAEMTZ. 1833. | BRAVAIS and MARTINS. 1841. | WACHSMUTH. 1841. | PELTIER and BRAVAIS. 1842. | General Mean. |
|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. | mm. |
| 0 | 557,88 | 551,02 | 553,16 | 556,14 | 556,42 | 554,93 |
| 2 | 557,66 | 551,13 | 553,28 | 556,09 | 556,49 | 554,93 |
| 4 | 557,50 | 551,14 | 553,30 | at 3 h. | 556,54 | 554,91 |
| 6 | 557,51 | 551,20 | 553,30 | 556,01 | 556,44 | 554,89 |
| 8 | 557,42 | 551,39 | 553,40 | 556,22 | 556,58 | 554,99 |
| 10 | 557,41 | 551,32 | 553,53 | at 9 h. | 556,64 | 555,03 |
| 12 | 557,29 : | 551,10 : | 553,32 | 556,27 : | 556,41 | 554,88 |
| 14 | 557,07 : | 550,70 : | 552,98 | 555,90 : | 556,08 | 554,57 |
| 16 | 556,89 : | 550,44 : | 552,78 | at 15 h. | 555,90 | 554,36 |
| 18 | 557,04 | 550,44 | 552,63 | 555,62 | 555,84 | 554,31 |
| 20 | 557,37 | 550,62 | 552,74 | 555,86 | 555,98 | 554,50 |
| 22 | 557,88 | 550,92 | 552,01 | at 21 h. | 556,27 | 554,81 |

(*Vide* Appendix, *fig.* 25.)

The first of these five series of observations does not accord with the following four; the latter agree with each other, and establish the existence of a *maximum* about 10 P.M., and a *minimum* about 6 A.M.; it appears, moreover, that the *maximum* of 10 A.M. has receded to three in the evening; and the *minimum* that follows it about 5 P.M. is very feeble; the slightest disturbance is sufficient to cause this retrograde range of the barometer to disappear. As the last four series are based on 106 days of observations made under varied circumstances, while the former series is the mean of twenty-five days, we must place less confidence in this series. Moreover, the general mean of the five series, such as we give it in the last column, cannot be very far from the truth. New observations are necessary in order to dissipate all the doubts that may remain as to the reality of the fall of the barometer between 3 and 5 P.M., at a vertical height of 2700 metres above the level of the sea.—M.

### DIURNAL VARIATION OF THE BAROMETER AT DIFFERENT HEIGHTS.

| HOURS. | ZURICH<br>mm.<br>720+ | RIGI.<br>mm.<br>610+ | DIFFERENCES.<br>mm.<br>100+ | ZURICH<br>mm.<br>730+ | FAULHORN.<br>mm.<br>550+ | DIFFERENCES.<br>mm.<br>170+ |
|---|---|---|---|---|---|---|
| Noon | 4,08 | 4,36 | 9,72 | 1,58 | 7,88 | 3,70 |
| 1 | 3,92 | 4,37 | 9,57 | 1,25 | 7,75 | 3,50 |
| 2 | 3,82 | 4,38 | 9,44 | 0,99 | 7,66 | 3,33 |
| 3 | 3,72 | 4,34 | 9,38 | 0,71 | 7,59 | 3,13 |
| 4 | 3,63 | 4,34 | 9,30 | 0,64 | 7,50 | 3,15 |
| 5 | 3,61 | 4,30 | 9,31 | 0,76 | 7,49 | 3,27 |
| 6 | 3,76 | 4,38 | 9,38 | 0,92 | 7,51 | 3,41 |
| 7 | 3,95 | 4,40 | 9,57 | 1,21 | 7,41 | 3,80 |
| 8 | 4,22 | 4,57 | 9,87 | 1,52 | 7,43 | 4,10 |
| 9 | 4,55 | 4,70 | 9,85 | 1,72 | 7,44 | 4,27 |
| 10 | 4,61 | 4,72 | 9,90 | 1,79 | 7,41 | 4,39 |
| 11 | 4,68 | 4,68 | 10,00 | 1,77 | 7,36 | 4,41 |
| Midnight | 4,58 | 4,58 | 10,01 | 1,72 | 7,28 | 4,44 |
| 13 | 4,43 | 4,45 | 9,99 | 1,63 | 7,19 | 4,45 |
| 14 | 4,28 | 4,30 | 9,98 | 1,54 | 7,08 | 4,47 |
| 15 | 4,19 | 4,17 | 10,03 | 1,51 | 6,96 | 4,55 |
| 16 | 4,18 | 4,09 | 10,10 | 1,54 | 6,90 | 4,65 |
| 17 | 4,25 | 4,03 | 10,23 | 1,66 | 6,90 | 4,76 |
| 18 | 4,31 | 4,03 | 10,28 | 1,79 | 7,05 | 4,76 |
| 19 | 4,38 | 4,05 | 10,33 | 1,97 | 7,16 | 4,80 |
| 20 | 4,41 | 4,13 | 10,28 | 2,13 | 7,36 | 4,77 |
| 21 | 4,38 | 4,16 | 10,22 | 2,20 | 7,62 | 4,57 |
| 22 | 4,29 | 4,23 | 10,06 | 2,12 | 7,89 | 4,24 |
| 23 | 4,19 | 4,34 | 9,86 | 1,87 | 7,99 | 3,97 |

(*Vide* Appendix, *fig*. 26.)

These correspondent observations shew that the laws of diurnal variation change as we ascend in the atmosphere. At Zurich, the barometer falls from mid-day to 5 P.M.; we find an analogous change on the Rigi; but the oscillations are smaller, and the difference between the two barometers continues diminishing, and attains its *maximum* between three and four o'clock; the two barometers then rise, but that of Zurich much more than that of the Rigi, and the difference between the two barometers increases. During the night the atmospheric pressure diminishes uniformly at the two stations, and the difference between the two barometers remains constant. However, the morning *minimum* falls at Zurich between three and four o'clock, and on the Rigi between five and six: the barometer then rises much more at Zurich than on the Rigi; at Zurich, the *maximum* is at about eight o'clock in the morning; on the Rigi the column rises uninterruptedly until about mid-day. The corresponding observations at the Faulhorn lead to the same results; the tropical hours differ; and while, in the evening, the difference between the two barometers of the mountain and the valley is 173$^{mm}$,02, it is 174$^{mm}$,82 in the morning.

In order to appreciate the influence of height, let us still consider the mean barometric oscillation; let us look for the two *minima* and the two *maxima* of Zurich, and deduct the mean *minimum* from the mean *maximum*. Let us then consider what was the barometric height of the upper station at the tropical hours of the lower, and subtract the mean from the hour of the *maximu*. The correspondents of Zurich and the Faulhorn will serve us to construct the following table:—

HOURS OF THE SMALLEST AND GREATEST HEIGHT OF THE BAROMETER AT ZURICH AND ON THE RIGI.

| BAROMETRIC HEIGHT. | HOURS. | ZURICH. | RIGI. |
|---|---|---|---|
| | | mm. | mm. |
| Minimum . | 4$^h$,38 | 723,62 | 614,31 |
| Maximum . | 10 ,70 | 724,68 | 614,71 |
| Minimum . | 15 ,53 | 724,18 | 614,03 |
| Maximum . | 19 ,67 | 724,41 | 614,10 |

At Zurich, the difference between the mean *maxima* and *minima* is 0$^{mm}$,644; on the Rigi, it is only 0$^{mm}$,237. Simultaneous observations at Geneva and Zurich give us the mean diurnal oscillation, 0$^{mm}$,897; whilst on the Faulhorn the *corresponding* difference was only 0$^{mm}$,268. Thus, at a certain elevation above the level of the sea, the diurnal oscillation would be null. In 1833, during my stay on the Faulhorn, the weather was constantly very bad; the mean diurnal oscillation at Berne, Basle, Geneva, and Zurich, was 0$^{mm}$,656; on the Faulhorn, the corresponding difference was 0$^{mm}$,178: whilst, in the plain, the barometer fell from the *maximum* of nine o'clock in the morning, to the *minimum* of three o'clock in the evening, about $0^{mm},68$; it rose on the Faulhorn from $550^{mm},83$ to $551^{mm},12$, that is, about $0^{mm},29$; thus, then, the phenomenon was the reverse on the mountain. Whilst on the plain the barometer generally falls during the day, it does the contrary on an elevated summit.

If we examine the mean diurnal oscillation at different points of the terrestrial surface, we shall have a correction to make in order to reduce these points to the level of the sea. The observations made on the Alps supply us with the elements of this correction. Let us admit that on the seashore the barometer is at $761^{mm},33$; let D be the mean oscillation: let us ascend without changing latitude, and suppose that the barometer is at $b$ millimetres below $761^{mm},35$, the diurnal variation will be $d$, and we shall have the equation

$$d = \mathrm{D} - a.b.$$

$a$ being a coefficient to be determined by observation, the series made in 1832 on the Rigi, compared with that of Zurich, gives us the value of $a$

$$a = 0{,}003694;$$

that made in 1833 on the same summit, compared with those of Basle, Berne, and Zurich, gives

$$a = 0{,}003986;$$

that of the Faulhorn, in 1832, compared with Geneva and Zurich, gives

$$a = 0{,}003674;$$

finally, the series of 1833 on the same mountain, compared with those of Basle, Berne, Geneva, and Zurich, gives

$$a = 0{,}002758;$$

a series made by **Buckwalder** on the Sentis, and by **Horner** at Zurich,

$$a = 0{,}003630;$$

the observations of **de Saussure** on the Col du Géant, compared with those of Geneva and Chaumouni,

$$a = 0{,}004053;$$

those made in the winter by **Eschmann** on the Rigi, corresponding to those at Zurich, give

$$a = 0{,}002856;$$

We admit that in the Alps the value of this coefficient is

$$a = 0,003507.$$

From a comparison of series made at Halle, Dresden, Jena, Prague, Zittau, Gotha, Freyberg, and Altenberg, we deduce

$$a = 0,003628\,;$$

those of many points in tropical America give

$$a = 0,002441.$$

we shall therefore adopt the mean of all these values, namely,

$$a = 0,003413.$$

Thus, then, in order to reduce the diurnal observations to the level of the sea, we shall first seek the difference between the mean *maxima* and *minima*; we then multiply the number of millimetres which the barometer is below $761^{mm},35$ by 0,003413, and we add this product to the difference found.*

**MEAN DIURNAL VARIATION AT DIFFERENT LATITUDES.**—The following table gives the size of the

---

* The process employed by the author, for correcting the value of the diurnal oscillation, does not appear to be entirely free from objection: $d$ is the diurnal variation on the mountain, and D the diurnal variation on the sea-shore; let us, in addition, take H for the mean height of the barometer on the mountain, expressed in millimetres. M. KAEMTZ establishes the following relation:—

$$d = D - 0,003413\,(760 - H).$$

The factor $(760 - H)$ is represented by $b$ in M. KAEMTZ's calculation. But what do $d$ and D represent? We must not mistake this: these quantities represent the mean rise from 4 to 10 o'clock, in the higher and lower stations. Take, for example, the barometric observations at the Faulhorn (*vide* the table in the preceding note); we have

$$d = \frac{554,81 + 555,03}{2} - \frac{554,91 + 554,36}{2} = 0^{mm},285$$

$$760 - H = 205^{mm}.$$

$$\text{Therefore } D = 0,285 + 0,70 = 0^{mm},985.$$

This is the value of *the oscillation at the sea-shore*, deduced from the formula. But, instead of operating thus, M. KAEMTZ takes for the value of $d$ the excess of the mean *maximum* over the mean *minimum*; so that, in the case before us, according to M. KAEMTZ's rule, we should have found

$$d = \frac{554,93 + 555,05}{2} - \frac{554,89 + 554,29}{2} = 0^{mm},40.$$

$$\text{Whence } D = 0,40 + 0,70 = 1^{mm},10.$$

Thus, after all, if we wish to employ the mode of reduction proposed by mean diurnal oscillation deduced from a greater or less number of observations. The second column indicates the latitude; the third, the mean height of the barometer; the fourth, the observed diurnal variation; the fifth, the diurnal variation reduced to the level of the sea, from the formula that we have given.

M. Kaemtz, and the coefficient 0,003413, we must measure the mean barometric oscillation by using the fixed terms 4h. 10h. 16h. and 22h., even though these terms should not exactly coincide with the epochs of *maxima* and *minima*.

We should remark that, by thus measuring the mean oscillation, the value obtained may be any thing but an exact representation of the amplitude of the curve of diurnal variation. Let us, indeed, conceive that, by some cause or other, the primitive curve, the epochs of whose *maxima* and *minima* coincide with the hours 4, 10, 16, and 22, is displaced without changing its form and size, and retrogrades three hours, the *maxima* now occurring at 7h. and 19h., and the *minima* at 1h. and 13h. It will follow that, at the intermediate hours, 4, 10, 16, and 22, the barometer will be somewhat nearer its mean state; the four relative readings at these hours will be the same, and the quantity $d$, deduced from the comparison of the fixed terms 4, 10, 16, and 22, will become nought. Yet the amplitude of the curve will not have changed; there will merely have been a displacement at the critical hours.

So that the employment of fixed terms is insufficient to enable us to appreciate the true amplitude, by calling M the first *maximum;* M′ the second *maximum;* $m$ the first *minimum;* $m'$ the second *minimum*. The quantity represented by the formula,

$$\frac{M + M'}{2} - \frac{m + m'}{2}$$

fulfils these conditions much better; but it is defective when the *minimum* of 4 P.M. so approaches the preceding *maximum* that their existence is rendered problematical; this happens in our climates at an elevation of 3000 metres above the sea.

This inconvenience might be obviated by agreeing to compare the *maximum* of 10 P.M. with the *minimum* that occurs between 3 and 6 A.M., and casting aside the other two epochs. M. A. Bravais proposed (*Journal de l'Institut*, année 1842, p. 309) to measure the *mean amplitude* of the diurnal variation of a given place, by taking the mean of the squares of the differences between the variable hourly readings, and the mean reading that is constant: this amplitude is then made equal to the square root of this mean. By operating thus, we find, at about the 46th degree of latitude,

At 400 metres above the sea $d = 0^{mm},40$
2700 „ „ $d = 0^{mm},28$.

And the formula that will express the extinction of the amplitude, as we ascend, will be

$$d = D - 0,0007\ (760 - H).$$

In the same manner we might put into a formula the law according to which the *mean amplitude* of the diurnal thermometric variation decreases as the observer ascends above the level of the sea.—M.

### MEAN HEIGHT AND DIURNAL OSCILLATION OF THE BAROMETER AT DIFFERENT LATITUDES.

| PLACES. | LATITUDE. | MEAN HEIGHT. | MEAN DIURNAL OSCILLATION. | |
|---|---|---|---|---|
| | | | Observed. | Calculated. |
| | | mm. | mm. | mm. |
| Lima . . . . . . | 12° 3′ S. | 741,72 | 2,71 | 2,78 |
| Caraccas . . . . | 10 31 N. | 681,94 | 2,17 | 2,44 |
| Payta . . . . . . | 5 6 S. | 757,96 | 2,08 | 2,08 |
| Sta. Fé de Bogota . | 4 36 N. | 759,90 | 2,01 | 2,69 |
| Ibagué . . . . . . | 4 28 | 658,70 | 1,92 | 2,27 |
| Popayan . . . . | 2 26 | 618,10 | 1,92 | 2,41 |
| La Guayra . . . | 10 36 | 759,31 | 1,89 | 1,90 |
| Calcutta . . . . | 22 35 | 758,86 | 1,84 | 1,85 |
| Callao . . . . . . | 12 3 S. | 759,76 | 1,84 | 1,84 |
| Cumana . . . . | 10 28 N. | 756,15 | 1,78 | 1,80 |
| Great Ocean . . . | 0 0 | ” | 1,71 | 1,71 |
| Rio-Janeiro . . . | 22 54 S. | 764,95 | 1,70 | 1,70 |
| Chittledroog . . . | 14 11 N. | 695,02 | 1,65 | 1,80 |
| Tahiti . . . . . . | 17 29 S. | 761,34 | 1,64 | 1,64 |
| Mexico . . . . . . | 19 26 N. | 583,13 | 1,59 | 2,20 |
| Great Ocean . . . | 16 0 S. | ” | 1,55 | 1,55 |
| Sierra Leone . . . | 8 30 N. | 754,34 | 1,55 | 1,57 |
| Cairo . . . . . . | 30 2 | 757,28 | 1,54 | 1,55 |
| Quito . . . . . . | 0 13 S. | 553,81 | 1,48 | 2,19 |
| Great Ocean . . . | 18 0 N. | ” | 1,45 | 1,45 |
| Antisana . . . . | 0 33 | 470,34 | 1,26 | 2,25 |
| Rome . . . . . . | 41 54 | 531,24 | 0,98 | 1,00 |
| Basle . . . . . . | 47 34 | 738,79 | 0,84 | 0,92 |
| Viviers . . . . . . | 44 29 | 755,47 | 0,84 | 8,86 |
| Brussels . . . . | 50 50 | 757,06 | 0,80 | 0,81 |
| Clermont . . . . | 45 27 | 727,96 | 0,77 | 0,82 |
| Milan . . . . . . | 45 28 | 752,09 | 0,75 | 0,78 |
| Coire . . . . . . | 46 51 | 711,04 | 0,71 | 0,88 |
| Frankfort-on-the-Maine . . . | 50 8 | 752,47 | 0,71 | 0,74 |
| Arnstadt . . . | 50 50 | 734,40 | 0,67 | 0,76 |
| Heidelberg . . . | 49 25 | 756,84 | 0,65 | 0,63 |
| Mannheim . . . | 49 29 | 750,74 | 0,58 | 0,61 |
| Paris . . . . . . | 48 50 | 756,61 | 0,55 | 0,56 |

| PLACES. | LATITUDE. | MEAN HEIGHT. | MEAN DIURNAL OSCILLATION. | |
|---|---|---|---|---|
| | | | Observed. | Calculated. |
| | | mm. | mm. | mm. |
| Jena . . . . . . | 50° 56′ N. | 749,16 | 0,54 | 0,58 |
| Christiania . . . . | 59 55 | 757,96 | 0,52 | 0,52 |
| Prague . . . . . | 50 5 | 743,97 | 0,51 | 0,57 |
| Padua . . . . . . | 45 24 | 756,84 | 0,48 | 0,51 |
| Halle . . . . . . | 51 29 | 753,45 | 0,47 | 0,50 |
| Dresden . . . . | 51 7 | 744,42 | 0,47 | 0,53 |
| Gotha . . . . . . | 50 56 | 730,89 | 0,45 | 0,55 |
| Zittau . . . . . . | 50 52 | 739,91 | 0,45 | 0,52 |
| Munster . . . . | 51 58 | 754,80 | 0,43 | 0,45 |
| Wetzlar . . . . | 50 32 | 743,75 | 0,39 | 0,45 |
| Apenrade . . . . | 55 3 | 758,86 | 0,36 | 0,37 |
| Berlin . . . . . . | 52 33 | 758,63 | 0,34 | 0,35 |
| Port Famine . . . | 53 38 S. | 750,51 | 0,34 | 0,34 |
| Altenberg . . . . | 50 45 N. | 695,69 | 0,33 | 0,55 |
| Freyberg . . . . | 50 55 | 726,15 | 0,31 | 0,42 |
| Cracow . . . . . . | 50 4 | 742,38 | 0,30 | 0,36 |
| Dantzic . . . . . . | 54 21 | 759,31 | 0,29 | 0,30 |
| Abo . . . . . . . . | 60 27 | 759,55 | 0,26 | 0,26 |
| Edinburgh . . . . | 55 55 | 746,90 | 0,21 | 0,26 |
| Koninsberg . . . | 54 42 | 760,88 | 0,19 | 0,19 |
| Petersburg . . . | 59 56 | 759,31 | 0,13 | 0,14 |
| Kasan . . . . . . | 55 48 | 758,19 | 0,12 | 0,13 |

This table shews in a very evident manner that the amplitude of the oscillations diminishes as we recede from the equator. Is this amplitude the same on the sea-shore and in the interior of continents? The series hitherto made do not enable us to decide this question. We will suppose, for the present, that the variation is the same in equal latitudes and heights of the barometer; if we examine the numbers reduced to the level of the sea, which are found in the last column, and if we deduce from them the law of diurnal variation dependent on the latitude, we shall find that it is 2$^{\mathrm{mm}}$,28 at the equator, and that it becomes for different latitudes:—

## DIURNAL VARIATION OF THE BAROMETER AT DIFFERENT LATITUDES.

| LATITUDE. | VARIATION. |
|---|---|
| | mm. |
| 0° 0′ | 2,28 |
| 5 26 N. | 2,26 |
| 17 52 | 2,03 |
| 23 55 | 1,80 |
| 29 28 | 1,58 |
| 34 26 | 1,35 |
| 39 4 | 1,13 |
| 43 34 | 0,90 |
| 48 1 | 0,67 |
| 52 33 | 0,45 |
| 57 17 | 0,23 |
| 62 25 | 0,00 |

(*Vide* Appendix, *fig.* 27.)

Taking any one of these values as a starting-point, we find that in the latitude of 60° or 70° the diurnal variation becomes null; and, on approaching still closer to the pole, the expressions of the mean oscillation become negative: which **Hallstroem** had already confirmed by his observations. These negative quantities signify that the mean barometric height is greater at four than at ten in the morning and evening. In their voyages to the pole, the English have made series from which nothing very positive can be concluded, their observations not being sufficiently brought together. However, the longest series of all those made by **Parry** at Port-Bowen, 73° 14′ north latitude, gives, as the diurnal variation, the value $-0^{mm},273$, a quantity which does not greatly differ from $-0^{mm},384$, furnished by calculation. I attach, however, but little importance to this result, because **Parry's** observations leave much to be desired.*

**CAUSES OF ALL THE BAROMETRIC OSCILLATIONS.**—There exist few phenomena on which so many

---

* In the winter solstice, as we advance toward the north pole, we see the diurnal variation of the thermometer diminish; beyond the polar circle there is no sensible diminution; the sun does not appear above the horizon, and the night becomes continual. The diurnal variation of the barometer is gradually destroyed under the same circumstances; but, beyond the polar circle, it has still an appreciable value; and it is to be believed, that it does not entirely disappear, except at the pole itself. At Bosekop, under the

hypotheses have been made as on barometric oscillations. If the barometer is high and the weather fine, or if it is low and it rains, the instrument is said to have predicted accurately the weather. But if, while the barometer is high, the weather remains cloudy or rainy, or if it is low during fine weather, every body cries out against the fidelity of this instrument; but it deserves neither the praises nor the reproaches that are addressed to it. The barometer indicates the pressure of the atmosphere; it rises or falls according as it increases or diminishes. If these changes for the most part coincide with the changes in the weather, it does not follow that they are intimately connected with them; this coincidence is due to the particular position of the European continent. When we possess observations from all countries on the globe, we shall see that they are a phenomenon entirely local.

About two centuries ago, a German philosopher, named **Sturm**, constructed an instrument which was rescued from oblivion by **Leslie** and **Rumford**; it is the differential thermometer, which indicates the difference of temperature be-

---

70th degree of latitude, the forty days preceding the winter solstice, combined with the subsequent forty days, gave M. BRAVAIS the following numbers as the mean hourly heights of the barometer:—

MEAN HOURLY BAROMETRIC HEIGHTS AT BOSEKOP, IN WINTER.

| HOURS. | MORNING. | EVENING. |
|---|---|---|
| | mm. | mm. |
| 0 | 744,36 | 744,38 |
| 2 | 744,34 | 744,335 |
| 4 | 744,22 | 744,36 |
| 6 | 744,13 | 744,31 |
| 8 | 744,22 | 744,25 |
| 10 | 744,42 | 744,29 |

The law of these numbers is almost the same as at other epochs of the year; but the amplitude of variation is scarcely equal to $0^{mm},3$. It follows that the polar regions also participate in the great atmospheric tide, which, in propagating itself from east to west on the globe, produces the phenomenon of diurnal variation.

The delay of about two hours, which the epochs of *maxima* and *minima* experience in their arrival, seem to prove that the atmospheric movements, then manifested beyond the polar circle, would be the result *derived* from the equatorial atmospheric wave, the northern part of which, in moving along the polar circle, would gradually put in motion the neighbouring zones of air, and would ultimately communicate to them its progressive march. It does not appear indispensable, in order to explain this periodic movement, to admit that a wave would go, in propagating itself from the equator toward the poles, along the same meridian.—M.

tween two points very near together. Bend a tube, from two to four millimetres in diameter, in two points at right angles, so that it shall present two branches, each terminated by a ball two centimetres in diameter; then pour into the tube a few drops of coloured liquid, and close the apparatus. The small columns of liquid will separate the air contained in the tube into two parts; if the temperature of the imprisoned air is equal on both sides, the liquid index will remain in the middle. But if one of the balls, A, is heated while the ball B remains at the same temperature, the equilibrium will be broken, the air contained in the ball A will expand, and the index will move toward the side of the ball B. The result would have been the same if the ball B had been cooled, while the ball A remained at the original temperature.

The barometer is greatly analogous to this differential thermometer; it points out to us the differences of temperature between two places situated at great distances. To understand this, let us recall to mind what was said respecting the origin of winds (p. 32): if the temperature were uniform on the entire surface of the globe, and if the aërial strata had the same temperature, the aërial ocean would be always calm; there would never be any currents; and, at equal heights, the atmospheric pressure would be every where the same. But as soon as the region E F (pl. II. *fig.* 1) is more heated, while the regions A E and F B preserve the same temperature, one part of the air of the heated countries passes above the high regions of the atmosphere, and the barometer must fall. If E F preserves the same temperature, while A E and F B are cooled, the result will be the same; but the atmospheric pressure will increase in the regions A E and F B, on account of the mass of air coming from E F that is added to that pressing on them. Thus, in the former case, the barometer will fall while the thermometer rises; in the latter, the barometer will rise while the thermometer falls. But here again is produced the uncertainty which we pointed out in respect to the differential thermometer; for, while E F is heated, the neighbouring countries preserve their temperature, the barometer falls in the region E F, and it rises in the spaces A E and F B, without their temperature changing. We may, therefore, sum up these relations by saying: *When the barometer falls in a country, it is because the temperature of this country is higher than that of the neighbouring countries, whether because it is heated directly or because these countries are cooled; on the contrary, the rise of the barometer proves that this country becomes colder than those which surround it.*

In order completely to demonstrate this theory, we must have correspondent observations at a great number of points; but, by observing the barometer and thermometer at a single station, we soon see that the thermometer generally rises when the barometer falls. To discover the law, we need only seek how much the thermometer rises or falls, when the barometer falls or rises 1, 2, $3^{mm}$. I have made this calculation for a great many localities; and the following table contains the results obtained. The sign + signifies that the instrument rises; the sign — that it falls.

CORRESPONDENT INVERSE OSCILLATIONS OF THE BAROMETER AND THERMOMETER.

| OSCILLATION OF THE BAROMETER. | CORRESPONDENT OSCILLATION OF THE THERMOMETER. | | | |
|---|---|---|---|---|
| | Bagdad. | Buda. | Cambridge. | Eyafiord. |
| mm. | | | | |
| +22,56 | " | " | " | — 8°,85 |
| +18,05 | " | " | " | — 5 ,99 |
| +15,79 | " | " | —6°,53 | — 2 ,35 |
| +13,54 | " | " | " | — 3 ,48 |
| +11,28 | " | —3°,42 | —5 ,59 | — 2 ,88 |
| + 9,02 | " | —2 ,55 | —3 ,19 | — 2 ,35 |
| + 6,77 | —3°,92 | —1 ,76 | —1 ,86 | — 1 ,56 |
| + 4,51 | —1 ,39 | —1 ,15 | —1 ,65 | — 1 ,00 |
| + 2,26 | —0 ,49 | —0 ,87 | —0 ,72 | — 0 ,74 |
| — 2,26 | +0 ,69 | +0 ,51 | +0 ,42 | + 0 ,20 |
| — 4,51 | +0 ,84 | +0 ,68 | +1 ,94 | + 1 ,11 |
| — 6,77 | +1 ,94 | +2 ,00 | +2 ,39 | + 1 ,64 |
| — 9,02 | " | +2 ,19 | +2 ,11 | + 2 ,56 |
| —11,28 | " | +1 ,95 | +2 ,78 | + 3 ,58 |
| —13,54 | " | " | " | + 4 ,31 |
| —15,79 | " | " | +3 ,70 | + 5 ,64 |
| —18,05 | " | " | " | + 7 ,00 |
| —22,56 | " | " | " | +10 ,50 |

(*Vide* Appendix, *fig.* 28.)

The places for which we have associated the results have no mutual analogy. Whilst Buda represents the climate of continental Europe; Bagdad, that of the Asiatic continent; Cambridge, in Massachusets, is situated on the east coast of America; and Eyafiord, in the island of Iceland. Notwithstanding these differences of climate and position, the law is verified; and the observations made at Santa Fé de Bogota by M. **Boussingault** still further confirm them. Although the above table presents very many anomalies, which occur because the meteorological series are too short, yet the antagonism of signs is apparent; and we may remark that the thermometric changes are greater as the barometric oscillations are more extended. These changes even preserve a certain proportionality among themselves.*

We may convince ourselves, especially in winter, of the accuracy of this law, by observing the barometer for several days. However, the barometer often suddenly falls without the thermometer rising; but then we may be sure that it has fallen in the neighbouring countries.

Add to this, that almost all meteorological instruments, viz. the vane, the thermometer, the hygrometer, only indicate what is going on at the place where they are stationed. Thus, although the rise of the thermometer often proves that the air is heated, the soil can sometimes produce a similar effect on the instrument. The difference of level between Halle and the summit of the Brocken gives a difference of temperature of about 4°; and yet, in the severe winter of 1837–8, we often saw that the thermometer of the Brocken was 6° or 12° higher than that of Halle. All the other instruments present similar indications, which frequently would cease to be the same at 50 metres apart;

---

* The great changes of temperature are generally produced by changes in the wind; and as the latter have a marked influence over the barometer, we see beforehand that the variation of the two instruments cannot be independent of each other. If, therefore, we compare together the barometric and thermometric card of winds in a certain locality on the globe, we may infer, *up to a certain point*, the relations which in this place connect the simultaneous observations of temperature and pressure. This comparison is generally very favourable to the law of *inverse oscillations;* the winds that depress the barometer make the thermometer rise; those which produce the high state of the barometric column give, at the same time, the lowest mean temperature.

But it is not always so: in certain places on the globe, the action of the winds is different. The observations made near the North Cape by the hybernating members of the Commission of the North, and calculated by M. Bravais, furnish us with a proof of this. When the W.N.W. or the north wind replaces the east or the S.E., blowing with a certain force, the barometer commences to rise at the rate of $0^{mm},25$ per hour, and the thermometer experiences a corresponding change of $+0^{\circ},75$, at least for the first six or twelve hours. If the west or S.W. winds had replaced these same east or S.E. winds, the results would have been somewhat different; the mean hourly rise of the barometer would have been equal to $0^{mm},17$, and that of the thermometer equal to $0^{\circ},5$.

In the case before us, the *law of variations in a contrary direction* has to contend against an influence unfavourable to it,—that produced by the changes of winds. But, on the other hand, there may be great changes in the barometer and thermometer without the wind changing: and it remains the barometer indicates the mean pressure of the atmosphere as far as its limits, and points out the ruptures of equilibrium in the temperature. If we had an instrument that could indicate to us the changes in the temperature of the higher regions of the air, a multitude of anomalies would be explained: we even see this, when we know the changes that have taken place at a point situated 1000 or 1200 metres over head.

The following table shews how the range of temperature may differ in the plain and on a mountain. At the commencement of November 1838, the weather was very variable at Halle; on the 18th, snow fell; and the east wind made the thermometer fall below zero; the barometer was low, and the sky cloudy. I here give the observations of 6 A.M. and 2 and 10 P.M., and also the quantity of millimetres that the instrument rose (+) or fell (—). For the Brocken, I merely give the thermometric indications, as they were collected with great care by M. **Nehse**, the innkeeper:—

for us to learn whether M. KAEMTZ's law is verified in this case. This actually takes place; and definitively, but for certain exceptions due to the paucity of observations, or to too great a part of the action exercised by the changes of the wind. The observations of the French Commission in Finmark, during the six winter months of 1838-9, verify the law of the antagonism of the ranges. Thus, on placing in the first column the diurnal change in the barometer from one minute to another, and in the neighbouring column the corresponding mean changes experienced by the thermometer, we find,

INVERSE RANGE OF THE BAROMETER AND THERMOMETER.

| DIURNAL CHANGE OF | |
|---|---|
| Barometer. | Thermometer. |
| mm. | |
| +6 | −0°,65 |
| +3 | −0 ,82 |
| 0 | −0 ,29 |
| −3 | +1 ,41 |
| −6 | +0 ,62 |

Beyond these limits, the antagonism is subject to more numerous exceptions, while *large* and *sudden* variations in the barometer generally suppose a change of wind.—M.

## BAROMETRIC AND THERMOMETRIC OSCILLATIONS AT HALLE AND ON THE BROCKEN.

| NOVEMBER. | HOURS. | HALLE. | | | | | | BROCKEN. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Barometer. | Oscillation. | Thermom. | Oscillation. | Wind. | Aspect of the Sky. | Thermom. | Oscillation. | Wind. |
| | | mm. | mm. | | | | | | | |
| 23 | 6h | 744,29 | + 0,82 | − 3°,8 | − 0°,3 | N.E. | Overcast. | − 7°,9 | − 7°,9 | E. |
| ” | 2 | 745,79 | + 2,71 | − 3,7 | − 1,4 | N.E. | Id. | − 5,6 | − 2,5 | E. |
| ” | 10 | 748,73 | + 5,16 | − 3,8 | − 0,1 | N.E. | Id. | − 6,1 | + 0,7 | E.S.E. |
| 24 | 6 | 749,40 | + 5,12 | − 4,8 | − 1,0 | E. | Id. | − 6,6 | + 1,3 | E.S.E. |
| ” | 2 | 748,66 | + 2,87 | − 4,2 | − 0,5 | S.E. | Id. | − 5,4 | + 0,2 | E. |
| ” | 10 | 748,98 | + 0,25 | − 5,4 | − 1,6 | E. | Id. | − 7,8 | − 1,7 | E. |
| 25 | 6 | 750,69 | + 1,29 | − 6,1 | − 1,3 | N.W. | Id. | − 9,8 | − 3,2 | N. |
| ” | 2 | 752,95 | + 4,29 | − 3,9 | + 0,3 | N.W. | Cloudy. | − 9,1 | − 3,7 | N. |
| ” | 10 | 756,20 | + 7,22 | − 6,0 | − 0,6 | N.W. | Serene. | − 9,2 | − 1,4 | N. |
| 26 | 6 | 757,39 | + 6,70 | − 9,6 | − 3,5 | W. | Id. | − 9,5 | + 0,3 | N. |
| ” | 2 | 758,24 | + 5,28 | − 4,4 | − 0,5 | N.W. | Id. | − 9,0 | + 0,1 | N.E. |
| ” | 10 | 758,78 | + 2,58 | − 6,6 | − 0,6 | W. | Fog. | −10,4 | − 1,2 | S.E. |
| 27 | 6 | 758,14 | + 0,75 | − 9,4 | + 0,2 | E. | Id. | −11,6 | − 2,1 | S.E. |
| ” | 2 | 755,81 | − 2,42 | − 9,2 | − 4,8 | E. | Serene. | − 9,5 | − 0,5 | S.E. |
| ” | 10 | 751,39 | − 7,38 | − 8,3 | − 1,7 | E. | Id. | −10,6 | − 0,2 | S. |
| 28 | 6 | 748,26 | − 9,87 | −12,4 | − 3,0 | E. | Id. | − 6,5 | + 5,1 | S.S.W. |
| ” | 2 | 747,09 | − 8,73 | − 4,6 | + 4,6 | S.E. | Cirrus. | − 5,0 | + 4,5 | S.W. |
| ” | 10 | 743,48 | − 7,92 | − 6,5 | + 1,8 | S. | Overcast. | − 4,1 | + 6,5 | S.W. |
| 29 | 6 | 737,94 | −10,33 | − 0,7 | +11,7 | S. | Id. | − 2,1 | + 4,4 | S.W. |
| ” | 2 | 737,39 | − 9,70 | − 3,8 | +13,0 | S.W. | Cloudy. | − 0,6 | + 5,6 | S.W. |
| ” | 10 | 738,65 | − 4,83 | − 2,7 | + 9,2 | S.W. | Overcast. | − 1,1 | + 5,6 | S.W. |

From the 23d to the 26th, the barometer constantly rose at Halle. The sky was overcast; the wind blew from the west, and, at the same time, the thermometer fell. We find no exception to this rule, except at two o'clock on the 25th and 26th, when the thermometer is higher by 0°,3 than at two o'clock on the 24th; but this is because the sun at last was able to pierce the clouds, and make the thermometer rise. From the 27th to the 29th, the atmospheric pressure diminishes, and the heat increases; however, on the 27th, and on the morning of the 28th, there is a remarkable exception, for the cold increased; but the sky was purer and more serene during this period than we are accustomed to see it during this season; the cooling was due to the intensity of radiation. The south wind prevailed in the higher regions of the atmosphere; and the temperature did not fall so sensibly on the Brocken as at Halle. Furthermore, on the morning of the 28th, when it attained its *minimum* at Halle, the thermometer was 6° higher on the Brocken; the radiation was probably less intense on the mountain, and the south wind raised the temperature.

I might cite a great number of similar examples. If the barometer oscillates much without the temperature changing, the reason must be sought for in countries that are far distant: such a sudden variation in Europe may be explained by great ruptures of equilibrium, of which the point of departure may be found in the centre of the Asiatic or American continent.[*]

**CAUSE OF THE DIURNAL VARIATIONS OF THE BAROMETER.**—If it is difficult to explain the irregular variations of the barometer, it is still more so to give an account of its daily oscillations. Some philosophers have admitted an attraction of the sun or moon, which would determine atmospheric tides analogous to those of the sea. Although these two phenomena have a certain relative analogy, they sometimes present such differences, that the same explanation cannot be applied to them; for, if we admit a lunar attraction, the moment of the *maximum* ought to vary with the position of the moon in relation to the meridian, as is observed with tides. Nothing similar occurs in the atmosphere.

It is probable that this phenomenon is due to the calorific

---

[*] Our readers, who may desire to know the developements of M. KAEMTZ's theory, will find them in M. SCHUMACHER's Annuaire for 1841, under the title, *Ueber den Zusammenhang zwischen Luftdruck und Windrichtung*. We have already extracted from this memoir the considerations of the poles of temporary cold. (*Vide* p. 163, note.)—M.

action of the sun; **Bouguer** suspected it, and **Laplace** and **Ramond** have admitted this explanation. Indeed, so long as the sun is in our meridian, it heats the portion of the terrestrial globe situated between the places at which it sets and those at which it rises at that moment. This heating is very marked, especially between the meridians indicating 9 A.M. and 3 P.M., while the sun indicates to us mid-day. In this interval the air expands, ascends, and passes into the neighbouring regions, and the barometer falls; but it rises, on the contrary, under the weight of the masses of air that pass between the meridians of nine and three o'clock, and then from $5^h$ to $21^h$ (9 A.M.). In the last of these spaces the atmosphere is less elevated, because the nocturnal influence is not yet destroyed, and the air passes above it. At five o'clock the air cools, because the heat of the day has passed away; this movement is thus propagated from one country to another. The barometer, therefore, falls between 9 A.M. and 4 P.M., because the heat of the day has diminished the density of the atmosphere, the height of which is less by the entire thickness of the strata that have passed away toward the neighbouring region; hence arise the two daily *maxima* and *minima*. With regard to the morning *minimum*, it is followed, at the east of the place where it occurs, by a *minimum* of temperature, and a part of the air of the west countries passes on this side; and hence arises the fall in the barometer.

The influence of the seasons on the phenomenon is easily explained in the same manner. As soon as the days of spring become longer, the *minimum* of morning temperature occurs earlier, the barometric *minimum* also approaches toward midnight. In summer, when the differences of temperature are greater, the diurnal variation is also greater.

We cannot deny that more than one difficulty remains to be resolved. We could not explain the increase of oscillatory amplitude, as we recede from the equator, when the differences of the extremes of temperature are not greater at a mean than in higher latitudes, unless we admit, with **Daniell**, that the air not only passes away in a direction perpendicular to the meridian, but also parallel to it, as from the equator to the pole. It is probable also that the amplitude of oscillation must be more feeble in the open sea than on the continents, where the extremes of temperature are more marked. The very few observations that we possess, made within the tropics, seem to confirm this hypothesis, whilst those that have been collected in higher latitudes are not favourable to it.[*]

M. **Dove** has assigned another cause to these variations; the pressure of the atmosphere on the barometer being equal to the sum of the pressures of the dry air and the vapour of water, the barometric column is composed, so to speak, of two parts; one corresponding to the air, the other to the vapour of water. Now, when the temperature rises, the density of the air diminishes, but the tension of the vapour increases; and it is not easy to determine the relations that exist between the diurnal variations of the thermometer and barometer, by including each of these two influences. To obtain this, M. **Dove** has analysed the observations made by **Neuber** at Apenrade with one of **Daniell's** hygrometers; he has calculated the tension of vapour for each hour of the day, and has subtracted it from the barometric columns; he also obtained the pressure of dry air, and saw that there was one diurnal *maximum* and *minimum*. In the following table I give the results obtained by M. **Dove**, and refer to his memoir for the rest (*Annales de Poggendorff*, t. xxii. p. 231).

---

[*] Captain Lamarche having sent to the Academy three large tables of meteorological observations that he made at Cherbourg in 1838, 1839, and 1840, M. Arago found the confirmation of a remark that he had long since made on the influence of the sea, which, by its vicinity, weakens the amplitude of the diurnal descending barometric period that is manifested at 9 A.M. and 3 P.M. Nothing is better suited to render this influence evident than the comparison of the observations at Toulouse with those at Marseilles.

At Toulouse, in north latitude 43° 36′, the mercurial column falls $1^{mm},2$, from morning till afternoon.

At Marseilles, 43° 17′, $0^{mm},8$.

At Cherbourg, 49° 38′, according to three years of observation, $0^{mm},4$.

At Paris, latitude 48° 50′, from the summary of observations, $0^{mm},8$.

At La Chapelle, near Dieppe, 49° 53′, M. Nell de Bréauté found only $0^{mm},36$. All these results are favourable to M. Kaemtz's explanation. (Vide *Comptes rendus de l'Académie des Sciences*, t. xiii. p. 637. 1841.)—M.

PRESSURE OF DRY AIR IN THE DIFFERENT SEASONS, AND AT DIFFERENT HOURS, AT APENRADE.

| HOURS. | YEAR. | SUMMER. | AUTUMN. | WINTER. | SPRING. |
|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. |
| Noon. | 749,06 | 744,61 | 743,85 | 752,90 | 754,52 |
| 1 | 748,89 | 744,43 | 743,68 | 752,62 | 754,38 |
| 2 | 748,82 | 744,38 | 743,61 | 752,52 | 754,32 |
| 3 | 748,85 | 744,46 | 743,66 | 752,50 | 754,34 |
| 4 | 748,98 | 744,67 | 743,81 | 752,56 | 754,44 |
| 5 | 749,21 | 744,99 | 744,39 | 752,70 | 754,63 |
| 6 | 749,49 | 745,40 | 744,37 | 752,74 | 754,88 |
| 7 | 749,80 | 745,88 | 744,51 | 753,08 | 755,15 |
| 8 | 750,27 | 746,41 | 744,56 | 753,25 | 755,65 |
| 9 | 750,35 | 746,93 | 744,82 | 753,34 | 755,77 |
| 10 | 750,55 | 747,41 | 744,88 | 753,36 | 756,02 |
| 11 | 750,67 | 747,82 | 744,90 | 753,30 | 756,22 |
| Midnight | 750,73 | 748,11 | 744,93 | 753,33 | 756,36 |
| 13 | 750,75 | 748,27 | 744,96 | 753,05 | 756,42 |
| 14 | 750,73 | 748,30 | 745,01 | 752,94 | 756,43 |
| 15 | 750,68 | 748,18 | 745,08 | 752,87 | 756,36 |
| 16 | 750,61 | 747,94 | 745,16 | 752,80 | 756,24 |
| 17 | 750,52 | 747,59 | 745,21 | 752,91 | 756,09 |
| 18 | 750,41 | 747,16 | 745,11 | 752,86 | 755,89 |
| 19 | 750,25 | 746,68 | 745,13 | 753,08 | 755,67 |
| 20 | 749,88 | 746,78 | 745,09 | 753,13 | 755,25 |
| 21 | 749,82 | 745,69 | 744,71 | 753,12 | 755,18 |
| 22 | 749,56 | 745,25 | 744,41 | 753,05 | 754,94 |
| 23 | 749,30 | 744,88 | 744,12 | 752,92 | 754,71 |

(*Vide* Appendix, *fig*. 29.)

On considering the annual relations, we see that, at a mean, the pressure of the dry air is greatest about one o'clock in the morning; it diminishes from this moment, and attains its *minimum* about two o'clock in the afternoon. The difference between the two extremes is $1^{mm},93$. In the different seasons this difference varies; thus, in summer, it rises as high as $3^{mm},6$; the phenomenon is very well deduced from the diurnal variations of temperature. When, in the morning, the temperature of the atmosphere increases, its upper limit rises, a part of the higher strata passes away, and the pressure diminishes until the moment of the greatest heat of the day; afterwards, new masses of air arrive from countries more highly heated, that are situated more to the east, and the pressure is augmented. This single *maximum* and *minimum* are also augmented by the vapour of water that rises during the day. In the morning, when the pressure of the dry air diminishes, not only does the tension of the vapour compensate this effect, but it makes the column rise; and it attains its *maximum* when the pressure of the air begins to diminish. For the same reason, we find a *minimum* in the morning, because the diminution of the vapour of water, during the night, is more rapid than the increase of the pressure of the dry air.

It is to be regretted that these results are not deduced from a series of several years, the more so as the observed year was more moist than usual. During the summer of 1837, in very dry weather, I made observations at a few hundred paces from the Baltic, and obtained results slightly differing; those of Halle are still more so, as well as the series of two consecutive months, made by **Stierlin** at Munster. The following table contains the results of several years for the months of January and July at Halle, and those of **Stierlin** for the end of April and the beginning of May, the end of August and the beginning of September; the quantities from the fourth to the seventh hours are found by interpolation :—

### PRESSURES OF DRY AIR, AT DIFFERENT HOURS, AT HALLE AND AT MUNSTER.

| HOURS. | HALLE. | | MUNSTER. | |
|---|---|---|---|---|
| | January. | July. | May. | September. |
| | mm. | mm. | mm. | mm. |
| Noon. | 750,41 | 741,75 | 745,07 | 744,29 |
| 1 | 750,18 | 741,80 | 745,13 | 744,39 |
| 2 | 750,11 | 741,77 | 744,91 | 744,05 |
| 3 | 750,12 | 741,74 | 744,57 | 744,00 |
| 4 | 750,22 | 741,66 | 744,24 | 743,85 |
| 5 | 750,33 | 741,53 | 744,29 | 743,69 |
| 6 | 750,40 | 741,44 | 743,97 | 743,36 |
| 7 | 750,48 | 741,21 | 744,01 | 743,61 |
| 8 | 750,57 | 741,31 | 743,95 | 743,78 |
| 9 | 750,62 | 741,52 | ” | ” |
| 10 | 750,65 | 741,76 | ” | ” |
| 11 | 750,64 | 741,94 | ” | ” |
| Midnight | 750,64 | 742,13 | ” | ” |
| 13 | 750,59 | 742,24 | ” | ” |
| 14 | 750,54 | 742,24 | ” | ” |
| 15 | 750,45 | 742,16 | ” | ” |
| 16 | 750,37 | 742,03 | ” | ” |
| 17 | 750,34 | 741,87 | ” | ” |
| 18 | 750,40 | 741,79 | 745,18 | 744,44 |
| 19 | 750,48 | 741,59 | 745,38 | 741,98 |
| 20 | 750,58 | 741,50 | 745,26 | 741,85 |
| 21 | 750,70 | 741,56 | 745,36 | 741,76 |
| 22 | 750,75 | 741,69 | 745,56 | 741,85 |
| 23 | 750,63 | 741,77 | 745,37 | 741,91 |

These quantities differ greatly from those that I deduced from the observations at Apenrade; for in July we find a *maximum* at Halle a short time after midnight, and the pressure of the dry air diminishes until 8 A.M.; it then again increases, and attains a new *maximum* at the moment when the sun passes the meridian: the *minimum* occurs about seven o'clock in the evening; the pressure then increases again. The difference between the extremes does not vary more than $0^{mm},9$ and $1^{mm},1$; consequently it is one-fourth of that found for Apenrade during the summer. In January there are two *maxima*, at 10 A.M. and 10 P.M.; and two *minima*, at 5 A.M. and 2 P.M. The series for Munster seems to indicate analogous laws.

It is not probable that, in places where difference of latitudes is so inconsiderable, the phenomenon should present such great differences; for, when we study the barometric oscillations without separately examining the pressure of the air, and that of the vapour of waters, these differences entirely disappear. The anomalies increase when we compare series made at great differences of level. If we would explain the great amplitude of diurnal oscillation in the open sea, by differences of tension, that would suppose a variation in the dew-point of several degrees; now, the observations of voyagers prove that the heat and the tension of the vapour of water vary but little during the day on the surface of the ocean.

Admitting the influence of this single cause, we remove other difficulties also. It is probable that the mean pressure of the atmospheric vapour of water, considered in the space of one day or one year, diminishes with the height, according to the laws of the tension of vapours *in vacuo*. Thus, from an observation made on one point of the vertical, we may deduce approximatively the tension to any height; but it would not necessarily follow that this rule might be applied to every hour of the day taken isolately. As the air opposes the liberation of vapours, it is evident that they are denser in the morning at the surface of the ground than an observation made at a certain height would lead us to suppose. So that, in the plains, the dew-point would be too high, and the pressure of vapour that we might deduce from it will be greater than if it were deduced from measures made at different heights; but, towards mid-day, the ascending current makes the vapours ascend, and the dew-point then becomes lower than it would have been according to the mean hygrometric state. These facts are a consequence from the observations I made on the Alps. At the sea-shore these laws are modified, for while the ascending current raises the vapours the sea-breeze is continually bringing new.

Whatever be the cause of these oscillations, their amplitude can never be so great above as below. Suppose that, in the plains, the barometer has the same height throughout the day, there will be above a variation, the laws of which it would be easy to deduce; for as soon as the presence of the sun above the horizon expands the air the latter ascends, and a part of the atmosphere that was below the elevated station rises above it, whence there arises an increase of pressure until the moment of the greatest heat. From this moment the barometer falls until the moment of the *minimum* diurnal temperature, which happens next morning. This period combines with that which takes place on the plain, for about mid-day the atmosphere becomes lighter below and above; but this diminution is less sensible above, because of the expansion of the entire atmosphere: the phenomenon, therefore, depends specially on the amplitude of the variation in the plain. The more we ascend the less does the barometer change from twenty-two hours to four hours, and it may happen that the pressure unceasingly increases until the moment of the greatest diurnal heat. In our latitudes this interversion will shew itself at a less height than within the tropics, where the diurnal oscillations are much more powerful.

**MEAN HEIGHT OF THE BAROMETER.** — Like as we have been able to deduce the mean temperature of a place from a few diurnal observations, so also can we conclude the mean height of the barometer for a tolerably long period of time, from a few readings made every day. I have designedly said a tolerably long period, for, if we desire to obtain the mean pressure of the air during the day, the value obtained by means of some observations may differ sensibly from the real mean. The mean barometric height is obtained approximately by taking observations at the morning *maximum* and the evening *minimum*. A great many meteorologists only read the instrument at these two moments of the day: I cannot press too strongly upon them to make several other observations in the morning and afternoon; for not only do they obtain the mean pressure more accurately, but their observations may serve for studying the irregular oscillations of the barometer. Further, if in any place an observer is engaged measuring heights by the barometer, two correspondents in the day are not sufficient; and that of mid-day, in particular, always gives differences of level that are too great: but, if observations were made four or five times a-day, we might then calculate the variation and the mean pressure, and appreciate the extent of irregular variations. The arithmetical mean of three observations made at eighteen hours, two hours, and ten hours, or, again, at nineteen hours, two hours, and nine hours, is sensibly equal to the mean barometric pressure, and the amplitude of the diurnal oscillations may be deduced from it. The barometer attains its mean height about mid-day, generally between mid-day and one o'clock; the moment varies according to the seasons.

**HEIGHT OF THE BAROMETER ON THE SEA-COAST.**—This was for a long time thought to be the same in all latitudes. The number of observations not being sufficient to solve the question, we trusted to theoretical considerations; it was said that the conditions of equilibrium of the aërial ocean did not sanction our admitting unequal pressure at different latitudes. It was forgotten that this assumed equilibrium did not exist; for if, in our latitudes, the oscillations due to changes in the weather end by compensating each other, it is not the same within the different zones; the existence even of trade-winds near the equator, and west winds in high latitudes, is a sufficient proof of this. The ascending current that, in the higher regions, is always directed toward the poles, draws along the air of the equator, and the stronger pressure that results from it leads the air of the pole toward the equator, and gives rise to trade-winds. MM. **Schouw, Erman, Herschel, Muncke,** and **Poggendorff,** have successively entered upon this subject; and, although the influence of latitude is not as accurately known as might be desired, yet we already possess very satisfactory approximations.

The principal results to which we have arrived are the following:

1st. We may admit that, at the sea-coast, the mean atmospheric pressure is $761^{mm},35$.

2d. At the equator, it is not more than $758^{mm}$, or a little above.

3d. At the latitude of 10° the pressure increases, and between the 30th and 40th degrees it attains its *maximum*, for it rises to 762 or $764^{mm}$.

4th. Starting from this zone it diminishes, and about the 5th degree of latitude it is no more than $760^{mm}$, and in the more northern countries it descends to about $756^{mm}$. We here give M. **Schouw's** table, as it was published by M. **Poggendorff** in the *Comptes rendus de l'Académie des Sciences*, t. ii. p. 573. 1836.

## MEAN HEIGHT OF THE BAROMETER AT THE LEVEL OF THE SEA, ACCORDING TO MM. **Schouw** AND **Poggendorff.**

| PLACES. | LATITUDE. | HEIGHT OF THE BAROMETER at the level of the Sea, at 0°. | |
|---|---|---|---|
| | | Not Corrected for Gravity. | Corrected for Gravity. |
| | | mm. | mm. |
| Cape . . . . | 33° S. | 763,01 | 762,20 |
| Rio-Janeiro . | 23 | 764,03 | 762,65 |
| Christianburg . | 5 30′ N. | 760,10 | 758,16 |
| La Guayra . . | 10 | 760,17 | 758,32 |
| Saint-Thomas . | 19 | 760,51 | 758,95 |
| Macao . . . | 23 | 762,99 | 761,61 |
| Teneriffe . . | 28 | 764,21 | 763,10 |
| Madeira . . . | 32 30 | 765,18 | 764,34 |
| Tripoli . . . | 33 | 767,41 | 766,60 |
| Palermo . . | 38 | 762,95 | 762,47 |
| Naples . . . | 41 | 762,34 | 762,06 |
| Florence . . | 43 30 | 761,93 | 761,81 |
| Avignon . . | 44 | 762,02 | 761,95 |
| Bologna . . . | 44 30 | 762,18 | 762,13 |
| Padua . . . | 45 | 762,18 | 762,18 |
| Paris . . . . | 49 | 761,41 | 761,68 |
| London . . . | 51 30 | 760,96 | 761,41 |
| Altona . . . | 53 30 | 760,42 | 761,01 |
| Dantzic . . . | 54 30 | 760,10 | 760,76 |
| Konigsberg . . | 54 30 | 760,49 | 761,14 |
| Apenrade . . | 55 | 759,58 | 760,71 |
| Edinburgh . . | 56 | 758,25 | 759,00 |
| Christiania . . | 60 | 758,64 | 759,63 |
| Hardanger . . | 60 | 756,94 | 757,04 |
| Bergen . . . | 60 | 757,01 | 758,00 |
| Reikiavig . . | 64 | 752,00 | 753,20 |
| Godthaab . . | 64 | 751,94 | 753,13 |
| Eyafiord. . . | 66 | 753,58 | 754,89 |
| Godhaven . . | 68 | 753,76 | 755,16 |
| Upenavik . . | 63 | 755,18 | 756,80 |
| Melville Isle . | 74 30 | 757,08 | 758,75 |
| Spitzbergen . | 75 30 | 756,76 | 758,48 |

We can understand that, at the equator, from which the air is constantly passing away, the pressure must be less; at the latitude of 30°, where the pressure attains its *maximum*, the upper south-west trade-wind contends with the lower north-east trade-wind, and an accumulation of air, with a very strong pressure, is the consequence.*

I cannot account for the pressure diminishing in the high latitudes; for, by merely paying attention to the temperature of the earth and the laws of permanent gases, it ought to augment as we recede from the equator: experience proves the contrary. But I doubt whether we may be able to apply to the *entire* atmosphere the laws of which we have spoken, for it is composed of air and the vapours of water: now, the tension of the vapour of water diminishes, and in high latitudes it is resolved into rain. The pressure of the dry air alone increases. Unfortunately, we are in want of a sufficient number of hygrometric observations, made at different latitudes, to enable us to isolate these two pressures: however, without any great error, we may estimate the ten-

---

* M. Erman (in his voyage round the world in a Russian brig, where the barometer, thermometer, and hygrometer, were observed six times a-day), having four times travelled in the space comprised between the 55th degree north latitude, and the 58th south latitude, saw that the mean pressure of the atmosphere, corrected for the intensity of gravity, is not the same on all points of the globe, but is found within a narrow dependence upon the two horizontal co-ordinates of each point. This result is in like manner verified, whether we consider the total pressure of all the constituent parts of the atmosphere, or, by making use of hygrometric observations in order to eliminate the tension of the aqueous vapour, we only compare the pressures of the permanent gases.

Let us first examine the influence of latitude; setting out from the 60th degree of south latitude, and following the same meridian, the mean pressures go on sensibly increasing to the 25th degree of south latitude, that is, to the limit of the trade-winds. From this parallel they regularly decrease to the equator, where they attain a relative *minimum*; they then increase again to the north limit of the trade-winds. In our hemisphere, the phenomena are repeated in a symmetrical manner as in the opposite hemisphere. The difference of pressure at the limit of the trade-winds, from one side of the equator to the other, is $4^{mm},06$. Sir J. Herschel has confirmed this result in his voyage to the Cape of Good Hope. Setting out from the *maximum* pressure, which is found in about 25° of latitude, and directing our course toward the pole, the diminution of pressure is much more rapid than in the zone of the trade-winds. Thus the mean pressures on the coast of Kamtschatka and at Cape Horn are respectively lower than the mean *maximum* pressure of the Great Ocean, by $12^{mm},86$, and $12^{mm},18$. Series of observations made on the coast of Iceland fully confirm this result.

The mean pressure of the atmosphere is, in the second place, dependent on the longitude. In equal latitudes it is $3^{mm},5$ greater on the Atlantic Ocean than in the Pacific. This result was obtained by the comparison of observations made under twenty-four different parallels, bearing in mind the influence of the seasons.

If we take account of the tension of the aqueous vapour, the *maximum* pressure in each hemisphere recedes a little toward the poles; and the difference between this *maximum* and the equatorial *minimum* is much greater, since it rises to $11^{mm},96$. (Vide M. Schumacher's *Annuaire* for 1840, p. 298).—M.

sion of the vapour of water under the equator at $25^{mm}$; in latitude 35°, at $14^{mm},6$; and in 70°, at $4^{mm},5$. By subtracting these quantities from those that we found for atmospheric pressure at the same latitudes, we shall obtain, for the pressure of dry air, the following numbers: at the equator, $733^{mm}$; in latitude 35°, $748^{mm}$; and in 70°, $752^{mm}$. Thus, in a general manner, the pressure diminishes from the equator to the poles.*

**HEIGHT OF THE BAROMETER IN DIFFERENT SEASONS.**—It was formerly thought that the length of the mercurial column must be the same in different seasons, and its less height during the spring was attributed to the atmospheric variations by which this season is characterised in Europe. No account was taken of the limited number of observations of the intertropical climates that we then possessed. M. **de Buch** was the first to shew, that between the tropics the atmospheric pressure diminishes in proportion as the sun approaches the zenith; M. **Dove** extended these researches. The following table shews what the mean

---

* Atmospheric pressure exercises an influence over the mean level of the seas; this level, which is obtained by taking the mean between two consecutive high tides, and the height of the intermediate low tide, has generally been regarded as constant. But M. DAUSSY, on comparing together the observations at Brest, saw that it was not so, and that this mean level varied according to the barometric pressure.

Observations made at Lorient furnished him with a new series of comparisons. Thus, 150 determinations of the mean level of the sea, arranged according to the height of the barometer observed each day, and divided into five groups of thirty each, gave the following results:—

VARIATION IN THE MEAN LEVEL OF THE SEA, ACCORDING TO THE HEIGHTS OF THE BAROMETER.

| HEIGHT OF THE BAROMETER. | MEAN HEIGHT OF THE SEA. |
|---|---|
| mm. | mm. |
| 745,7 | 3,597 |
| 752,9 | 2,926 |
| 756,5 | 2,854 |
| 760,5 | 2,796 |
| 765,2 | 2,757 |

Designating the observed height of the barometer by H, the mean level N of the sea is very well represented by the formula: $N = 2^{m},823 - 15,5 (H - 0^{m},760)$.

M DAUSSY was convinced, in the course of his researches, that this mean level was not sensibly altered at Lorient by breezes or fresh winds; but that it fell $0^{m},08$ by violent winds from the N. to N.E., and rose the same quantity by those from the S.W. the S. or the S.E. (*Comptes rendus de l'Académie des Sciences*, t. iii. p. 136. 1836.)—M.

pressure is in the northern hemisphere as far as the 30th degree of latitude:—

### MEAN MONTHLY HEIGHT OF THE BAROMETER BETWEEN THE EQUATOR AND THE 30TH DEGREE OF NORTH LATITUDE.

| MONTHS. | HAVANNAH. | CALCUTTA. | BENARES. | MACAO. | CAIRO. |
|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. |
| January | 765,24 | 764,57 | 755,41 | 767,93 | 762,40 |
| February | 760,15 | 758,86 | 752,91 | 767,01 | ,, |
| March | 760,98 | 756,24 | 751,19 | 766,08 | 759,43 |
| April | 759,58 | 753,83 | 747,33 | 761,93 | 760,10 |
| May | 758,19 | 750,81 | 745,01 | 761,64 | 758,23 |
| June | 760,67 | 748,10 | 741,13 | 757,31 | 754,42 |
| July | 760,67 | 747,54 | 740,65 | 757,91 | 753,90 |
| August | 757,33 | 748,53 | 743,31 | 757,91 | 754,06 |
| September | 757,46 | 751,85 | 745,98 | 762,22 | 756,70 |
| October | 758,19 | 755,25 | 750,35 | 763,37 | 759,70 |
| November | 761,25 | 758,37 | 753,06 | 766,17 | 760,76 |
| December | 763,62 | 760,59 | 755,57 | 768,65 | 761,82 |

(*Vide* Appendix, *fig*. 30.)

It is evident that, in all places situated north of the equator, the pressure diminishes from January, and increases toward winter. At Calcutta, where a series of observations have been made comprising eight years, and where no accidental disturbances exist, this difference rises to more than sixteen millimetres; it appears to be greater in India than in America, and diminishes as the distance from the equator increases. The following table gives us these differences for places situated in high latitudes:—

### MEAN MONTHLY HEIGHT OF THE BAROMETER BETWEEN THE 49TH AND 60TH DEGREE OF NORTH LATITUDE.

| MONTHS. | PARIS. | STRASBURG. | HALLE. | BERLIN. | PETERSBURG. |
|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. |
| January . | 758,86 | 751,62 | 754,64 | 761,91 | 762,54 |
| February | 759,09 | 752,43 | 753,44 | 761,23 | 763,10 |
| March . | 756,33 | 751,19 | 751,62 | 759,90 | 760,76 |
| April . . | 755,18 | 749,95 | 750,98 | 757,82 | 761,19 |
| May . . | 755,61 | 750,49 | 752,57 | 759,88 | 760,94 |
| June . . | 757,28 | 752,16 | 752,70 | 759,81 | 759,83 |
| July . . | 756,52 | 751,64 | 753,27 | 759,58 | 758,25 |
| August . | 756,74 | 752,03 | 752,18 | 759,02 | 759,94 |
| September | 756,61 | 752,59 | 753,42 | 760,53 | 761,19 |
| October . | 754,42 | 751,82 | 755,55 | 761,25 | 760,82 |
| November | 755,75 | 751,28 | 753,27 | 759,43 | 758,05 |
| December | 755,09 | 750,70 | 754,10 | 760,35 | 760,22 |

(*Vide* Appendix, *fig.* 30.)

In this table we again find that law by virtue of which the pressure is less in summer than in winter; at the same time a double period is observed. Setting out from winter, the pressure diminishes till the equinox; it then increases in summer, without, however, attaining the winter mean: traces of a second *minimum* are then found in autumn; the curve afterwards ascends until winter.

If we would deduce from these numbers laws on the state of the atmosphere, we should first inquire whether they could be compared directly; it is evident that the pressure of the vapour of water contained in the atmosphere must be deducted. For this purpose we must have hygrometric observations, made at different heights in the atmosphere; but, as the resistances opposed by the air to the rise and fall of vapours are reciprocally destroyed, we may regard the numbers obtained for the tension of vapour at the surface of the ground as very nearly approaching the truth, and may subtract the tensions of the total pressure. The following table gives the pressure of dry air at Calcutta and at Apenrade, according to M. **Dove's** calculations; at Halle, according to my own observations; and at St. Petersburg, according to those of the Academy. However, I may remark, that in this latter town the hygrometric observations only comprise one year; those of the barometer embrace three. In like manner, the hygrometer at Halle was not observed so long as the barometer:—

MEAN MONTHLY PRESSURE OF DRY AIR, AT DIFFERENT LATITUDES.

| MONTHS. | CALCUTTA. | APENRADE. | HALLE. | PETERSBURG. |
|---|---|---|---|---|
| | mm. | mm. | mm. | mm. |
| January . | 750,74 | 754,91 | 750,47 | 759,13 |
| February | 746,95 | 756,90 | 748,89 | 759,94 |
| March. . | 741,47 | 752,30 | 746,48 | 756,38 |
| April . . | 737,50 | 751,44 | 744,88 | 756,04 |
| May . . | 726,72 | 749,77 | 744,63 | 756,09 |
| June . . | 725,29 | 748,44 | 742,48 | 752,59 |
| July . . | 724,84 | 745,46 | 741,74 | 748,71 |
| August . | 725,88 | 745,53 | 741,45 | 750,80 |
| September | 729,92 | 747,09 | 743,49 | 754,58 |
| October . | 735,24 | 745,03 | 747,90 | 755,34 |
| November | 746,82 | 748,01 | 747,56 | 755,05 |
| December | 748,96 | 749,71 | 748,60 | 757,51 |

Although these numbers still present numerous anomalies, especially in Europe, because the series of observations are not sufficiently long, yet they shew that the pressure of dry air attains its *maximum* in winter and its *minimum* at the period of the greatest heats. The difference between these two extremes diminishes as we recede from the equator; for, if we deduct the mean of the three summer months from that of the three winter, the difference is, for Calcutta, $23^{mm},55$; at Apenrade, $7^{mm},40$; at Halle, $7^{mm},49$; and at St. Petersburg, $8^{mm},16$.

If we examine the pressure of the entire atmosphere, this period partly disappears in the high latitudes: the summer *minimum* differs from the winter *maximum* by only a small number of millimetres; and, in the hot season, the difference is disguised by the tension of the vapour of water. The combination of these two pressures brings a *minimum* in the spring, because the pressure of the dry air then rapidly diminishes, whilst the quantity of vapour is not yet very considerable. Traces of a second *minimum* are found in autumn, because the quantity of the vapour of water is rapidly diminishing, whilst the pressure of the dry air increases slowly. Between the tropics this period of the pressure of the dry air is very marked; and, although the pressure of the vapour increases in summer, yet its variations are not sufficiently great to disguise those of the dry air.

This fact, that the height of the barometer is less in summer than in winter, is the consequence of causes already enumerated, namely, changes of pressure; and it evidently shews the movements of the aërial ocean over the whole surface of the globe; not only are these movements felt in countries near at hand, but even from one pole to the other. At the period of the equinoxes, when the temperature all over the earth is equal to the annual mean, the mean pressure of the dry air is almost every where observed. If the sun advances toward the northern hemisphere, the latter is heated, while the opposite hemisphere is cooled. A passage of air from the northern to the southern hemisphere, and a displacement of the trade-winds toward the north, are the consequence; in other words, the barometer is lower in the hemisphere where summer prevails, and higher in that where winter prevails. The closer countries are to the limit where this exchange takes place, the more marked will the differences be. The resistance experienced by the air, at the surface of the earth, will render these effects much less appreciable in countries at a distance from this limit; therefore it is, that the differences between the pressure of dry air in summer and winter are less in high latitudes than under the equator. Further observations will prove that, in equal latitudes, they are greater in the interior of continents than on the sea-coast.

This exchange is intimately connected with the dependence which the winds have on the seasons of the year (p. 52), and with the properties they derive from them. In spring, when the atmospheric pressure approaches the mean, the air is heated, and the wind reaches us from northern countries, driving away the prevailing S.W. wind. Hence the equatorial tempests and gales. This contest of cold north winds with warm south winds produces mixtures of dry and moist air, and variable weather, during which, rain, snow, and sleet, alternate at short intervals, with a perfectly clear sky. In the autumn, on the contrary, when the air comes from the south, the south winds predominate; they pour upon the south of Europe the water with which they are charged, and reach us perfectly dry; hence the beautiful weather that sometimes prevails in the middle of autumn, and which is known in France under the name of *St. Martin's summer;* in Germany it is called *the summer of old men;* and in North America, *the Indian summer.*

**IRREGULAR OSCILLATIONS OF THE BAROMETER.** — After having proved the dependence existing between these great movements of the atmosphere and temperature, it will be easy for us to deduce from the same cause the accidental oscillations of the barometer; the amplitude of these irregular oscillations is greater as we recede further from the equator.

The study of the laws of these oscillations, according to latitude, for example, presents great difficulties. Ancient philosophers took the difference between the *maximum* and *minimum* observed during the course of a great many years. This method was then renounced, in order to seek the difference between the two extremes for each month. It was observed that the oscillations became less as the heat increased; if the work embraces a great many years, we end by finding for each month constant numbers, giving the mean amplitude of the oscillation: we will call this the *mean monthly oscillation*. The observations of a single year are sufficient for obtaining an approximate datum, but a long series alone can lead to a rigorous result.

Although subject to great inconveniences, this method is the only one that can be used. It supposes, indeed, that the *real* extremes are observed, which occurs in only a few cases: thus the differences are in general too small; for one meteorologist, who should notice the height of the barometer more frequently than another, would obtain higher means. However, as the instrument is generally observed three times a-day, the errors are ultimately compensated. Another circumstance to be noticed is, that no regard is paid to the regular diurnal oscillations: for, if an accidental atmospheric disturbance diminishes the pressure, the latter will probably be still less at the period of the diurnal *maximum* than if this had not occurred.

The surest means of attaining the end consists in preferring intervals as short as possible; we should make observations every day at determinate hours, and take the differences of an observation at that hour of the following day, which corresponds to the same hour, and then divide the sum of these differences by their number; we thus find the amplitude of the diurnal oscillation, and the mean of the results obtained for each month gives the mean amplitude of the place. Further on, I will communicate several results of this kind.

**CARDS OF BAROMETRIC WINDS.** — After having discovered the pressure of the air, philosophers were not slow in perceiving that it varied according to the state of the atmosphere, and diminished singularly during storms. A great many hypotheses were proposed in order to explain these differences; all suppose that the air in motion must exercise a less pressure than still air. But the elements of these researches are taken only in Europe, and in stations near to each other. If the comparison had been made between barometric observations made simultaneously in the United States, in Europe, in Asia, in the polar regions, and between the tropics, we should have recognised that an extraordinary fall in the barometer at one point on the surface of the globe is compensated by an extraordinary rise on another point. Thus, instead of asking why the barometer is low on the approach of storms, we should have thought that great differences of pressure would bring about great movements in the aërial ocean. We should have seen that things go on in the air as in a mill-pond; as soon as the sluice is opened, the pressure of the water diminishes in this point, and the water is set in motion through the whole extent of the pond, but with a rapidity greater as it is nearer the sluice.

In these researches philosophers succeeded in recognising that the different winds had a different action on the pressure of the air. However, **Lambert** was the first who, in 1771, furnished the means of arriving at a positive result: we must choose, says he, a long series of observations; we must notice the height of the barometer accompanying each wind, and determine the mean pressure corresponding to each. Thirty years after this, **Burckhardt** undertook a task of this kind for Paris, and **Ramond** did one for Clermont, in Auvergne. In 1818, M. **de Buch** studied these laws from the Berlin observations; and, by demonstrating the influence of each wind on the aërial pressure, and on the weather in general, he raised the veil by which these complicated relations are concealed. After him MM. **Buch, Dove, Eisenlohr, Kuppfer, Schouw,** and **Kaemtz,** studied the phenomenon at different places in Europe; so that we can now deduce the direction of the wind from the height of the barometer with a very sufficient approximation.

The following table shews what the mean pressure of the barometer is at fifteen places in Europe with the eight principal winds:—

## CARD OF BAROMETRIC WINDS IN MEAN LATITUDES.

| WINDS. | LONDON. | MIDDLEBURG. | HAMBURG. | COPENHAGEN. | APENRADE. | PARIS. | MINDEN. | CARLSRUHE. |
|---|---|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| N. | 759,20 | 762,61 | 758,86 | 764,52 | 758,32 | 759,09 | 760,15 | 755,14 |
| N.E. | 760,71 | 761,73 | 759,76 | 765,13 | 760,55 | 759,49 | 760,37 | 755,59 |
| E. | 758,93 | 761,52 | 758,64 | 763,69 | 759,52 | 757,24 | 759,83 | 754,73 |
| S.E. | 756,83 | 756,99 | 758,41 | 759,40 | 760,53 | 754,03 | 756,49 | 752,34 |
| S. | 754,37 | 753,29 | 755,48 | 759,54 | 754,01 | 753,15 | 754,67 | 750,61 |
| S.W. | 755,25 | 754,46 | 754,80 | 759,11 | 756,06 | 753,52 | 755,28 | 752,36 |
| W. | 757,28 | 758,07 | 756,83 | 761,07 | 758,50 | 755,57 | 756,58 | 753,38 |
| N.W. | 758,03 | 759,04 | 758,41 | 763,49 | 758,97 | 757,78 | 760,15 | 754,67 |
| Mean. | 757,58 | 758,46 | 757,73 | 762,26 | 757,78 | 756,22 | 760,19 | 753,85 |

(*Vide* Appendix, *fig*. 31.)

## CARD OF BAROMETRIC WINDS IN HIGH LATITUDES.

| WINDS. | BERLIN. | HALLE. | VIENNA. | BUDA. | STOCKHOLM. | PETERSBURG. | MOSCOW. |
|---|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| N. | 758,68 | 755,61 | 749,88 | 744,00 | 757,91 | 759,72 | 743,07 |
| N.E. | 759,36 | 756,00 | 749,14 | 745,08 | 758,88 | 761,97 | 745,06 |
| E. | 758,77 | 754,51 | 745,78 | 743,25 | 757,31 | 762,00 | 743,90 |
| S.E. | 754,69 | 752,14 | 748,30 | 745,82 | 754,73 | 762,25 | 741,74 |
| S. | 751,33 | 751,10 | 747,74 | 741,88 | 753,90 | 759,90 | 740,63 |
| S.W. | 752,57 | 751,39 | 745,89 | 740,52 | 754,12 | 759,88 | 740,34 |
| W. | 756,00 | 752,21 | 745,84 | 742,71 | 756,04 | 759,43 | 741,06 |
| N.W. | 757,62 | 754,24 | 749,16 | 743,75 | 756,56 | 757,58 | 741,76 |
| Mean. | 756,02 | 753,29 | 747,79 | 743,27 | 756,18 | 760,64 | 742,19 |

These numbers clearly shew that the atmospheric pressure varies with the direction of the wind; the barometer is every where very high when the wind blows between the east and the north, and very low when it comes from a point comprised between the south and the west; its height varies very regularly between these two extremes. In certain places, however, anomalies are found; thus, at Vienna and Buda, the pressure is very feeble with east winds; and, at St. Petersburg, the *minimum* almost coincides with the N.W. These anomalies have not yet been well explained, for they are not derived merely from the continental positions of these two towns, since the results obtained at Stockholm and Moscow agree with the laws which regulate western Europe. The only difference consists in that the oscillations are a little smaller in the interior of the continent than on the west coast.*

Analogous laws are found in other countries, only the wind that corresponds to the *maximum* barometric height varies according to the position of these points in relation to

---

* In one of the preceding notes, p. 161, I have given the mean temperatures corresponding to the different directions of the wind, as they were observed at the period of the winter solstice at Bosekop (Norway), latitude 69° 58′ north, by the French Commission sent into the north of Europe. The mean barometric pressures corresponding to the same epoch, and in the same place, were calculated by M. BRAVAIS. They are ranged in their turn within the following little table, which shews the *barometric card of winds* for this locality:—

BAROMETRIC HEIGHTS FOR THE DIFFERENT WINDS AT BOSEKOP.

| | mm. |
|---|---|
| N. | 742,9 |
| N.E. | 753,2 |
| E. | 743,1 |
| S.E. | 740,9 |
| S. | 740,5 |
| S.W. | 744,8 |
| W. | 746,7 |
| N.W. | 745,6 |

It is to be believed that the barometric height 753,2, which corresponds to the N.E. wind, is too high; this rests on only a few observations. But this table, when placed in contrast with the thermometric card (p. 161), proves that the coldest winds keep the barometer lower, and that the warm winds from the west and S.W. raise it several millimetres: this fact is a remarkable exception for Europe. According to WRANGEL, this is nearly the range of the barometer at New-Archangel (DOVE, in SCHUMACHER'S *Jahrbuch für* 1841, p. 311). We should further observe the anomaly presented by these same facts, in another point of view: at Bosekop, the land-breezes depress the barometer; the column rises with the sea-breezes. An anomaly of the same kind exists at the mouth of the Rio de la Plata.—M.

Europe. Thus, in the United States, the barometer is highest with the N.W. winds, and lowest with the S.E.; it is the same at Pekin in China. On collecting these facts together, we conclude that *the barometer attains its maximum when the winds blow from the north and from the interior of continents, its minimum when they come from the equator or the sea.*

After what we have said in respect to the influence of winds over temperature, we may easily explain these phenomena,—the pressure is great with cold winds, feeble with warm winds. If the air is cooled with north winds, it contracts, the limits of the atmosphere fall, and the hot air flows in from all sides, and hence the rise of the barometer. If the air is heated by south winds, it ascends and flows away in all directions.*

**INFLUENCE OF THE ROTATION OF THE WINDS ON THE HEIGHT OF THE BAROMETER.**—In the researches, of which we have given the results in the preceding table, no attention has been paid to the hour of the day, except that for Paris and Halle I have chosen the hour of noon. However, on considering that in our climates the wind presents a regular and constant rotation, we ought to discover this regularity in the oscillations of the barometer, as we have formerly found it in those of the thermometer and the hygrometer. M. **Dove** arrived at this result by comparing the observations made at Paris at 9 A.M. and 9 P.M.; my own observations at Halle, when compared hourly, lead to the same results. I inquired what was the principal direction of the wind for each day, and I calculated the mean height of the barometer for each hour of the day; I then subtracted this mean from the general pressure observed at this hour with any particular wind. In the following table, the sign + means that the barometer was above the general mean; the sign —, that it was below it. However, I should observe that the absolute

---

* M. DOVE, according to the small number of existing meteorological observations, inquired what might be the influence of the direction of the wind over the height of the barometer in the southern hemisphere, and over the temperature and the humidity of the air. The examination of the registers of the ship *la Princesse Louise*, and the accounts given by Captains FITZROY and WENDT, have led to the following conclusions:—

1st. The barometer rises with west, S.W., and south winds; it attains its *maximum* height when the wind blows from the S.E., it then falls when the wind passes to the east, the N.E., and the north; its *minimum* height corresponds to the N.W.

2d. The temperature and the tension of aqueous vapour diminish with west, S.W., and south winds; they attain their *minimum* when they blow from the S.E.; they then augment with the east, the N.E., and the north, to attain their *maximum* when the wind is at N.W.—(SCHUMACHER'S *Annuaire* for 1841, p. 317.)

value of these differences is not, perhaps, rigorously exact; for the researches on the winds embrace a period of only four years; the general mean, on the contrary, was deduced from eleven years of observations, namely, from 1827 to 1838, but in this period there are likewise blanks of several months.

EXCESS OF THE MEAN HEIGHT OF THE BAROMETER, FOR A GIVEN WIND AND HOUR, OVER THE MEAN HEIGHT OF THE COLUMN, AT THE SAME HOUR, WITH ANY WIND.

| HOURS. | N. | N.E. | E. | S.E. | S. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| 6 morning. | +1,96 | +2,59 | +1,40 | −0,45 | −1,78 | −1,74 | −1,33 | +0,23 |
| 7 „ | +2,03 | +2,66 | +1,42 | −0,51 | −1,83 | −1,76 | −1,29 | +0,29 |
| 8 „ | +2,12 | +2,73 | +1,42 | −0,59 | −1,85 | −1,76 | −1,24 | +0,41 |
| 9 „ | +2,21 | +2,75 | +1,37 | −0,68 | −1,91 | −1,78 | −1,22 | +0,54 |
| 10 „ | +2,28 | +2,75 | +1,35 | −0,83 | −1,98 | −1,80 | −1,15 | +0,65 |
| 11 „ | +2,32 | +2,75 | +1,29 | −0,99 | −2,10 | −1,85 | −1,13 | +0,81 |
| noon. | +2,35 | +2,71 | +1,22 | −1,13 | −2,19 | −1,89 | −1,08 | +0,95 |
| 1 evening. | +2,39 | +2,71 | +1,15 | −1,22 | −2,28 | −1,89 | −1,02 | +1,08 |
| 2 „ | +2,44 | +2,68 | +1,08 | −1,31 | −2,35 | −1,89 | −0,97 | +1,20 |
| 3 „ | +2,46 | +2,66 | +1,04 | −1,42 | −2,44 | −1,89 | −0,97 | +1,35 |
| 4 „ | +2,46 | +2,62 | +0,97 | −1,51 | −2,48 | −1,87 | −0,88 | +1,47 |
| 5 „ | +2,53 | +2,59 | +0,92 | −1,58 | −2,53 | −1,85 | −0,81 | +1,60 |
| 6 „ | +2,55 | +2,59 | +0,92 | −1,62 | −2,53 | −1,82 | −0,74 | +1,71 |
| 7 „ | +2,59 | +2,57 | +0,90 | −1,65 | −2,58 | −1,85 | −0,72 | +1,80 |
| 8 „ | +2,64 | +2,59 | +0,90 | −1,65 | −2,61 | −1,85 | −0,72 | +1,87 |
| 9 „ | +2,71 | +2,62 | +0,92 | −1,65 | −2,64 | −1,82 | −0,68 | +2,00 |
| 10 „ | +2,77 | +2,66 | +0,97 | −1,60 | −2,64 | −1,82 | −0,68 | +2,05 |

(*Vide* Appendix, *fig.* 32.)

In this table we clearly recognise the influence of the rotation of the wind, it generally turns from the north to the N.E.; we may also remark that the barometer almost always rises during the days when the wind blows from the north, so that its height, after a deduction is made for the diurnal oscillation, is about two millimetres greater at 10 P.M. than at 6 A.M. As the pressure attains its *maximum*, when the wind is in the N.E., we find that the barometer changes but little during the day. However, long series of observations might permit us to appreciate its rise from morning till noon, and its fall till evening; for it frequently happens that the wind blows from the north during the morning, from the N.E. at noon, and from the east in the evening. I have placed my observations of this kind in the column N.E.; in the morning the barometer rose, it fell in the evening. The wind continuing to turn passes to the east, the S.E., and the south, and the pressure goes on diminishing; so that the barometer falls until it attains its *minimum* with the S.W. wind. The barometer then remains stationary throughout the day, only at noon it is a little lower than in the morning and evening. If it passes from the west to N.W. and the north, there is an increase in the pressure which may be appreciated in the course of the day.

The oscillations of the barometer depending on the direction of the wind explain to us the anomalies that we observe between the cards of barometric winds in places that are very near together. If we choose as the elements of the calculation the morning observations, the *maximum* approaches the N.E., the *minimum* the S.W.; if we take those of the evening, the *maximum* approaches the north, the *minimum* the south. The differences presented by the diurnal oscillations of the barometer in the same month, considered in different years, recognise the same cause. If in any month the west winds have been predominant, the *minimum* will take place a little earlier in the afternoon, the *maximum* a little later in the evening, than in the mean of observations comprising a great number of years. Moreover, the evening *maximum* exceeds that of the morning, whilst the contrary is the case with east winds. We must not forget that, in order to recognise the principal points of a barometric card, one year or even a few months are sufficient; but, to determine them rigorously, prolonged observations are required: for, if the S.W. winds predominate during a month, the barometer remains, for the few days that the east winds blow, below the habitual mean that corresponds to these winds.

**CORRESPONDING BAROMETRIC HEIGHTS FOR DIFFERENT PLACES.**—Barometric oscillations in general describe curves that are sensibly parallel, when they are studied for places that are not very far distant from each other; but, at great distances, the barometer may rise in one place and fall in another. Neighbouring places also present differences that are easily appreciated, by calculating their differences of level by means of those of the barometric columns. I have taken the difference of level between Halle and Paris, and between Halle and Zurich, and I have arranged them according to the winds that prevail at a mean in North Germany. The years of observations furnish me with the following differences with regard to the general mean:—

VARIATIONS OF THE DIFFERENCES OF LEVEL CALCULATED BY THE BAROMETER, ACCORDING TO THE DIFFERENT WINDS.

| TOWNS. | N. | N.E. | E. | S.E. | S. | S.W. | W. | N.W. |
|---|---|---|---|---|---|---|---|---|
| | m. | m. | m. | m. | m. | m. | m. | m. |
| Berlin. | + 2,9 | — 9,7 | —14,4 | —14,2 | — 6,8 | + 1,7 | + 7,0 | +10,1 |
| Paris. | + 8,2 | +22,0 | +26,7 | +35,5 | +23,8 | — 6,6 | —25,0 | —24,3 |
| Zurich. | +25,7 | +42,9 | +36,1 | +27,3 | — 6,2 | —21,4 | —24,0 | —13,8 |

(*Vide* Appendix, *fig.* 33.)

These quantities were obtained by comparison with the general mean. If we suppose all these points at a level with Halle, the sign + means that the place is situated above this level; the sign —, that it is below. Or else, if we regard the height of the barometer, + signifies that the barometer, supposing it on a level with that at Halle, is lower than in the town, while the sign — indicates the reverse. From the preceding table, the following may be deduced:—

DIFFERENCES OF MAXIMUM LEVEL OBTAINED WITH THE BAROMETER ACCORDING TO THE DIFFERENT WINDS.

| | | | | |
|---|---|---|---|---|
| Berlin . | E. 12° S. | —15$^{m}$,73 | W. 32° N. | + 9$^{m}$,93 |
| Paris . | S.E. | +33 ,30 | W. 15 N. | — 29 ,74 |
| Zurich . | N. 62° E. | +44 ,31 | S. 70 W. | — 27 ,57 |

The geographical position has also an immense influence, as the example of Zurich proves. These differences are connected with great laws, which cannot be established except by comparing a great number of places. If we arrive at this result, that the winds are engendered by an increase of pressure in the countries whence they come, we might establish, as well as the insufficiency of the materials at our disposal permits us, that these inequalities in the height of the barometer arise from differences of temperature. Thus, let us take a period during which the south-east wind blows at Halle, and compare the temperatures of the different places in Europe; if we make the corrections required by the differences in mean temperature, supposing that all Europe has the same mean temperature as Halle, we shall find that Vienna and Prague are 2° or 3° colder than Halle; Breslau, 1° or 2°; Konigsberg and Memel have the same temperature; in many towns in England the air is 2°, and at St. Petersburg 4°, warmer than at Halle. Consequently, at the east and the south of Halle the cold is more intense; the pressure, therefore, increases, and the wind blows from the south-east.

Other philosophers who have studied the same subject have arrived at very discordant results. Thus, **Brandes** found that the height of Saint-Gothard above that of Geneva was equal to the mean with the south-east winds, whilst it was too great with the north-west winds; which accords tolerably well with a result that I found, by comparing my barometric observations at Halle with those of M. **Maedler** at Berlin. The two directions given by the extreme differences of level are sensibly perpendicular to the line joining the two stations. **Ramond** convinced himself that the greatest difference between Paris and Clermont-Ferrand coincides with the north wind; the least coincides with the south wind; that is, with winds whose direction is parallel to the line joining the two stations. This result is directly opposed to those that we have hitherto related. We should not forget that **Ramond** did not consider the four cardinal winds; then, were his places well chosen? Paris participates in the ascending currents of mean Europe; Clermont, on the contrary, belongs to the zone of Mediterranean climates that are influenced by the great current of Sahara. Unfortunately, I have not around me in Germany a sufficient number of correspondent observations to enable me entirely to throw light on this subject.

**ACCIDENTAL DIURNAL OSCILLATIONS.**—They are dependent on the seasons, the geographical position, and the winds; in order to recognise their connexion with temperature, it would be well to follow the barometric oscillations from one observation to the observation of the next day, that corresponds to the same hours, comparing them with those of the temperature. I have made this tedious calculation for a great many places, and have deduced from them the following tables:—

## MEAN CHANGE OF THE BAROMETER BETWEEN TWO CONSECUTIVE NOONS.

| MONTHS. | SANTA FÉ DE BOGOTA. | CALCUTTA. | BAGDAD. | RIO-JANEIRO. | SAINT-BERNARD. | SAINT-GOTHARD. | MAFRA. | GENEVA. | MILAN. | PADUA. | BUDA. | LA ROCHELLE. | CAMBRIDGE (Massachusets). | EYAFIORD (Iceland). |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. | mm. |
| January . | 0,561 | 0,817 | 2,297 | 1,372 | 2,827 | 3,068 | 4,081 | 4,213 | 2,923 | 4,124 | 4,131 | 4,797 | 7,602 | 7,813 |
| February . | 0,550 | 0,821 | 2,443 | 1,906 | 2,829 | 2,858 | 3,271 | 3,885 | 3,773 | 3,790 | 3,718 | 4,598 | 5,972 | 6,273 |
| March . . | 0,501 | 1,022 | 3,158 | 2,552 | 2,933 | 2,752 | 3,248 | 3,813 | 3,555 | 3,966 | 4,095 | 4,613 | 5,049 | 7,113 |
| April . . | 0,479 | 0,972 | 1,494 | 1,721 | 2,387 | 2,407 | 3,226 | 2,741 | 3,628 | 3,076 | 3,194 | 2,743 | 5,856 | 4,844 |
| May . . . | 0,550 | 1,116 | 1,169 | 1,868 | 1,787 | 1,846 | 2,030 | 2,317 | 2,095 | 2,256 | 2,355 | 2,752 | 3,824 | 3,803 |
| June . . . | 0,370 | 1,413 | 1,393 | 2,145 | 1,886 | 1,730 | 1,422 | 1,884 | 2,258 | 2,080 | 2,109 | 2,369 | 2,865 | 3,573 |
| July . . . | 0,429 | 0,916 | 1,286 | 1,372 | 1,818 | 1,791 | 1,399 | 1,986 | 1,557 | 2,173 | 1,915 | 2,514 | 3,329 | 2,933 |
| August . . | 0,321 | 1,008 | 1,031 | 1,057 | 1,647 | 1,631 | 1,669 | 1,868 | 2,103 | 1,742 | 1,884 | 2,876 | 3,075 | 4,598 |
| September . | 0,501 | 1,065 | 1,165 | 1,304 | 2,098 | 2,024 | 1,660 | 2,340 | 2,917 | 2,472 | 2,340 | 3,381 | 3,891 | 5,198 |
| October . . | 0,408 | 0,952 | 1,317 | 1,460 | 2,335 | 2,161 | 2,120 | 2,775 | 3,786 | 2,725 | 3,268 | 3,730 | 4,638 | 4,841 |
| November . | 0,490 | 0,548 | 1,671 | 1,685 | 2,131 | 2,452 | 2,865 | 2,883 | 2,793 | 3,219 | 2,967 | 3,810 | 5,848 | 6,756 |
| December . | 0,645 | 0,561 | 1,607 | 1,660 | 2,808 | 2,919 | 3,970 | 3,452 | 3,427 | 3,386 | 3,226 | 3,079 | 6,907 | 7,054 |
| Mean . . | 0,483 | 0,934 | 1,669 | 1,687 | 2,256 | 2,295 | 2,582 | 2,847 | 2,900 | 2,917 | 2,933 | 3,438 | 4,905 | 5,401 |

Rio-Janeiro, which occupies a place in this table, being in the southern hemisphere, I have placed, in the month of January, the values found for July; in that of February, those for August, &c. The influence of the seasons is very evident; thus, the oscillations are always smaller in summer than in winter. Calcutta, the calculations for which rest on the observations of a single year, forms the only exception to the rule. If long series made in India should lead to the same result, it must be attributed to the influence of the south-west monsoon, which often brings violent storms.

This fact is intimately connected with accidental variations of temperature; for, if we seek for the difference of temperature observed at the same hours, we shall find that they are smaller in summer than in winter; principally so, if we take the mean difference of localities that are near each other, but very unequally elevated above the level of the sea. In summer, the mean temperature decreases with the latitude much faster than in winter; and, if the winds bring masses of air from a distant place, their difference of temperature will be less than in winter: and hence the lesser differences of pressure. For the same reason the accidental oscillations are much feebler at the equator, because the variations of temperature are less extensive; and, on a given space, the difference between the *maxima* and the *minima* means increases with the latitude. The columns of Saint-Bernard and Saint-Gothard also prove that these oscillations have less amplitude the higher we rise in the atmosphere; they diminish almost in the same progression as the mean heights of the barometers.

**MONTHLY EXTREMES.** — If, in a long series of observations, we look for the difference between the *maximum* and the *minimum* of each month, we shall not only find the influence of seasons, of which we have already spoken, but, thanks to the number of observations coming from all countries, we may also calculate the differences of these oscillations in different climates. The following table presents the mean monthly oscillation, as well as the mean oscillations of winter and summer.[*]

---

[*] The mean of the monthly oscillations observed at Bosekop (latitude 69° 58′), during the six months of the winter of 1838-9, is equal to $38^{mm},52$; it has almost the same value as at Umeo, a town situated 6° more to the south.—M:

MEAN AMPLITUDE OF BAROMETRIC OSCILLATIONS DURING THE YEAR, THE WINTER AND THE SUMMER, IN DIFFERENT PLACES.

| TOWNS. | LATITUDE. | LONGITUDE. | YEAR. | WINTER. | SUMMER. |
|---|---|---|---|---|---|
| | | | mm. | mm. | mm. |
| Batavia | 6° 12′ S. | 104° 33′ 36″ | 2,98 | 2,80 | 2,71 |
| Tivoli (Saint-Domingo) | 18 35 N. | 72 20 24 | 4,11 | 4,96 | 3,32 |
| Seringapatam | 12 45 | 74 30 36 | 5,53 | 5,12 | 5,03 |
| Havannah | 23 9 | 84 43 24 | 6,38 | 9,63 | 3,84 |
| Calcutta | 22 34 | 86 8 36 | 8,28 | 6,81 | 9,05 |
| Teneriffe | 28 20 | 18 36 24 | 8,48 | 12,71 | 4,51 |
| Isle of France | 20 9 S. | 55 9 36 | 8,62 | 6,99 | 7,90 |
| Aleppo | 36 11 N. | 34 29 36 | 9,09 | 14,21 | 5,57 |
| Cairo | 30 2 | 28 58 36 | 9,25 | 12,93 | 4,74 |
| Funchal (Madeira) | 22 37 | 19 16 24 | 10,42 | 13,99 | 6,23 |
| Bagdad | 33 20 | 42 4 36 | 10,45 | 13,83 | 8,60 |
| Cape of Good Hope | 33 55 S. | 16 3 36 | 12,45 | 15,07 | 9,79 |
| New Harmony (Indiana) | 38 11 N. | 90 15 24 | 16,40 | 22,90 | 8,89 |
| Pekin | 39 45 | 114 7 36 | 16,65 | 16,92 | 11,57 |
| Paramatta (N. S. Wales) | 33 49 S. | 148 40 36 | 16,92 | 17,37 | 15,72 |
| Lausanne | 46 31 N. | 4 25 36 | 17,08 | 21,20 | 12,11 |
| Bermuda | 32 15 | 62 20 24 | 17,10 | 20,46 | 15,77 |
| Rome | 41 53 | 10 7 36 | 17,15 | 22,92 | 9,93 |
| Marseilles | 43 18 | 3 1 36 | 17,69 | 23,08 | 17,44 |
| Saint-Gothard | 46 0 | 6 14 36 | 17,96 | 23,76 | 13,08 |
| Montpellier | 43 36 | 1 32 36 | 18,02 | 23,08 | 12,86 |
| Turin | 45 4 | 5 14 36 | 18,09 | 22,58 | 12,25 |
| Mantua | 45 10 | 8 27 36 | 18,14 | 24,59 | 14,14 |
| Phschminsk | 57 0 | 76 29 36 | 18,99 | 1,43 | 12,79 |
| Dijon | 47 19 | 2 41 36 | 19,13 | 25,49 | 11,44 |
| Milan | 45 28 | 6 51 36 | 19,24 | 24,90 | 12,36 |
| Buda | 47 30 | 16 42 36 | 19,92 | 26,78 | 13,08 |
| Augsburg | 48 22 | 8 33 36 | 20,33 | 25,33 | 14,19 |
| Vienna | 48 13 | 14 2 36 | 20,53 | 26,78 | 13,02 |
| Mulhouse | 47 49 | 4 49 36 | 20,64 | 27,75 | 13,02 |
| Munich | 48 8 | 8 13 36 | 20,73 | 27,25 | 13,94 |
| Metz | 49 7 | 3 49 36 | 20,80 | 26,23 | 13,99 |
| Prague | 50 5 | 12 4 36 | 21,54 | 27,32 | 14,66 |
| Ratisbon | 49 1 | .... | 21,66 | 27,63 | 14,98 |
| Bourdeaux | 44 50 | 2 54 24 | 21,68 | 29,33 | 14,05 |
| Kamyschin | 50 5 | 43 3 36 | 21,86 | 27,23 | 16,20 |
| Strasburg | 48 35 | 5 24 36 | 21,93 | 28,36 | 14,48 |
| Nantes | 47 13 | 3 53 24 | 22,92 | 28,81 | 15,34 |
| Arnstadt | 50 50 | 8 36 36 | 23,01 | 27,82 | 16,33 |
| Breslau | 51 7 | 14 41 36 | 23,14 | 29,17 | 15,27 |
| La Rochelle | 46 9 | 3 30 24 | 23,17 | 31,74 | 15,79 |
| Paris | 48 50 | .... | 23,66 | 30,45 | 17,17 |
| Mannheim | 48 29 | 6 7 36 | 23,66 | 31,06 | 16,45 |

| TOWNS. | LATITUDE. | LONGITUDE. | YEAR. | WINTER. | SUMMER. |
|---|---|---|---|---|---|
| | | | mm. | mm. | mm. |
| Moscow | 55°46′ N. | 35° 12′ 36″ | 24,05 | 31,31 | 15,59 |
| Sitcha | 57 3 | 140 20 24 | 24,50 | 25,83 | 17,19 |
| Sagan | 51 42 | 13 1 36 | 24,57 | 31,42 | 16,58 |
| Fort Churchill | 58 47 | 96 24 24 | 22,76 | 30,72 | 18,79 |
| Berlin | 52 31 | 11 1 36 | 25,24 | 33,07 | 17,33 |
| Hamburg | 53 33 | 7 38 36 | 25,38 | 32,19 | 17,21 |
| New Haven (Connecticut) | 41 10 | 74 50 24 | 25,29 | 33,18 | 14,46 |
| Penzance | 50 12 | 7 52 24 | 25,42 | 33,32 | 18,68 |
| Brussels | 52 31 | 2 1 36 | 25,65 | 32,64 | 18,90 |
| Cambridge (Massachus.) | 42 23 | 74 37 24 | 25,65 | 32,35 | 17,17 |
| New Bedford | 41 59 | 74 10 24 | 25,65 | 33,45 | 16,51 |
| Göttingen | 51 32 | 7 34 36 | 25,74 | 32,01 | 17,55 |
| Iakoutsk | 62 2 | 127 21 36 | 25,92 | 25,72 | 20,39 |
| Tomsk | 59 39 | 80 49 36 | 26,01 | 31,58 | 17,66 |
| Catarinenburg | 56 50 | 58 14 36 | 26,64 | 34,81 | 19,67 |
| Bristol | 51 27 | 4 55 24 | 26,73 | 34,13 | 19,92 |
| The Hague | 52 5 | 1 58 36 | 26,94 | 34,90 | 18,34 |
| Copenhagen | 55 41 | 10 13 36 | 27,77 | 34,49 | 20,03 |
| London | 51 31 | 2 20 24 | 27,88 | 35,15 | 20,32 |
| Franecker | 52 36 | 1 58 36 | 27,93 | 34,15 | 22,26 |
| Gosport | 50 48 | 3 26 24 | 28,69 | 34,76 | 21,14 |
| Middleburg | 51 30 | 1 16 36 | 28,99 | 38,44 | 20,03 |
| Iloulouk | 53 53 | 170 49 24 | 28,99 | 34,88 | 19,22 |
| St. Petersburg | 59 56 | 27 58 36 | 29,24 | 36,93 | 19,97 |
| Torneo | 65 51 | 21 49 36 | 29,75 | 38,42 | 21,61 |
| Stockholm | 59 21 | 15 42 36 | 29,87 | 37,97 | 22,11 |
| Abo | 60 27 | 19 59 36 | 29,96 | 37,20 | 19,76 |
| Upsal | 59 52 | 15 18 36 | 30,16 | 36,88 | 21,43 |
| Bergen | 60 24 | 3 00 36 | 31,27 | 37,13 | 22,74 |
| Nain (Labrador) | 57 8 | 63 40 24 | 32,35 | 40,61 | 24,43 |
| Umeo | 63 50 | 17 54 36 | 32,39 | 39,50 | 22,06 |
| Christiania | 59 55 | 8 28 36 | 33,05 | 41,87 | 22,06 |
| Naes (Iceland) | 64 30 | 22 35 24 | 35,91 | .... | .... |

These numbers are only approximate, for it is rare that observers have noted the real extremes; but their data approach nearer to the truth, and the differences are greater, as the daily observations have been more multiplied. However, we may draw from these materials certain general inductions. We clearly see that the amplitude of the accidental variations increases as we recede from the equator, and we may appreciate the influence of geographical position. Although India is situated under the same parallel as the Antilles, yet the oscillations are much greater. In higher latitudes, other relations are found. The accidental variations are much more extensive on the east coast of

America than on the west coast of Europe: the *maximum* of difference is found at the point where the Gulfstream turns to the east, and where the isothermals are very near to each other. Thus, in the State of Massachusets (42° N.), the oscillations have the same amplitude as they have at 10° more north in Western Europe; but, in penetrating into the interior of the old continent, they continue diminishing, and appear to increase anew on the east coast of Asia. Thus, their amplitude is the same at Göttingen (latitude 51° 32′ N., longitude, 7° 36′ E), Tomsk (latitude, 56° 29′ N. longitude, 82° 50′ E), and Iakoutsk (latitude, 62° 2′ N., longitude, 127° 24′ E).

On the west coast of America, the oscillation is the same in equal latitudes as that part of the corresponding coast of Europe, as is proved by the observations made at Sitcha and Ilounouk; in the interior of America it is less than on the coasts. If we join by lines the places where the amplitude is the same, we obtain isobarometric curves. I understand by *isobarometric line* of 4mm,51, for example, that which passes through all the points in which the mean difference between the monthly extremes is 4mm,51.

**ISOBAROMETRIC LINES.**—If we deduce from the observed barometric amplitudes the latitudes where the isobarometric lines cut the meridians, we shall construct the following table:—

ISOBAROMETRIC LINES.

| MEAN MONTHLY OSCILLATION. | EAST AMERICA. | WEST EUROPE. | GERMANY AND ITALY. | RUSSIA IN EUROPE. | INDIA AND SIBERIA. |
|---|---|---|---|---|---|
| mm. | | | | | |
| 4,51 | 15° 33′ | 15° 9′ | 21° 15′ | 23° 36′ | . . . . |
| 9,02 | 23 55 | 26 17 | 29 38 | 31 51 | 23° 36′ |
| 13,54 | 30 27 | 34 4 | 36 43 | 39 2 | 35 29 |
| 18,05 | 36 14 | 42 14 | 43 18 | 45 51 | 46 34 |
| 22,56 | 41 40 | 47 8 | 49 48 | 52 43 | 57 55 |
| 27,07 | 46 58 | 51 4 | 56 34 | 60 5 | 72 23 |
| 31,58 | 52 21 | 57 47 | 64 6 | 68 50 | . . . . |
| 36,09 | 58 1 | 65 22 | 73 48 | 83 38 | . . . . |

The following is the conversion of these figures into ordinary language:—1st. The oscillations of the barometer are very small at the equator; if we could calculate them so as entirely to eliminate the diurnal variation, we should find that they are $2^{mm}$ at most. In the Indian Sea they are twice as great, which is due to the disturbances brought about in the atmosphere by the monsoons.

The isobarometric line of $4^{mm}$,51, cuts the coast of North America in the Bay of Honduras; it is then determined directly toward the east, reaches Africa at the north of Cape Verd, then rises toward the north, traverses Egypt, and afterwards descends toward the equator, which it reaches a little to the west of the meridian, under which the point of the Indian peninsula is situated. In the southern hemisphere it again directs its course toward the west.

The isobarometric line of $9^{mm}$,02 cuts the east coast of America at the east of Zacatecas; it then rises toward the north, reaches the west coast of Africa between Cape Bojador and the Canaries, traverses the north part of Fezzan and the Delta of the Nile; it then passes between Bagdad and Bassora, inclines greatly toward the south, and terminates near Calcutta.

The isobarometric line of $13^{mm}$,54 touches the north part of the Gulf of Mexico, reaches the old continent in the north part of the kingdom of Fez, traverses Sicily, attains its most northern point in the neighbourhood of the Caspian, and at the east descends toward the south.

The isobarometric line of $18^{mm}$,05 cuts the southern part of the Bay of Chesapeake; it then rises abruptly toward the north, passes by the northern part of the Spanish peninsula; and this movement toward the north appears to continue even into the interior of Asia.

The isobarometric line of $22^{mm}$,56 cuts the east coast of America in the neighbourhood of Boston, the west coast of Europe at the north of the mouth of the Loire; continues to rise toward the north, and attains its northern limit in the neighbourhood of Krasnojarsk in Siberia. From this point it descends again toward the south.

The isobarometric line of $27^{mm}$,07 cuts the east coast of America in the State of New Brunswick, reaches Europe in the neighbourhood of London, traverses southern Sweden, passes between Novogorod and St. Petersburg, and appears to reach the Frozen Ocean in the neighbourhood of Cape Taimura. In the interior of America it passes several degrees to the north of Fort Churchill, then inclines toward the south as it advances westward, and appears to be prolonged several degrees to the north of Sitcha, since in this point the mean monthly oscillation is only $25^{mm}$: but it then directs its course toward the south-west, and leaves Ounalaschka in the north, where the oscillation is $29^{mm}$.

The isobarometric line of $31^{mm},58$ passes through the southern part of Labrador, the northern part of Scotland and southern Norway; it passes to the north of Saint-Malo, and is prolonged toward the north.

Although we are not in possession of any long series of barometric observations in the north, yet the direction of the lines shews that they return on themselves, like the isothermals, and form two different systems. The centre of these two systems, or the *poles* of the irregular oscillations of the barometer, are not found, like the poles of cold, on the two continents, but they are placed in the ocean by which they are separated.

In the south of Africa and in New Holland, the size of the oscillations is the same as in western Europe; but, in their course from the Cape of Good Hope to New Holland, these lines appear to approach the equator: this is in consequence of the agitation of the air in the Indian Sea.

When, in 1831, I made known in my *Treatise on Meteorology* the direction of the isobarometric lines deduced from existing facts, I announced that this attempt should be considered merely as the prelude to a more extensive work. I am forced to repeat this observation in the present place. The variability of the elements of a calculation of this kind demands a great number of observations, made in localities very near to each other. Now, if the known barometric series are sufficient for Europe, they are not so for other parts of the world. Since I published this work, we possess a still greater number of observations; however, their increase has not been such as to change notably the results that have been obtained.

**De Saussure,** who has contributed so much to the progress of Meteorology, said that every hypothesis intended to explain barometric oscillations ought to give an account of their increase with the latitude. The connexion existing between changes of temperature and changes of pressure accounts for this increase, and for the curving of the isobarometric lines. Thermometric variations arise, as we have previously mentioned, from the winds mixing strata of air of different temperatures, and transporting these masses from the north to the south, and from the south to the north. The more we recede from the equator, the more does the mean temperature of the years and of the seasons vary for a given latitudinal distance. The mean temperature of the equator is 27°,5; that of Teneriffe, 21°,7: thus, for a difference in latitude of 28° 30′, the difference in temperature is only 5°,8. But, if we go from Teneriffe to Edinburgh, the mean of which is 8°,6, we shall have, for the same difference in latitude (28°), a difference of 13°,1 between the mean temperatures of these two points. Add to this, that Edinburgh is under a meridian remarkable for the elevation of its temperature. If we had chosen a town situated in the interior of the continent, the difference would have been still greater. Let us admit, for simplicity's sake, that a country receives air coming from two others, situated one to the north, the other to the south, but equidistant in latitude; the difference of temperatures will be greater as these places are further from the equator, and the barometric oscillations will increase in the same ratio. In high latitudes we have sudden changes in the direction of the wind, the aspect of the sky, and the height of the barometer. Between the tropics, the trade-winds throw into circulation an air, the temperature of which is uniform: the thermometer, therefore, remains almost stationary; and the mean temperatures of the same month, considered for several different years, vary much less than in the high latitudes. We shall not find notable variations in the barometer except in latitudes such as the Indian Sea, where changes in the direction of the winds bring about corresponding changes in temperature.

When the mean temperature of the air changes very rapidly under the same parallel, then the barometric oscillations are greater than in the contrary case. The summit of the curve of the isothermals passes through the west of England; but if we could determine the mean temperature of points situated on the sea, by turning to account the innumerable observations made by nautical men, it is then probable that the summit would be carried into the Atlantic Ocean. Thus, then, the changes of temperature due to the alternation of N.E. and S.W. winds ought to be more notable in the British isles than in the interior of the continent; the barometric oscillations are also more marked in England. The same phenomenon occurs on the east coast of America, where the warm air of the Gulfstream, and the winds evolved in the icy solitudes of Canada, determine considerable variations in the temperature.

The direction of these winds tends to exaggerate these variations; when the S.W. winds blow in Europe during winter, they not only act by virtue of their high temperature, which determines a notable diminution in the pressure, but at the same time the sky being habitually overcast opposes radiation from the ground, which becomes heated on the surface: thus the air passes away in greater proportion to the higher regions than if the vapours were not condensed into clouds. Reciprocally, when the winds blow from the east, the sky is serene, and the cooling of the ground very considerable; whence arises an increase of pressure. In the interior of the continent, whither the sea-breezes arrive, loaded with a less quantity of vapour, the sky is generally more pure, the heating of the ground less marked, and the barometer more tranquil.

From this fact, that the decrease of temperature with latitude is more rapid as we recede farther from the equator, a second consequence may be drawn. If we admit that the two winds, which cause the barometer to rise and fall, always bring air coming from countries situated in the circumference of a circle, at the centre of which the observer is placed, we can comprehend that for hot winds blowing from the south the barometer falls less below the mean than it rises by north winds, which are relatively colder. As all these changes oscillate about the mean, the barometer ought to fall more slowly than it rises; observation confirms this anticipation. If we calculate the cases in which the barometer rises, setting out from any hour to the same hour of the next day, this number is to that of the case in which it falls as 10:11; that is to say, that the time required by the barometer to rise a certain quantity is to that during which it falls the same quantity as 10 : 11. Now, as it rises with north winds, the latter draw along a mass of air proportionate to that which the south winds can draw as 11 : 10. This fact explains to us a circumstance, in the table of the relations of the winds (p. 48), that is difficult of comprehension. We have found, indeed, that the north winds blow less frequently than the south, in the relation of 10 : 11,8; if, then, they draw along as much air as those of the north, the atmosphere would finally be carried towards the pole: but we have just seen that the north winds, compared with those of the south, draw along a mass of air greater in about the same proportion, namely, as 10 : 11,3.

**STATE OF THE BAROMETER DURING RAIN.**—**Toricelli** had long ago remarked that the barometer was low at the approach of rain; it is admitted as positive that the diminution of pressure ought to bring rain; whilst the weather ought to remain fine, as long as the barometer is high. If this coincidence did not occur, then would there be lamentations without end on the inaccuracy of barometers in general, or of accusations against him who should be particular in observing it. It would be more wise to lament that a prejudice on this point could become rooted in the generality of minds.

The law that presides over all the oscillations of the barometer, which only indicate differences of temperature between countries that are not far apart, likewise finds an explanation here. If the fall of the column generally precedes rain, this is due to the particular position of Europe; in fact, the S.W. winds, which are the warmest, make the barometer fall; they likewise bring rain: hence the observed coincidence. The cold winds of the N.E., on the contrary, raise the barometric column, and almost always accompany a clear and serene sky.

For a long time, philosophers vainly endeavoured to explain the relation by which the two phenomena are connected; **Deluc** was the first to point it out in general terms, and, although his hypothesis does not induce a searching investigation, it is yet generally adopted. A cubic decimetre of the vapour of water not being so heavy as a cubic decimetre of air, **Deluc** explains all barometric oscillations by the greater or less proportion of the vapour of water contained in the atmosphere. Indeed, when a certain quantity of air absorbs a certain quantity of vapour, it expands; the atmosphere at this point is higher than in the neighbouring points, a part of the air passes away on all sides, and the pressure of the remaining part is less on account of the proportion of vapours that it contains. This principle being established, he deduces from it a host of consequences, of which the following are the most important:—

1st. When the air, loaded with vapours derived from the sea, traverses the continent, the atmospheric pressure diminishes throughout the whole of the course it pursues, and the barometer falls. 2d. If these masses of moist air accumulate in any country, the vapours finally rise into the higher regions of the atmosphere, where they form clouds. The barometer then falls still lower; not because the clouds diminish the weight of the atmosphere, but because the proportion of vapour continues constantly increasing. 3d. The vesicles of the cloud finally collect together, and then the rain falls. 4th. When the sky is clear and the air moist, the barometer falls, if the dew is abundant. 5th. The barometer falls with south and with west winds, because they bring to us moist air; it rises, on the contrary, under the influence of dry east and north winds; it rains also with the former, whilst it is fine weather with the latter. 6th. If the sky is clear with south winds, or clouded with north winds, the barometer does not indicate it. 7th. Should the arrival of air, loaded with vapours, cease during rain, the latter then draws the vapours toward the earth, the dry air flows in from all sides, the pressure increases, the barometer rises, and we may conclude that the rain will not last long. 8th. Should the barometer begin to rise merely because the wind that is loaded with vapours ceases to blow, the rain may then continue as long as the clouds are sufficiently dense to dissolve into water; but if the wind veers to the N.E., this dry wind dissolves the vapour, and the clouds are instantly dissipated. 9th. When the vapours that are accumulated in any region ascend in the atmosphere, they condense into clouds; a wind may then rise, blowing only in the higher regions of the atmosphere, and driving the clouds towards a country where the barometer is high: it will rain there without the mercury falling, because that wind does not arrive loaded with vapours. It therefore rains in this country although the barometer is high, and it does not rain in that where the clouds were formed, although the barometer is low. 10th. As the barometer indicates the state of the entire column of the air, and the hygrometer merely that of the air in the place of observation, the range of the two instruments may be very different. 11th. Heat expands the air, and diminishes its weight; it acts much more energetically on vapours. The more the winter mean differs from that of summer, and the more the proportion of the vapour of water differs in the two seasons, the greater also are the barometric oscillations. For if, during summer, the air is hot and at the same time loaded with vapours, the barometer must fall: also in the north, where the difference between the temperature of winter and that of summer is very great, the barometer oscillates greatly, whilst it is almost motionless in the neighbourhood of the equator.

This theory was received with much favour, because it embraced the entire mass of phenomena better than all those that preceded it. However, its author himself so modified it subsequently that he did not fear to maintain that the air was metamorphosed into vapours of water, and even into water itself, under the influence of certain affinities, to pass again into the state of air under different circumstances. The consequences remained in detail the same. But the fundamental idea of **Deluc's** hypothesis is contrary to the most simple notions in physics and chemistry; for when the elements of the air combine, nitric acid, and not water, is produced. **De Saussure**, a fellow-countryman and contemporary of **Deluc's**, had already shewn that barometric oscillations do not depend solely on vapours; his arguments have been corroborated by all the subsequent labours of philosophers on this subject, and yet **Deluc's** hypothesis is produced in almost all treatises on natural philosophy and Meteorology, from the end of the last century and the commencement of the present. **De Saussure's** objections rarely find a place in them. I think that, without being persuaded of the truth of **Deluc's** assertions, his contemporaries adopted them to avoid the labour of refuting them. **Deluc** built up a system of Meteorology easy of comprehension and of explanation; **de Saussure**, on the contrary, only gave meteorological fragments, disseminated throughout his *Travels in the Alps*, and his *Essay on Hygrometry*. It was difficult to collect and to arrange them, in order to oppose them to **Deluc**; they preferred neglecting them.

After having determined the quantity of vapour contained in the air, at different degrees of the thermometer and the hair-hygrometer, **de Saussure** made known a great number of facts that do not accord with **Deluc's** theory; for, if vapours acted as he contended, the barometric variations would be enormous. Suppose, for instance, that the dew-point was at 25°, the tension of the vapour would be *in equilibrio* to a column of mercury $23^{mm}$ in length; if all this vapour were then precipitated in the state of water, which never happens, the barometer would rise the same amount. But, in our countries, we never observe such difference in the quantity of the vapour of water, whilst the extremes of barometric oscillations far exceed $23^{mm}$. Moreover, it is in countries and in the season where the heat is greatest, and the evaporation very active, that we should observe the greatest oscillations, namely, in summer, and in the neighbourhood of the equator; now experience shews precisely the contrary.

**Deluc's** hypothesis rests on a principle the fallacy of which has been proved by **Dalton, Gay-Lussac,** and others. At equal tensions a volume of moist air weighs less than an equal volume of dry air; but, when water quietly evaporates in the open air, the vapours ascend through the interstices of the aërial particles, without having any influence by their weight or their elasticity on the movements of the air. The atmospheric pressure is, therefore, increased by the weight of the vapour of water, all other things being equal. The barometer ought to be higher in moist than in dry air. Observation seems contrary to this assertion, since the barometer is lowest with winds loaded with vapours. But

S.W. winds, which bring rain, are also the hottest of all: they tend to raise the barometric column by the pressure of their vapour, and to lower it by their temperature. This last influence being the more energetic, the pressure diminishes; and it is by their temperature that sea-breezes in our climates make the barometer fall. In other countries they act differently: thus **Flinders** has shewn, in a work on the barometric oscillations on the coasts of New Holland, that beyond the tropics the dry winds, blowing from the shore, make the barometer fall; which is very well explained by **Peron's** remarks on the high temperature of these winds. At the mouth of La Plata, the barometer is higher during east sea-breezes than with west winds blowing from the land.

In these researches, we should in the outset distinguish the state of the barometer during continued rains from that which accompanies short and isolated showers. If the latter are frequent, and are due to clouds that approach the zenith, we may calculate on the barometer's rising several tenths of a millimetre; this often happens at the approach of storms. Sometimes the barometer falls again to its original height, when the cloud has departed. During storms we may affirm that the period of their greatest violence is passed when the barometer ceases to rise or begins to fall; this is because the rain that falls cools the lower strata of the atmosphere, and that masses of air flow in from all parts toward this spot. It also happens that the barometer rises regularly for several days: in this case the south winds have been driven away by the north winds; and, at the place where they meet, the mixture of strata of air, of different temperatures, produces a condensation of the vapours; the barometer then rises, under the influence of these cold winds: we see this during storms in the winter. If the storm comes from the south, and the barometer falls, it will rise again after the first flashes of lightning.

But generally, during rainy weather, the barometer is about $5^{mm}$ below its mean; a height corresponding to south and S.W. winds. M. **de Buch** compared the heights of the barometer during rainy weather at Berlin, and obtained the following results:—

### HEIGHT OF THE BAROMETER AT BERLIN DURING RAINY WEATHER.

| | mm. |
|---|---|
| N. | 754,39 |
| N.E. | 755,93 |
| E. | 756,09 |
| S.E. | 751,26 |
| S. | 749,16 |
| S.W. | 750,20 |
| W. | 753,85 |
| N.W. | 755,79 |

(*Vide* Appendix, *fig.* 34.)

All these heights are less than those generally accompanying the same winds; it follows that we must not expect continuous rain, except when the barometer is below the height that corresponds to the prevailing wind. These phenomena are connected with what we have said respecting the formation of rain. As soon as S.W. winds rise, there is a diminution of pressure, and a formation of *cirri;* but it is only when the wind continues, and the barometer falls more and more, that the quantity of vapours becomes of sufficient amount to fall in rain: with these winds, also, the height of the barometer is less than their general mean. The same phenomena belong to north winds; as soon as they begin to blow the barometer rises, but, as they mix with an atmosphere that has been loaded with vapours by the preceding west winds, they determine the precipitation of rain by the influence of their temperature. If they continue blowing, the air dries, the barometer rises, and fine weather returns.

Thus we act correctly in marking the word *rain*, on ordinary barometers, at a point situated four or five millimetres below the annual mean; but we should never lose sight of two circumstances,—the direction of the wind, and the state of the atmosphere at the moment of the observation.

M. **Dove** has carefully studied the influence of the wind, and I believe I cannot do better than relate his conclusions. He rests on the theory of the rotation of the winds from the east, through the south, to the west (*vide* p. 50); and, setting out with the principles that he has established, he deduces the following conclusions:—

1st. At the west of the card of winds, a cold succeeds a warm wind; at the east, on the contrary, a warm succeeds a cold: for the N.W. is colder than the west, and the S.E. warmer than the south (*vide* p. 159).

2d. At the west, the north wind, which is heavier, drives away the south, which is lighter. At the east, the south wind does not drive away the north wind so quickly; so that the barometer falls more frequently than it rises; but it rises faster than it falls.

3d. At the west of the card of winds, the elasticity of the vapour of water of the wind that follows is greater than that of the wind that precedes; it is the contrary in the east: the N.W. is not so moist as the west; the S.E. is more charged with vapours than the east.

4th. In the west, the cold wind blows in the lower strata, and is substituted, from below upwards, for the south wind that preceded it; in the east, the warm wind arrives from above, and is substituted for the cold wind from above downwards. At the same time, the velocity of the wind diminishes in the west, from the south to the north; and increases in the east, from the north to the south.

It follows, from these facts, that the number of precipitations of aqueous vapours (regard being paid to the relative frequency of the winds) is greater in the west than in the east; this is not merely due to the tension of the vapour of water, for it rains much more with the west than the S.E. wind, although the elasticity of their vapour of water is sensibly the same. In the west, as a cold succeeds a warm wind, and in the east, as a warm succeeds a cold, we can explain why it was said that the capacity for vapour increased in the east and diminished in the west. The rain will depend on the predominance of the moist or of the dry wind. The irruption of north winds in the west, and the gradual predominance of south winds in the east, cause that, at the west, there will be a sudden mixture of strata of air unequally heated; in the east, a slow substitution of one wind for the other. It is, therefore, between the south and the west that we shall have the greatest rain, and the least between the north and the east: for, on account of the rapid rotation from the south to the north, the differences of the temperature of winds that will mix in the west will be greater than those of the east winds; and, for the same reason, rains will rise more toward the north in the west region than in the other. But, as it is in winter that the temperatures of winds exhibit the greatest differences, there will be more rains in winter than in summer; and, at the same time, the rotation of the wind will be more rapid: in the N.E. it will snow more frequently than it will rain.

If an instantaneous mixture of winds is a favourable condition for the precipitation of aqueous vapour, it will follow that, during rain, the barometer ought to rise rapidly in the west, and fall in the east. The wind, it is true, does not pass regularly through all the azimuths of the card of winds; it frequently leaps in a contrary direction, especially in the west. But it follows, from what we have said, that in the west a change in the direction of the wind in an opposite direction to the normal rotation is rarely accompanied with a precipitation of aqueous vapours; in the east, on the contrary, the rare and exceptional changes in the direction of the rotation will be accompanied by rain: thus, with a rising barometer, we are more likely to see rain in the east than it will be observed in the west with the falling barometer. The rise of the barometer during the rainy wind will, therefore, be greater in the west than its mean rise for west winds. For rainy east winds, on the contrary, the fall will be less than the mean for east winds in general; but, on account of the normal rotation, these retrograde steps must be compensated by steps in advance. However, a retrograde range being much more frequent in the west than in the east, it follows that the fall of the barometer with west winds will indicate the approach of rain; because the wind must turn again to the north,—a fresh cause of rain in the west half of the card of winds. A continued rain is not a single precipitation, but the frequent repetition of the same phenomenon which the vane indicates, by turning constantly from the west to the S.W., and the barometer by continually oscillating.

M. **Dove** proved the accuracy of his anticipations on studying the Paris observations, for it follows from them that the barometer falls during rain with east winds, and rises with west winds. The observations at Stockholm lead to the same result. Taking as a starting point the wind that blows at 2 P.M., I determined the quantity that the barometer had risen (+) or fallen (—) every day from 6 A.M. till 9 P.M.; I calculated the same element for the days that preceded the rain, and constructed the following table:—

NUMBER OF MILLIMETRES WHICH THE BAROMETER DIFFERS FROM ITS HEIGHT AT 2 O'CLOCK, ON THE DAYS AND ON THE EVENINGS BEFORE THE DAYS OF RAIN AT STOCKHOLM.

| WINDS. | DAY BEFORE THE RAIN. | DAY OF THE RAIN. |
|---|---|---|
| | mm. | mm. |
| N. | +0,947 | +1,354 |
| N.E. | +0,135 | +0,993 |
| E. | —0,023 | —0,925 |
| S.E. | —1,128 | —1,467 |
| S. | —0,925 | —1,377 |
| S.W. | —1,602 | —0,609 |
| W. | +0,293 | +0,496 |
| N.W. | + 0,699 | +2,391 |
| Mean. | —0,203 | +0,383 |

(*Vide* Appendix, *fig.* 35.)

This table proves decisively that at a mean the barometer falls before rain, and rises when it has fallen; but at the same time, during east winds, with which the barometer falls, this fall is more rapid on the day of rain than on that which precedes it. Something analogous occurs with the fall for west winds.

The rapid rise which accompanies the rotation from west to north furnishes, according to M. **Dove**, a simple means of finding the direction of the rotation in a given place; ten observations with the N.W. are sufficient for this. When we confounded the phenomena of the west with those of the east, we always wished that the barometer should rise or fall before rain, and we were thus involved in an inextricable labyrinth of contradictions. When, during the conflict of the south and north winds that blow in the west semicircle of the card of winds, all the vapour in excess in the former is precipitated, then the N.E. wind that blows from a colder country to a warmer, and the capacity of which for the vapour of water incessantly increases, does not precipitate any aqueous vapour in the state of rain; and thus *fine weather*, or *very dry*, has been placed opposite to the point where the barometric column remains when this wind blows. If the barometer falls, we say it is going to rain; we ought to say, the south wind is going to blow again. If we understand by fall before rain, the time during which the wind is going from the N.E. to the east and south, then, without contradiction, the barometer falls before rain. But it is evident that this is connecting together two phenomena, which have no relation together, and the theory first given by **Leibnitz**, and then revived under so many forms, will be always incomplete, because, in the case of irregular or contrary rotation, the phenomena are opposite in the two semi-circumferences, the east and the west of the card of winds.

In comparing the range of temperature with that of the winds, and especially the range of the instrument from morning till evening with different winds (*vide* p. 162). M. **Dove** arrived at the following results:—

In the west semi-circumference of the card of winds, snow succeeds rain; in the other, it is the contrary.

Snow with west winds announces fresh frost, with east winds it precedes heat. The proverb, *fresh snow, fresh cold*, is true; for it snows more frequently with west than with east winds.

Would we apply these principles to accidental variations, they are thus explained: snow with a fall of the barometer is transformed into rain; rain with a rise of the barometer is transformed into snow. Snow with a rising barometer indicates a more rigorous cold; with a fall, a milder temperature.

It follows, also, that it cannot snow during severe cold; for, when the north wind becomes predominant, and drives away the south, there is no excess of water in the atmosphere.

A continued high temperature after rain announces fresh rains; for, in the east, it depends on the regular predominance of the south wind. In the west, it rises from a change in a contrary direction to that of regular rotation—a change which will be compensated by the return of the normal state, and which will consequently induce a fresh precipitation of aqueous vapour.

In the western half of the card the coldest wind blows below, as being the heavier; in the eastern half, the warmer gradually absorbs the colder from above downwards. With rain, the wind from below will, at a mean, have a greater barometric height than the wind above; so that the height of the barometer during rain will be less than the mean of the wind in general, since it is during rain that one drives away the other. The difference existing between the barometric height of a rain wind, and the mean height of the same wind, will depend on the barometric value of the winds, and on the rapidity with which they replace each other. In winter, the barometric differences of the winds attain their *maximum*, and their changes are very sudden; at this period, also, the difference between the rain mean of a wind and the general mean is as great as possible. In high latitudes, the aqueous vapour falls in the state of snow: it is with snow, therefore, that the barometer remains most below the general mean; but, if rain and snow fall during the same rotation in the card of winds, then the rain corresponds to the lesser height.

The substitution from below upwards of the colder for the warmer wind on the west side of the compass announces the simultaneous formation of clouds, their precipitation in the form of snow or rain, and a rise in the barometer. The wind often precedes the other phenomena; whilst, in the east, the formation of clouds precedes the wind. In the west, the formation of clouds occurs from below upward; in the east, from above downwards. When the clouds cease to form, as the north wind becomes predominant, they are said to tear up,—a phenomenon very different from the dissolution of the *cumulus*, which takes place on fine days when the ascending current begins to cease. Sudden formations of clouds belong to the west, where rapid mixtures are made; their successive developement occurs in the east: the *cumulo-stratus* is peculiar to the west, the *cirrus* to the east. The latter is a precipitation due to the intervention of a more south wind; the former, a precipitation determined by a cold wind penetrating into a warm air.

In our climates things frequently happen thus; however, on comparing the range of the barometer with the modifications of the atmosphere, we often observe a different succession in the phenomena. Let us not forget in the outset that the direction of the wind sometimes varies in points that are very near to each other; the barometric height is then attached to a wind to which it does not correspond. Moreover, we must not only take account of the temperature and the moisture of the mass of air that arrives, but also of the same elements in the air surrounding the observer. If this air is very moist, there will be a much greater probability of rain than in the opposite case. Such a relative state may prevail for whole seasons, to which it impresses its character. In this point of view, I may refer to the two summers of 1834 and 1838. During the former, the east winds prevailed, and it was remarkably warm.

Whilst the barometer was falling, the sky became covered with *cirrus;* then came thick *cumulus*, of a deep blue; rain seemed near at hand, and a storm was expected; but the vapours were soon dissipated in the atmosphere. This is especially the case if a few drops of rain have fallen, and the clouds, at the end of some hours, have disappeared. In the wet and cold winter of 1838, things went on differently. The S.W. winds so filled the atmosphere with vapours, that it was always saturated, and each change of wind, each oscillation of the barometer, was attended with violent rains. Scarcely were the clouds broken up when the moist sea-wind brought a fresh supply, without the east wind being at any time able to drive them away.

We should never lose sight of all these circumstances, when we wish to estimate the value of barometric oscillations. Add to this, that meteorological instruments only tell us what is going on in the place where they are situated. If we could know the mean heat, and the degree of humidity as well as the direction of the wind in all regions of the atmosphere, then we might foretell the weather with great certainty. A single example is sufficient to prove this. Suppose that, at the height of 1300 metres, the dew-point is at zero: if the temperature is only 1° above zero, there will ere long be formed several isolated clouds, that will be easily dissipated by the sun; if the temperature falls, on the contrary, to —1°, there will be rain. But at these heights there are much greater variations of temperature, even when the thermometer at the surface of the earth does not move. At present, we are in want of observations made on more elevated spots in order to prove this assertion by facts; for the small number of places on the Alps for which we possess series of any length are situated in valleys, where local currents change the direction of the general winds. A comparison of observations made during one year by an innkeeper who dwells at the Brocken (1140$^m$), with those at Halle, shews this most evidently. At a mean, the thermometer on the Brocken is 5°,84 lower than that at Halle; this difference, however, varies with the different winds. The differences of temperature are greater at Halle on those days when it rains or snows.

DIFFERENCES OF TEMPERATURE BETWEEN HALLE AND THE BROCKEN DURING DIFFERENT WINDS AND RAIN.

| WINDS. | GENERAL MEAN. | DAYS OF RAIN. |
|---|---|---|
| N. | 5°,78 | 6°,53 |
| N.E. | 5 ,70 | 6 ,10 |
| E. | 5 ,01 | 6 ,44 |
| S.E. | 4 ,51 | 4 ,86 |
| S. | 5 ,03 | 6 ,26 |
| S.W. | 6 ,24 | 6 ,36 |
| W. | 6 ,31 | 5 ,96 |
| N.W. | 6 ,62 | 6 ,03 |

(*Vide* Appendix, *fig.* 36.)

Many consequences are derived from this table. First, the difference of temperature between Halle and the Brocken is less by 1°,9 with east than with west winds; the decrease of temperature, therefore, is less rapid with east than with west winds: and this difference is about one-third of the difference of temperature between the two places. A consequence follows, which we have already pointed out. If we compare the relative moisture of east and west winds, we may believe, from hygrometric observations made in the plain, that the difference is not so great as the frequency of rains would seem to indicate. But with east winds the decrease of temperature is much slower; and, if the tension of the vapour diminishes in the same proportion, the temperature of the air during east winds does not approach so near the point of saturation as during west winds, and rain is less probable, even though the hygrometer in the lower strata should be near the point of saturation: this happens principally in winter. In 1838, during the months of January and February, the air was constantly saturated with the vapour of water, and yet there was not a cloud over the sky; but, in this case, the lower strata were so cooled by radiation, that on the Brocken the thermometer was sometimes 10° higher than at Halle.

We shall see presently that during rain the difference of temperature between the plain and the mountain is greater than the mean difference. Excepting with the S.E., which rarely brings rain, the difference is 5°,84 greater than the mean; and with this wind only the decrease of temperature is not so rapid as the mean decrease. Thus, every thing else being equal, rain is much more probable, as the decrease of temperature with the height is more rapid; and, if we knew this decrease, the indications of the barometer would be much more intelligible to us.[*]

Long series would put these facts beyond doubt. Indeed, as the decrease of temperature varies with the seasons, and even with the hours of the day (*vide* p. 211), I have taken for each day the winds prevailing at 6, 2, and 10 P.M.; I compared the means obtained for each wind with the general mean of the month. I did the same for the means prevailing during rain, and compared these with the general mean of the month during rain. The winter during which I made my observations was remarkable for the predominance of dry east winds. The decrease of temperature being thus slower than the mean, it is certain that the difference of temperature obtained is less than that which would be derived from several years of observations. The same remark for the west winds that prevail throughout the summer. Series of several years would enable us much more readily to set off the difference of the means relating to different winds and to rain; for certain winds have never been accompanied with rain in winter. Others have been constantly rainy in summer: thus, when accompanied with rain, their temperature is not very different from their general mean.

**OF THE BAROMETER DURING TEMPESTS.**—When the temperature is very high on one spot of the earth and very low on others, the equilibrium can no longer be preserved; a portion of the air passes away from the hotter to the colder regions, and the pressure is different in countries which are at a greater or less distance. These changes are rarely brought about without agitation: the air moves with velocity, and tempests are the result. The barometer oscillates and falls rapidly, and rises again in the same manner. These characteristic oscillations are made at short intervals; they are irregular, and should be regarded as a consequence of the inequality of pressure that gives rise to the tempest. What we have said concerning winds

---

[*] The observations made in the Alps and on the Brocken justify the law of a more rapid decrease of temperature during rain. The same facts have been established by the French commission in the very high latitudes of Europe, on the Tyvefield, latitude 70° 37′, height, 418$^m$), and on the Sloadberg, at Spitzbergen (lat. 77° 30′, height 560$^m$). The observations of aërial temperature in *the open atmosphere*, made at Bosekop, by means of kites and captive balloons, no less clearly indicate the same results.—M.

fully confirms this opinion. Continued tempests (for I am not speaking of those which last merely for a few minutes) are almost always preceded by great barometric oscillations, which as it were announce their approach.

These oscillations are not generally noticed, and the barometer is merely said to be very low. This law is not general. With us, the most violent tempests are brought with the S.W. wind, and the barometer then falls very quickly. It frequently happens that the wind suddenly ceases, calm follows, and, at the end of a brief interval, the wind blows violently from the N.W. and afterwards passes to the N.E.; the temperature falls; and, although the wind blows as strongly as in the former case, the barometer rises. I have often observed this, and particularly during the tempests of January 14 and 15, 1827. For several days the sky was cloudy, the winds blew from the west, and torrents of rain fell. On the 14th, clouds came from the S.W. with extraordinary rapidity; tiles were carried away from the roofs by hundreds; the rain fell, but the temperature continued becoming milder. In the night, the wind turned to the north; on the 15th, it blew from the north and the N.W., and the barometer rose very rapidly. The following was the height of the two instruments:—

HEIGHT OF THE BAROMETER AND THE THERMOMETER DURING THE TEMPEST OF JANUARY 14 AND 15, 1827.

| JANUARY. | HOURS. | BAROMETER. | THERMOMETER. |
|---|---|---|---|
| | | mm. | |
| 13 | 10$^h$ evening. | 748,78 | —0°,1 |
| 14 | 8 morning. | 738,49 | +3 ,2 |
| " | 10 " | 738,06 | 4 ,0 |
| " | 12 " | 736,05 | 4 ,5 |
| " | 2 " | 734,65 | 5 ,4 |
| " | 4 " | 731,88 | 6 ,2 |
| " | 6 " | 730,32 | 6 ,5 |
| " | 8 " | 727,48 | 6 ,6 |
| " | 10 " | 729,53 | 6 ,2 |
| " | 11 " | 731,20 | 6 ,2 |
| 15 | 8 morning. | 739,87 | 1 ,4 |
| " | 10 " | 741,94 | 1 ,2 |

(*Vide* Appendix, *fig.* 37.)

Nautical men, who have so great an interest in knowing the precursory signs of tempests, relate a multitude of cases of their connexion with barometric oscillations. **Krusenstern** attributed the success with which he always knew how to anticipate gales of wind to the constancy with which he observed the barometer; **Scoresby** affirms, that he predicted tempests, seventeen out of eighteen times, by consulting the barometer. My own observations shew that we should fear a gale, especially in winter, when the thermometer is high and the barometer suddenly falls. Often, when I had observed these two signs, the tempest was not violent at Halle, but it was let loose over other parts of Germany and Europe. I might relate a great many examples of this kind, but whoever possesses a barometer may observe for himself.

The want of simultaneous observations on a great number of points does not permit of our following this phenomenon into its details. When the air moves rapidly from one region to another, the barometer will fall in the former and rise in the latter. It is a wave that rises in one point and falls in another; but it would be no easy matter to determine its form, because we do not know how much each of these points is elevated above the mean of the sea. The observations made in Europe are not sufficient for the solution of the problem: falls of several centimetres often take place over the whole surface of Europe, and we must seek for the corresponding rise in Asia and America. Observers of antiquity, such as **Woodward**, **Wallis**, and others, had even found, that in west Europe the barometer fell or rose simultaneously; **Brandes** and **Pictet** afterwards confirmed this fact. But though the direction of the oscillations be the same over a great surface, their amplitude is not so; this is particularly observable when we are calculating the differences of level of two places by means of the barometer. Thus, at different periods I found differences between Berlin and Halle, which were fifty metres above or below the mean difference of level. The comparison of Halle and Paris has given still greater deviations. Let us, therefore, admit that the barometric pressure attains its *maximum* in any place, and continues diminishing along all the radii of a circumference, of which this point is the centre, disappearing at the distance of several hundred myriametres where the instrument is found to be above the mean of the place. **Brandes**, in his *Meteorological History for the Year* 1783, relates facts which confirm what we have said. He compared observations made in Europe, from Mafra, near Lisbon, to Torneo and St. Petersburg; and he saw, that the barometer fell in one point while it rose in a distant point. He recognised that these oscillations were accompanied by changes in temperature. The cold was very intense in the first days in January; but about the 5th it diminished rapidly in Germany and France. At Torneo and St. Petersburg, on the contrary, the thermometer fell; and in this latter town it fell on the 9th as low as —31°, during fine weather. Until this day, the barometer had constantly fallen in all parts of middle Europe. At Berlin, Sagan, Copenhagen, it fell 29 or $30^{mm}$; at Baden, Vienna, Prague, Erfurt, Göttingen, $24^{mm}$; at Wurzburg, $20^{mm}$; at Mannheim, $18^{mm}$; at Munich, $16^{mm}$; in Switzerland, $7^{mm}$. At La Rochelle, it remained at the mean height; at Marseilles and at Rome, it fell from the 6th to the 7th, and it then rose again until the 9th; at St. Petersburg and Torneo, where the thermometer had fallen, the barometer had risen $11^{mm}$ in the former town, and $16^{mm}$ in the latter. There was, therefore, a space included between Berlin, Sagan, and Copenhagen, where the relative heat attained its *maximum;* and it is from this centre that the height of the barometer continued increasing along all the radii. One portion of the air was displaced towards the north, which is much colder: this movement of the atmosphere extended beyond the limits of Europe. The same day, when the barometric pressure was so feeble in Europe, it was very strong at New York and at Ipswich in the north of America. **Beauchamp's** observations at Bagdad, in the interior of Asia, prove that the thermometer, in the morning of the 10th, fell there to —1°,2, and that the barometer, which from the 5th to the 8th had risen $9{,}62^{mm}$, attained its monthly *maximum*, and was $13^{mm}$ above the mean. Thus, then, at Ipswich, Bagdad, and St. Petersburg, the temperature had sensibly fallen; and we can understand that the more highly heated air of Germany would pass away from this coast and induce a rise of the barometer. There was, therefore, a warm region with a feeble pressure, and a cold region with a very strong pressure. Between these two regions every imaginable condition was found. If we place the limit at the spot where the barometer had preserved its mean height, and had not greatly oscillated, we may join these points by a line passing through La Rochelle, Marseilles, and Rome; then passing to the east of Hungary and to the north of Stockholm and Torneo, so as to form a reentering curve.

The masses of air, between which the equilibrium was thus broken, moved with great rapidity. On the evening of January 8, there was a violent gale in south Germany. At Ratisbon it lasted from eight till nine in the evening, and began again at ten. At Mannheim the tempest was felt in the night from eight till ten; it came from the W.S.W. On St. Gothard, and in Bavaria, the days from the 8th to the 10th of January were very stormy. At Prague there was a violent gale in the night from nine till ten; but the storm does not appear to have continued. At Sagan a violent wind from the S.W. blew from the 9th to the 11th of January; at Berlin the wind was fresh; but it became violent during the day of the 11th. At Göttingen, there was a great tempest from 8 in the evening. At Copenhagen, it appears that there was merely some wind about nine o'clock. In all these places the wind came from the west; at Marseilles, and on St. Gothard, from the N.W.; in the centre, and in the north of Germany, from the S.W. and the west. In Italy it was variable without being very violent. On the 8th and the 9th it blew strongly from the S.E. at Stockholm; from the east at St. Petersburg; from the N.W. at Spydberg, in Norway; from the west at Bagdad. In a word, says **Brandes,** it seemed that a strong pressure of the atmosphere at St. Petersburg and at Torneo, had determined in the north the establishment of a current coming from the east; whilst a no less powerful pressure in the south and west regions drove the air in the direction from S.W. to N.E., in order to compensate the feeble pressure existing in north Germany. All that we know respecting the formation of winds renders this explanation very plausible. This also explains to us why, according to **Scoresby's** observation, the tempest does not commence until the barometer has attained its *minimum*. As long as there is an ascending current in the neighbourhood of the ground, the thermometer falls; it does not rise until the lower currents arrive to fill the vacuum. These S W. winds bring with them a mass of vapours, which resolve into rain.

In the example that we have just seen, there was a sort of compensation in Europe between the different heights of the barometer. This does not always happen, and we often find great differences at the surface of our continent. This was the case on the 21st of December. Let us take another tempest of the year 1783. The barometer fell very low till the 9th of February, especially in the centre of England; thus, at Lyndon, in Rutlandshire, where it was lowest, it was 31$^{mm}$ above the mean. The region, in which it was 30$^{mm}$ below the mean, may be marked out by a line running from the west of Franecker, passing through

Amsterdam, and then through south Germany. The line, where it was at $29^{mm}$, is directed from Middleburgh to St. Malo. That, where it was at $27^{mm}$, leaves the south of Middleburgh, traverses Iceland, leaves Dunkirk to the north, and is directed towards Paris, and thence toward the centre of Britain. The zone, where the barometer was $25^{mm}$ below the mean, goes from Brussels directly toward the south, then to the S.W., by Orleans toward La Rochelle; that, where it was only $20^{mm}$ below the mean, goes from Göttingen to Mayence, to the north of Metz, to the south of Troyes, to the north of Limoges, and terminates in the direction of Bordeaux. At Copenhagen the barometer was $18^{mm}$ below the mean; and this zone is limited by a curve, which is directed toward the south of the coast of Erfurt, then to the S.W., toward Wurzburg, through Alsace, toward Lyon and the west Pyrenees. The barometer was $16^{mm}$ below the mean, in a region limited by a line joining Spydberg, in Norway and Stockholm, passing to the east of Berlin, going to the north of Ratisbon, to Munich, and to the south of Geneva toward Dauphiny. The barometer was $13^{mm}$ below the mean at the south of Sagan, at Prague, Ratisbon, on Mount St. Gothard, in certain parts of Dauphiny, and at Montpellier. It was $11^{mm}$ lower at Marseilles, and at Mont Louis, at the foot of the Pyrenees. Finally, at Buda and Padua, it was $9^{mm}$; at Mafra, $10^{mm}$; at St. Petersburg and Torneo, at Boulogne and Rome, $7^{mm}$ below the mean.

In Europe these variations are all in the same direction, but much more extensive the farther we go from the centre of England. **Brandes** notices that, on the 8th of February, the barometer at New York was 20 or $22^{mm}$ above the mean; and the observations at Bagdad shew that, from the 8th at noon to the same hour of the 9th, it rose $12^{mm},58$; a considerable quantity for this country. At the same time, the thermometer had fallen more than 10°, and the wind had turned to the north. In the greater part of the European countries only small oscillations of the thermometer were observed, but there were tempests, storms, and rain. After these tempests, the barometer rose very fast in Europe, whilst it fell at Bagdad, where the temperature rose without cessation.*

---

* During the violent tempest of January 7th, 1839, the barometer fell at Edinburgh to $702^{mm},30$; this *minimum* occurred at half-past five in the morning. At Altona, M. Schumacher proved that the *minimum* occurred between 9 P.M. and midnight; but it did not fall so low as Edinburgh: for at forty minutes past eight it was still at $716^{mm},8$. (*Comptes rendus de l'Acad. des Sciences*, t. viii. pp. 176 and 309. 1839.)—M.

The great depression of mercury observed in these cases, is due to the constancy of the south winds, which for some time predominate over those from the east. It occurs much more rarely after north winds. When, during its normal rotation, the wine suddenly turns from the south to the north, it often happens that a notable rise succeeds a very considerable fall. M. **de Buch** insists on this circumstance. "All they," says he, "who are in the habit of observing the barometer know very well that in winter the two extremes often occur, with but a few days intervening; and I think I have remarked that the barometer rises much faster than it falls." All the observations that I have compared confirm this fact, which is a necessary consequence of the law of rotation, discovered by M. **Dove,** and of the influence of the wind over temperature and pressure. Abundant rains are the consequence of these mixtures of air. If the north wind predominates, the clouds disappear, and the increase of pressure is accompanied by a very intense radiation, which determines cold. However, it is only when the barometer rises slowly that we must expect a continued cold: if the barometer has risen rapidly, it is not long in falling, but the second *minimum* is not so low as the first.

When the barometer oscillates much, we must conclude that the temperature and the weather will experience extraordinary variations somewhere on the globe. Although the lack of observations does not permit of our proving this truth in its minor details, it may be established in general terms. The years 1821 and 1822 offer a remarkable example of this. About Christmas, in the year 1821, the barometer in Europe experienced an extraordinary fall. It was followed by a very mild winter in Paris, and in the other cities of west Europe; the mean temperatures of January and February were higher by several degrees than the general mean. In the United States, on the contrary, the winter was very severe; the current of the *Gulfstream* was directed towards places which it does not usually visit. In Persia, according to **Fraser's** account, the winter was very cold; as it was also in Africa, where the plains of Kordofan were covered with a bed of snow, which disappeared, it is true, very rapidly. At Paris, the following summer was drier and hotter by several degrees than usual. But, whilst the dry winds regained their sway in Europe, moist and violent winds constantly blew in India; at Bombay, 83,7 centimetres of rain above the mean fell; and in Kordofan, also, the Turkish army suffered much from continual rains.

Something analogous occurred in 1824 and 1825. The terrible inundation of the Rhine in the autumn of 1838, the overflow of the Neva at St. Petersburg, the gales from the S..W., which, according to the observations of **Munke** and **Schubler**, took place in Schlesvig, and in all Holstein, are a proof of this. The barometer oscillated incessantly, and the rains were so abundant that every where, but principally in south Germany, springs burst forth in the streets and squares of the towns. In the same year the mean for the winter months was very high. In Iceland, on the contrary, according to **Thorstensen's** observations at Reikiavig, the mean of December was several degrees below the ordinary mean, and the barometer was very high, whilst it was very low at Copenhagen. This year, which was so rainy in Europe, was very dry in India; for at Bombay the quantity of rain was 118 centimetres below the mean. In Africa, it appears that there were violent gales; for, in the night of January 19th, 1825, the English ship, *Clyde*, being 100 myriametres from the coast of Africa, was covered with fine sand, which the east winds had brought from the desert. In east Africa, **Ruppel** experienced violent storms: phenomena which are very rare in these countries, as may be discovered from the fear of the inhabitants. **Ley** experienced the same thing in Upper Egypt. In the following summer, all the north part of tropical Africa was a prey to excessive drought, and the inundation of the Nile having failed, there was a complete dearth.

The same disturbances were manifested on the two shores of the Great Ocean. In California, there were violent tempests during the autumn, as there were also at the Sandwich and Philippine Islands. But the trade-winds were no longer blowing regularly over the sea. These facts prove that the anormal phenomena of Europe are not isolated, but are propagated over the whole circumference of the globe.

In order to demonstrate this truth, I will further relate the following observations. We know that the winter of 1829-30 was one of the coldest that had occurred in Europe for a long time; this same winter was so mild in America, that there was no ice on the west coast: which permitted Captain **Ross** to advance so far to the north.

The mildest winter that we have had for a long time was that of 1833-4, but it was preceded by violent disturbances. From the commencement of July, the S.W. winds prevailed in almost the whole of Europe. They were frequently of extreme violence, especially at the end of August and beginning of December; the journals were filled with news of shipwrecks on the coasts of France and England. In the Alps there were tempests; and such masses of snow and such quantities of rain fell, that the inhabitants were forced to take refuge in the plains with their flocks. From the beginning of September violent gales were experienced in the sea of the Antilles, and at Nova Zembla. In India, in Brazil, and Guiana, the drought was so great, that very many of the inhabitants died of hunger. In China, there were terrible inundations; but the swelling of the Nile was quite insignificant. The contest between the south and the north winds was renewed several times in the course of the autumn; the former always prevailed; and the wind rarely blew from the east for several hours together. Abundant rains fell in January; the rivers overflowed their banks. The south winds extended over to the region of the trade-winds; and ships were delayed in their voyage from France to Demerara. The thermometer rarely fell as low as zero; trees put forth their buds in the month of January, and many species remained in blossom throughout the winter: around Halle, I observed the *Lamium purpureum*, several species of *Crepis* and the *Thlaspi arvense*. But we shudder on reading the description given by Captain **Back** of the cold he endured in his expedition across the north countries of North America. In the United States, and in Persia, the winter was also extremely rigorous. During this conflict of land and sea winds, the barometer in Germany did not deviate much from its mean height; but it oscillated considerably. The weather was rough and disagreeable, and quite in contrast with the mild temperature of the preceding winter. Finally, the east winds predominated: the sky became serene, and the sun was able to warm the earth. It seldom rained; and there was a general drought throughout Europe. Meanwhile, the west winds several times strove to obtain the sway in the atmosphere; but, during the contest, there were violent storms, such as those of the 5th and the 21st of July. On the 21st of July, the barometer began to fall; the sky was still of great purity, because these south winds dissolved all the fogs; but, on the morning of the 21st, the *cirri* began to multiply. In the afternoon, a violent storm formed: west winds prevailed above; in the lower strata, all the vanes indicated an east wind. Thick clouds extended from the west to the east, whilst all the *cumuli* moved from east to west. In proportion as the west wind gained the lower levels, the vapours were precipitated; but the east wind incessantly drove them back. The storm was accompanied with hail and rain. This contest took place in a straight line that passed above Halle, and was directed north and south; for several days this contest was renewed, and its issue was uncertain.

But, like as currents of waters, flowing in opposite directions, produce whirlpools, so there were in this case very abundant local showers. Finally, on the 26th of July, the east wind obtained the mastery at Halle, and drove back its antagonist. On the 27th, the barometer rose; the weather again became fine, but in the evening there were violent storms on the borders of the Rhine. On the 29th, Holland and the north of France were the theatres of this contest, and, on the 30th, a violent storm burst over England. For the space of a month the east winds maintained the weather fine, and obtained the mastery in a contest that had commenced in the Alps on the 25th of August, and, by the 27th, was propagated as far as the north of Germany. They then prevailed without interruption until the middle of October, when the west winds prevailed in their turn, after gales that had lasted several days, and changed the physiognomy of the weather. Whilst in Europe the summer was remarkably dry, the swelling of the Nile was considerable, and violent storms inundated India and China.

Such contrasts are not uncommon in Europe, and, in this respect, the Alps often form a remarkable limit; for they separate the climates of the north of Europe from the Mediterranean climates, where the distribution of rain is not the same as in the centre of Europe. Hence the differences between the climates of the north and south of France. If the winter is mild in the north, the newspapers are filled with the lamentations of the Italians and the Provençals at the severity of the cold. Not to multiply examples to no purpose, I will simply allude to the first months of the year 1838, which were so rigorous in Germany, France, England, and Russia. At Lisbon, on the contrary, the weather was rainy, but very mild; at Marseilles, the almond-trees were in bloom in the month of January; at Naples and at Algiers, the winter passed unperceived. But this proves that the Mediterranean climates alone were privileged; for, on the other side of the Apennines, at Bologna, and in Lombardy, where the climate resembles that of the rest of Europe, the cold was very intense.

Thus, then, a great fall of the barometer, or frequent oscillations of the column, prove that there are meteorological disturbances on the surface of the globe, and conflicts of opposite winds, which change the weather. Further, when the barometer rises and falls rapidly, we may affirm that the weather will be variable for a long time. If we knew the weather that prevailed on the rest of the globe, we might conclude that which could be expected. We ought to know, when the barometer is low, whether the cold is very intense in America or in Asia. In the first case, the west winds will bring rain; in the second, the east winds will bring cold. However, on studying in the spring the barometer and the direction of the gales of wind, we may establish certain probabilities. If the barometer has fallen considerably during S.W. winds, and then rises slowly; if the wind passes from the west to the N.W., and remains in that direction; it is a proof of the predominance of west winds, and the weather will be influenced by them: we saw this in 1833. If the barometer, on the contrary, rises very quickly, and if the wind passes in a short space of time from the S.W. to the N.E., where it stops, we may expect a prolonged cold, like that which prevailed in 1829.

# VI.

# ELECTRICAL PHENOMENA

# OF

# THE ATMOSPHERE.

THERE are few men on whom thunder does not make a lively impression; the learned and the ignorant are equally struck with the grandeur of this phenomenon. The people whom the Europeans have discovered in past centuries regarded it as the sign of celestial anger, as did the Greeks and Romans. Also Jupiter Tonans was the greatest of the pagan gods; and in the Bible it is said that thunder is the voice of the angry Lord. Some philosophers of antiquity disputed this opinion; but this prejudice remained: and even in the present day we hear sermons in which the thunderbolt that falls on a house is considered as a punishment deserved by its inhabitants. Some ancients considered thunder as produced by emanations arising from the earth. This idea was adopted by many learned men; and, although **Aristophanes** ridiculed it in his comedy of *The Clouds*, yet the fear of the gods always served to weaken it in proportion as the doctrine of **Epicurus** was the more spread. This opinion still existing at the epoch of the revival of the sciences, thunder was compared to the explosion of a piece of artillery; and it was pretended that saltpetre and sulphur exist in the atmosphere. But, in the middle of the seventeenth century, **Otto de Guericke** having produced an electric spark, and observed the power by which it is accompanied, more legitimate ideas of it were conceived.

The philosophers of this epoch were for the most part occupied with the laws of mechanics, and the knowledge of electric phenomena made little progress. But the invention of the Leyden jar, in 1746, led back the attention to the powerful effects of electricity. **Nollet** ingeniously points out the analogy between thunder and electricity, to which Dr. **Paccard**, of the valley of Chamouni, who followed his lessons, had drawn his attention. "If any one," said he,* "after comparing the phenomena, undertook to prove that thunder is in the hands of nature what electricity is in our own; that those wonders, which we now dispose of as we wish, are trifling imitations of those great effects which terrify us; that the whole depends on the same mechanism; if he should shew that a cloud prepared by the action of the winds, by heat, and the mixture of exhalations, is, in respect to a terrestrial object, what the electrised body is when in presence and at a certain distance from the one which is not so; I acknowledge that this idea, if it were well maintained, would please me much. And to support it how many specious reasons present themselves to a man well skilled in electricity! The universality of electric matter, the speed of its action, its inflammability, and its quickness in igniting other matters, the property which it has of striking bodies exteriorly and interiorly to their smallest particles, the singular example we have of this effect in the Leyden experiment, the idea may lawfully be maintained by supposing a greater degree of electric fluid, &c.; all these points of analogy, which I have considered for some time, induce me to believe that we might, by taking electricity for a model, form more enlightened and truer ideas concerning thunder and lightning than any we have hitherto imagined."

What **Nollet** and **Winckler** expressed as a matter of doubt was soon demonstrated by **d'Allbard** and **Franklin**. It was discovered that storms, and even every shower, is accompanied by electricity. They varied and multiplied experiments; but, after **Richmann** was killed by lightning, they proceeded with more prudence. Before describing the apparatus and analysing the electric phenomena, I think we should call to mind the elementary principles of the theory of electricity.

**ELECTRIC ATTRACTIONS AND REPULSIONS.**—The effects of electricity developed by friction may be easily studied with glass or resin. If we rub sealing-wax or glass with cloth, or rather with leather spread with an amalgam

---

* Leçons de Physique, t. iv. p. 314, 6th edition, 1771.

of mercury, then light bodies, such as hair and feathers, may be attracted from a certain distance.* But, the better to understand the repulsive force of electricity, it is a good plan to suspend a small piece of cork or elder-pith to a thread of silk-worm's silk, and to fix the upper end with a portion of sealing-wax. Silk, resin, glass, and other bodies which produce electricity by rubbing, easily retain electricity on their surface, whilst metals, water, and all damp bodies, let it pass away freely. These last-named bodies are called *conductors* or *anelectrics;* the others, *insulating* bodies, *non-conductors*, or *idio-electrics.*

The small suspended ball will be projected with vivacity against a stick of resin previously rubbed; then it will recede after having touched it, and it will be repelled as soon as the stick of resin is brought near it. The same phenomena occur if we use glass instead of resin; and we thence conclude, that bodies which are reciprocally electrised by contact repel each other. The same thing happens when they have obtained electricity from the same source. Fasten two smooth and flexible wires to a stick of sealing-wax, and attach to the extremity of each of them a small ball of cork. If the two balls touch each other, when they are in the natural state, they will recede the one from the other as soon as they have been electrised by a stick of sealing-wax, and will fall back on each other as soon as they are touched by the hand, because the electricity which was communicated to them by the resin is conducted by the body into the earth.

These experiments exhibit another interesting peculiarity. If the little ball has been in contact with the resin, and is repelled by it, it will be attracted more strongly by the glass than if it had not been in contact with the resin; then, if it touches this glass, it will be drawn back and attracted anew by the resin. The same results if the experiment had been made in an inverted order: if we bring near a ball, thus electrised by resin or glass, any electrised bodies whatever, we shall always find that they will attract or repel it. But we see, that those which attract it when it is electrised by resin repel it when electrised by glass, and reciprocally. Thus the electricity of glass and resin have the common character of attracting and then repelling light

---

* In damp weather, cloth which contains cotton may lead to error. If we lightly rub a stick of gum lac, covered over with the film of moisture that the air has deposited on it, the sign will be positive instead of negative. It is only by continuing the friction that negative electricity can be obtained.—M.

bodies; but the fact we have just enunciated obliges us to admit two kinds of electricity, of which the one attracts what the other repels.

Several hypotheses have been proposed to explain these two phenomena: two have been adopted by philosophers. In the one, two different electricities are admitted, which are represented as fluids: the one is developed on glass when rubbed, and is called *vitreous* electricity; the other, on resin, is called *resinous* electricity. In every non-electrised body, each of them is equal in quantity in each molecule; they mutually attract each other, and do not manifest their presence externally, because the one attracts what the other repels. But, if we rub certain bodies together, then there is a separation of the two fluids. The one is in a greater quantity than the other in the former of the two bodies, the other in the latter; and they manifest their presence externally. If the two bodies are isolated, as in certain electric machines, the experiment always shews that one of the bodies is vitreously electrised, the other resinously.

In the second hypothesis, which is due to **Franklin,** there is but one electric fluid. Every body in nature possesses a certain quantity of it, and it is then found in its natural state. Friction changes this state, inasmuch as one of the bodies gives to the other a part of its electricity. Thus one possesses a superabundant quantity, the other has less than its proper share; or, as we frequently say, the one has a *positive* electricity, the other a *negative:* an expression synonymous to *vitreous* and *resinous* electricity, which we shall sometimes designate by abridged notations, +E. and —E.[*]

Experiment cannot decide between these two hypotheses, which equally explain the facts observed; and a discussion on their respective merits would be reduced to a dispute of words. Let us simply add, that it is

---

[*] Modern physics lead to a third theory, in which electric phenomena are considered as the result of particular modifications in the imponderable fluid which fills space, and which we call *ether*. We know that, since the discovery of interferences, and the labours of Young and Fresnel, light is no longer considered as the produce of an emitted substance, but as the result of an oscillating movement of the molecules of *ether*. The works of Professor Melloni lead to the same consequences for heat. In his *Traité sur l' Electricité*, M. Becquerel has often made use of expressions which indicate his tendency to admit certain vibratory motions, in this same *ether*, as being the cause of electric phenomena. In fine, M. Peltier has distinctly laid down the idea, that the electric phenomena are not owing either to one or to two special principles, but to two particular states of one and the same principle. Having completely separated the static from the dynamic phenomena, by demonstrating these completely opposed actions (*Annales de*

easy to distinguish the two sorts of electricity. If we approach to a ball of elder pith, previously electrised, a stick of resin that has been rubbed, it will possess negative electricity if the stick repels the ball; if the ball be attracted, it is because it contains positive electricity. In the case of the attraction, it is better to repeat the experiment with rubbed glass, to see if there be any repulsion.

**ELECTRICITY BY INDUCTION.** — Conducting isolated bodies may be directly electrised by contact, like the pith ball; but another way exists of destroying the equilibrium of the two fluids to a body in the natural state. If the latter has the form of a cylinder, such as a stick covered with gilt paper, and if we hold, at the distance of several centimetres, a rod of glass previously rubbed, it will give unequivocal signs of electricity, which will be more energetic as the glass rod is approached nearer; but which will disappear as soon as we withdraw it. If we study the nature of the electricity of the cylinder, electrised by the influence of the glass (+E), we shall find —E at the end nearest the glass, and +E at the opposite extremity. Each of the two electricities diminishes as we pass from the extremities towards the middle part, where there are no more signs of electricity. On using a rod of resin, previously rubbed (—E), the same results might be obtained; but then the cylinder would have had +E at the end nearest the resin, and —E at the opposite extremity. The effects which sometimes take place in the clouds are only a consequence of what we have seen. Indeed, the two electricities exist, in each molecule of the cylinder, in an equal quantity; but as soon as we bring near it a glass rod that has been rubbed, its positive electricity decomposes the neutral electricity of the cylinder; it attracts —E, which is concentrated at the nearer extremity, whilst it repels +E, which is accumulated at the other end. As soon as we with-

*Chimie et de Physique*, t. 67), he has thence deduced that the former are, and could only be, the result of an unequal distribution of the ethereal substance itself in the bodies; and the latter only the product of the propagation of this *ether* between the molecular interstices of the conductors, in order to re-establish the equilibrium between the body which possesses the most of it and that which possesses the least. From the action of burning bodies, which always give the *resinous* sign to the substances with which they combine, from the constant presence of ponderable matter in all electric phenomena, and from the powerful *resinous* tension of the terrestrial globe, he has concluded that the *resinous* state is indication of a greater coercion of the *ether*, and that the *vitreous* state is a lesser coercion than in the natural state. The words *negative* and *positive* being contrary to the phenomena such as he considers them, he prefers the words *resinous* and *vitreous*, as more insignificant.—M draw this glass rod the two electricities unite, and become neutralised.

We should have had the same phenomena, if instead of glass we had taken a metallic sphere, isolated and electrised by induction. In this case the experiment shews that the electric force varies according to different circumstances. If the sphere is withdrawn from every conducting body, then each point of its surface possesses the same quantity of electricity; but, as soon as we bring it near to the cylinder, the equilibrium is destroyed, the electricity accumulates on the portion turned towards the cylinder, and diminishes in intensity, radiating from this centre. The nearer the cylinder is to the sphere, the more the intensity increases; because the electricity of the sphere, by attracting the electricity of the contrary name of the cylinder, is attracted by it in turn, and accumulates in a greater quantity in the corresponding point.

Things being thus arranged, if we leave the cylinder and sphere in their relative positions, but connecting the extremity of the cylinder that is farthest from the sphere with the earth, then the part of this sphere near the opposite end will be charged with a still greater quantity of electricity. If we destroy the communication between the cylinder and the earth, then we may deprive the sphere of all its electricity, and the cylinder is charged on the whole of its surface with the electricity, which was developed at the extremity turned towards the sphere. If the sphere had +E, it would strongly attract —E at the nearer extremity of the cylinder; but this attraction was weakened, because + E of the other extremity attracted — E of the cylinder, and repelled + E of the sphere. But, as soon as this extremity has been brought into connection with the earth, then + E flows into the ground; + E of the sphere, and — E of the cylinder, can then act on one another with more energy. If + E of the sphere is taken away, then — E of the cylinder remains on its surface, because + E has flowed away into the earth.

These effects always occur, whatever be the form of the two bodies placed in juxtaposition. Take, for example, large metallic discs, and suspend them at a certain distance from each other; place the lower one in connexion with the earth, the upper one with a source of electricity: the lower one will have its upper face charged with a strong proportion of electricity, of a contrary sign to that of the upper plate. This experiment enables us to accumulate a great quantity of electricity in a conductor, and to retain it there for a long time; for, if we leave an insulated conducting body to itself, we find that the electricity, which has been communicated to it, always becomes weaker, and finally disappears entirely; and the faster in proportion as the air is damper and the barometer lower. Dry air is an insulating body, but the mobility of its particles diminishes this property; indeed, the electrised body attracts a molecule, electrises it, then repels it; it, therefore, carries off a small quantity of electricity. This effect, on being often renewed, finishes by restoring the conductor to the neutral state. The effect is still more rapid if the air be damp; for the vapour of water conducts the electricity, and diminishes the action of isolating supports by depositing itself on their surface. It is for the same reason that a conductor can only borrow from a constant source of electricity a given quantity of fluid. If we turn the plate of an electric machine, the quantity of electricity increases rapidly on its conductors; but at the end of a very short time it reaches its *maximum*, and it is in vain to turn, there is no further augmentation. It is because the air carries off from the conductors every moment as much electricity as they receive.

The phenomena due to electricity by induction prevent the loss of electricity. In the experiment of the two discs suspended over one another, + E acts on — E with such energy, that the effect of the aërial particles is much weaker, and the loss much less. Let us bring to the *maximum* the electricity of a plate joined to the electric machine, then let us hold for some time the other disc below it; if we measure comparatively the electric tension after having withdrawn the lower disc, we shall find that it has become stronger: the pressure of the lower disc restrained it, that is to say, prevented it from acting without,—an effect which is reproduced as soon as we have taken it away.

The phenomena of which we have just spoken shew themselves every instant in the atmosphere. A cloud charged with electricity acts by induction, not only on other clouds, but even on the earth; to the surface of which it attracts electricity of a contrary name. It is also on these principles that all the apparatus rest, which we use to measure the atmospheric electricity. These effects not only take place when the two bodies are separated by an insulating bed of air, but even when idio-electric bodies, such as resin, or glass, are interposed between them. The insulating bed formed of the idio-electric bodies need not be so thick as that of dry air, and the electricity produced by induction is stronger in proportion as the insulating body is thinner. The construction of the Leyden jar is founded precisely on this property.

**ELECTROMETERS.**—These instruments serve to recognise and to measure atmospheric electricity. That of **Volta** is composed of a glass jar, surmounted by a metallic rod, which passes into the jar, and carries two straws freely suspended, a very fine metallic wire passing through a hole. It is good sometimes to choose for these straws portions of certain light stubble, furnished by species of the genus *Poa* or *Agrostis*. As soon as the straws are electrised, they separate. A scale is pasted on the side of the glass. In **Volta's** electroscope the divisions were at the distance of a millimetre. When the electric tension is very strong, as in storms, this instrument is not good; we then prefer a less sensitive electroscope, in which little pieces of wood are used instead of **Volta's** straws. To render these instruments comparable, they are made to communicate with the same source of electricity; and the respective deviations that take place, when equal quantities are communicated, are measured.

To study the electricity of the clouds, **Franklin** was the first to employ the electric kite. He fastened a common kite to a ball of pack-thread, either wetted, or containing a fine metallic wire; when the kite rose, he placed the ball of thread in connexion with an electrometer. This experiment is very dangerous; it is better to employ insulating conductors, which are fixed on the roof of a house or to a glass rod, the electric state of which is then studied by the aid of the electrometer.* According to **Volta**, an iron wire two metres long, held vertically, perfectly fulfils the end proposed. If a positive cloud, for instance, is formed above the rod, it is negatively electrised at its upper extremity, and positively at the lower. To measure the tension at one of the extremities, it is sufficient to discharge the lower extremity and to examine the electric state of a ball situated at the other extremity; this electricity will always have a sign contrary to that of the atmosphere. **Coulomb,**

---

* FRANKLIN, in his excellent work on the influence of points, had indicated the means of investigation which he proposed using to study the electricity of the clouds; but it was in 1752 that D'ALIBARD was first to mount at Marly-la-Ville a fixed apparatus, with which he drew forth sparks from a storm cloud, and it was ROMAS who first sent up the electric kite, in the same year. See the translation of FRANKLIN'S *Letters*, by D'ALIBARD, 2d edit. t. ii. p. 99, and that of BARBEU-DUBOURG, 1st part, p. 105; the *Mémoires des Savants Etrangers de l'Acad. des Sciences de Paris*, t. ii. p. 393; and finally, FRANKLIN'S *Letter* to COLLINSON, on 29th July, 1750, and that of 19th October, 1752.—M.

and all other philosophers, have had recourse to this process. It is better to terminate the rod in a point, which will allow the electricity with which it is charged to escape; the lower extremity will then preserve the same electricity as that of the clouds. The flame of a piece of tinder, or a lock of flax, or a brimstone match, or a spirit of wine lamp, placed on the extremity of the rod, favours still more the electric radiation, and the quantity of electricity becomes more considerable in the lower extremity.[10] To discover the nature of the electricity, we bring near to the electrometer a rod of resin that has been rubbed: if the parts recede further, they are charged with negative electricity; if they approach each other, they contain positive electricity. I prefer **Bohnenberger's** electrometer, which indicates more surely, and more quickly, the nature of the electricity.

If, in an open plain, or on the top of an elevated edifice, we make experiments of this kind, we almost always obtain signs of atmospheric electricity; but, if the observer be surrounded by objects which are higher than he is, then he does not obtain any electric sign: in this case, he must employ the condenser devised by **Volta.** Above the metallic rod which bears the straws a disc of copper is fixed, of from four to six centimetres in diameter, perfectly smooth, and having its upper surface coated with a varnish of lac; a second disc is coated with a similar varnish, and surmounted by a glass rod. Let us suppose that space is charged with a very weak positive electricity; this will not be able to diverge the two straws, because the electricity is distributed in its course along the metallic rod. But if we place these two discs on one another, making the upper one communicate with the earth, this will be negatively electrised (—E) at its lower part, and will fix the positive electricity (+E) of the electroscope on the upper part of the lower plate; then the instrument will be able to receive a fresh quantity of it through the rod: if afterwards we lift up the upper plate, there will be a very strong divergence of the two straws.

**Volta** has described this process in detail in his *Lettres Météorologiques;* and M. **Colladon** shews that we may use with advantage the deviation of the magnetic needle produced by electric currents. This method appears to me preferable, when we observe with a fixed apparatus. M. **Peltier** was

---

[10] *Vide* Note *i*, Appendix, No. II.

the first to construct an apparatus of this kind, capable of giving rigorous results; M. **Becquerel** has minutely described it in his work on electricity.[*]

**CAUSES OF ATMOSPHERIC ELECTRICITY.** — After having discovered that storm-clouds were highly charged with electricity, it was perceived that rain was almost always electric,[11] and that there was electricity in the air, even during the calmest weather; and the question of its origin presented itself. Friction was then the only known productive cause of electricity; it was thought that that of the atmosphere proceeded from the friction of masses of air against one another. Notwithstanding the objections of several philosophers, I do not think that this cause is completely null: when we shake in the air a piece of silk, it is electrised; why then should it not be the same with two masses of air? If the temperature, moisture, &c. of the two masses are the same, there will be no production of electricity, in the same way that there will be none if we rub two perfectly similar rods of resin together. But, as soon as one of them becomes warmer than the other, the cooler becomes positive, the warmer negative: a law verified for all bodies of the same nature when rubbed against one another. Thus, then, the upper masses of air would be positive, the lower ones negative.[12]

Chemical actions, which are constantly taking place in the atmosphere, are infinitely more powerful; we shall place evaporation in the first rank. **Volta** first shewed that evaporation produced electricity; **de Saussure** confirmed this opinion. But M. **Pouillet** has described the details and conditions of the phenomenon. Pure and simple evaporation does not produce any electricity, provided there be no chemical decomposition: if distilled water evaporates on platinum plates, there is no production of electricity; but if we add portions, however small they be, of salts, acids, &c., then there is a production of electricity as soon as the vapour of water is separated from the bodies to

---

[*] M. PELTIER has since devised a new electrometer whose indications are much more extended, and the reading more certain, than in the usual electrometers. Independently of the differences in its form and index-needle, the rod of this instrument is not terminated by a point; it is, on the contrary, surmounted by a ball of polished metal. It is by means of these ball electrometers that he has endeavoured to shew that the atmosphere has no electricity of its own, that it yields nothing to the instrument; that it is the terrestrial globe, which is a body permanently charged with *resinous* electricity, which acts on the instrument by induction, when it is raised and lowered. (Vide *Annales de Chimie et Physique*, 3d series, t. iv.)—M.

[11] *Vide* Note *k*, Appendix, No. II.

[12] *Vide* Note *l*, Appendix, No. II.

which it was united. The vapour is positively electrised, the vessel negatively; now, as the earth incessantly emits vapours, and the water in nature always contains foreign substances in solution, the vapours rise charged with positive electricity, whilst the earth preserves negative electricity.[13]

Combustion is another productive cause of electricity. When coal is burning, a current of carbonic acid escapes positively electrised, whilst the coal remains negative. The atmosphere, therefore, contains all the electricity that results from combustions made on the surface of the earth. Indeed, when plants spring up, the carbonic acid they exhale carries off the positive electricity, whilst the vessels through which the gas escapes remain charged with negative fluid; the same thing probably takes place during the life of the plant, from whence results a great proportion of the positive electricity which vegetation pours into the atmosphere.

**ELECTRIC LIGHT.** — When two fluids of contrary names unite by passing over a badly conducting body, there is a production of sparks if they are in a sufficient quantity. They may even be observed when a rod of resin is rubbed in the dark, and touched by the finger; with the electric machine and other energetic apparatus, the phenomenon is still more evident. If the spark crosses the air, we hear a dry noise, the intensity of which is in general in proportion to that of the light.

Without entering further into details on the nature of this spark, I will content myself with a few remarks which apply to thunder. The more intense electricity is, or, in other terms, the more electricity there is passing through the air in a given time, the whiter and more dazzling is the light. The light which escapes from the obtuse extremities of the machine is reddish and violet; it only becomes white on a point where it is more concentrated. In the same way, the spark from a Leyden jar is of a dazzling white. If in the vacuum of an air-pump we place two bodies between which an electric spark is made to pass, the latter will appear under the form of a violet light, whilst it is white and circumscribed in air that preserves its habitual density. Between storm-clouds that are near the earth, the sparks are of a dazzling white; storms, on the contrary, which are at a great height in the atmosphere, cast forth reddish or violet lightnings.

---

[13] *Vide* Note *m*, Appendix, No. II.

When the tension of the two electricities which unite is considerable, the spark does not always follow a straight line; this is even seen in weak machines, where it often divides and moves in a zigzag. If a little ball is fixed to the conductor of a machine, and the hand be held open at a certain distance, then it is often struck by ramified sparks: slight differences in the constitution of the air, particles of dust, which are often found on the path of the spark, are the probable causes of its division. It is the same with lightning during a violent storm.

**ELECTRICITY DURING SERENE WEATHER.**— When the sky is clear and without clouds, a sensitive instrument placed in an open place almost always indicates positive electricity; it only becomes negative in the case where there are distant storms. But this positive electricity varies in intensity; passing clouds, puffs of wind, modify it in a few seconds. The causes of these changes have not been as yet sufficiently studied. If we always observe at stated hours, we find in our countries the existence of a curve, the elements of which **de Saussure** and **Schubler** have endeavoured to determine.

At sunrise the atmospheric electricity is feeble; it continues to increase as the sun rises and the vapours are collecting in the lower regions of the atmosphere. This increasing period lasts in summer till 6 or 7 o'clock in the morning; in the spring and autumn, till 8 or 9; and in winter, till 10 or 12 o'clock in the day. By degrees the tension attains its *maximum;* during this time the lower regions are filled with vapours, the humidity of the air increases, and the hygrometric tension is stronger than in the morning; in the cold season there is often fog. Generally electricity decreases immediately after attaining its *maximum*, at first rapidly, then more slowly. The visible vapours of the lower strata disappear, the fogs disperse, the atmosphere becomes clear, and distant objects seem to approach the spectator. Towards 2 o'clock in the afternoon, the atmospheric electricity is very feeble, and scarcely stronger than at sunrise. It continues to diminish till about two hours before sunset; in summer, till 4, 5, or 6 o'clock in the evening; in winter, till 5 o'clock. Its *minimum* lasts longer than its *maximum*. As soon as the sun approaches the horizon it again begins to advance, increases sensibly at the moment of sunset, goes on increasing during twilight, and attains a second *maximum* an hour and a half or two hours after sunset. Then vapours form in the lower regions of the air, damp increases, and the night-dew falls. This second *maximum* usually equals that of the morning, but it continues a shorter time, and the electricity decreases slowly till the next morning.

It is desirable to multiply this kind of observation in such a manner as to possess series comprising several years, in order that we may know the relation which exists between these indications and those of other instruments. I have begun series at different periods, but the unfavourable situation of my house, and other circumstances, have prevented my continuing my labour. The results obtained at Halle have, however, appeared to me to differ from those found in south Germany. It is the same on the mountains. But observations on the Alps seem to shew that there is but one *minimum* in the morning and one *maximum* in the evening.

Besides the diurnal period, there is also an annual period. Positive electricity in serene weather is much stronger in winter than in summer, and varies in a regular manner in the interval which separates these two seasons.

The want of prolonged observations does not permit me to point out the cause of this difference. The vapours which are incessantly rising from the lower regions take with them into the elevated regions a considerable quantity of positive electricity, the presence of which is shewn by the instrument. We may, however, ask ourselves if the changes we observe in the lower have really a range agreeing with the mean state of the upper strata. Experiment shews us that positive electricity becomes stronger as we rise higher in the atmosphere. The absolute height, and the absence of all shelter, have a great influence: thus **de Saussure** did not fear to say that we should have as strong an electricity on a plain as on the top of a mountain, if we were not surmounted by surrounding objects. Two conditions modify the indications of our instruments: they are the electricity of the air, and its insulating power.

Let us suppose, for greater simplicity, that the air on the surface of the earth does not possess electricity, and that we find only at a certain height an aërial stratum, which gives signs of electricity: it is, therefore, as though an electrised body were suspended above the earth; this body acts downward, by contact and by induction. Which of these two modes of action is it that has the advantage over the other? This is a point difficult to decide. Perhaps both have equal influence; but when the sky is clear, as in the present case, it is the mode by induction which is the more powerful. The positive electricity of space attracts negative electricity into the point of the metallic rod; positive electricity is repelled into its lower part, and, as the former passes away, the latter gives signs of its presence. Let us suppose that the electricity of the vault of the sky always preserved the same intensity, but approached the earth; then, surely, the electricity produced by induction on the electrometer would have a stronger tension: but, at equal distances, the insulating action of the air, which is not the same, would produce an analogous effect. Let us call to mind the experiments of the electrical machine: the distance of two bodies not being changed; the electricity produced by induction is the more energetic when the two bodies are separated by a stratum of air; but bodies that are bad conductors, such as glass and resins, without being so thick, determine a tension equally strong. These experiments clearly shew, that at equal distances we obtain different tensions, according to the insulating power of the interposed bodies. It is very possible that experiments made in the same place, but in different thermometric and hygrometric states, would give very unequal tensions, even though the distance should still remain the same. With a dry air, which insulates very well, the tension will be less than in damp weather.

The same thing probably takes place in the atmosphere. The force of the electricity of high regions remaining the same at equal distances, that of a contrary name, which is attracted in the earth, will increase or diminish as the air is damp or dry; and the observer would be wrong to conclude that that of space has increased or diminished.

The hypothesis we have formed is never completely realised in nature: for, as vapours are incessantly rising, and, vegetation being in activity during a part of the year, the earth is in a negative state, whilst the atmosphere is positive. Each aërial particle equally possesses positive electricity; but the influences of the earth, and those of the upper strata, decompose the two electricities of the particle, which will be charged at its lower part with a little more positive electricity than at the upper. This renders the question of the increase of electricity with the height singularly complicated. All the particles act on the rod which surmounts the electrometer, but their action diminishes with the distance, and is much less energetic as the air insulates better. What the observer regards as an effect of the upper strata is often owing to the action of the strata scarcely elevated a hundred metres above the instrument.

I have thought it necessary to consign these remarks to this place, for a greater degree of importance is often assigned to the indications of the electrometer than they really possess. If, then, we endeavour to explain the diurnal and annual variations of electricity, we must not lose sight of the hygrometric state of the air. After sunrise, evaporation begins with the increase of temperature; a multitude of vapours, charged with positive electricity, rise in such a manner, that a greater number of electrised bodies are found in the lower strata than during the night. But the quantity of vapour of water contained in a cubic metre of air principally increases in the lower strata, and, as the air is still rather damp, the particles may act at a distance on the electrometer, the tension of which increases. In proportion as the temperature rises, the evaporation becomes more active; but in summer it produces at the same time an ascending current, which carries away the vapours with it, the quantity of which diminishes below about 9 o'clock in the morning; then fewer particles act on the electrometer; and, as the relative humidity tends to diminish, the action by induction is less energetic: hence the *maximum* which precedes this moment. As soon as the ascending current becomes more energetic, the vapours rise faster, the dryness increases below, the tension diminishes, and we find a *minimum* which succeeds the greatest diurnal heat. Then the ascending current is reduced, the vapours do not rise any higher, the air becomes damper, the greater proportion of aërial or aqueous particles endowed with electricity, which are formed in the neighbourhood of the electrometer, act more strongly on it, through the medium of damp air; the tension increases, and, at the time when the pressure of the aqueous vapour is as strong as possible, the electricity also attains its *maximum*. The evaporation then diminishes, the vapour is precipitated, and the electric tension continues to decrease till the next morning. In winter, when evaporation and vegetation are much less active than in summer, the tension is nevertheless stronger; the reason of it is in the less insulating power of the air, which, being damper, permits a greater number of particles to act on the instrument.

To follow these laws into their minutest details, it would be necessary to observe the electrometer for a long series of years, simultaneously with other instruments in different places. However, the few facts we possess give a high degree of probability to the theory laid down; for in summer, when the quantity of vapour of water is much less during the afternoon than in the evening or morning, we find the greatest diminution of electricity in the afternoon; then the vapours ascend rapidly towards the upper strata, their quantity increases, and the relative humidity changes much less than in the lower; it is even stronger in the afternoon than in the morning, and the electricity only attains its *maximum* in the afternoon. Perhaps it is the same on the coasts of the sea; for in winter, when the air attains its *maximum* of humidity in the afternoon, the electricity attains its *maximum* at the same epoch (see Note E).

**ELECTRICITY OF DEW AND FOGS.**—When the vapour of water is precipitated into the atmosphere, a greater or less quantity of positive electricity becomes free. However, whether the augmentation of electric tension is due to the damp air permitting the more distant particles to act on the electrometer, or whether the electricity becomes free through the precipitation of vapours in the same manner as latent heat, is difficult to decide. Indeed, electricity is very strong when the dew is deposited; if this is abundant, then the *maximum* of the diurnal period takes place towards evening. The signs of electricity are also very marked during fog; all observers have acknowledged it, and **de Saussure** affirms that he never saw a fog without a notable developement of electricity. In general, it is positive and stronger in winter than in summer, according to **Schubler's** observations. The electricity is stronger as the fogs are thicker; they rarely give signs of negative electricity: yet these phenomena are too little known for me to be able to enter into further details.[14]

The received opinion, on the increase of electricity during the formation of fogs, deserves to be submitted to new experiments. We must not forget that but few experiments on atmospheric electricity exist. For whole months, meteorologists do not observe the instruments. If a storm arises, or rather, if the straws of the electrometer diverge strongly, then they look at them and note their indications. But we cannot conclude from these indications whether the divergence was strong or weak relatively to the mean divergence. From my own observations at Halle, I should be tempted to believe that, during a fog, the electricity is weaker than in clear and damp weather. On the Alps I have always found, under these circumstances, a strong positive electricity; but as soon as clouds approached its intensity diminished, and it was almost null when I was surrounded by clouds: at Halle, the same remarks. It is for experiment to decide if these are exceptional facts, resulting from the fact that electricity easily flows into the

---

[14] *Vide* Note *n*, Appendix, No. II.

earth because the air is damp, or if it is the normal and usual state.

**ELECTRICITY DURING RAIN.** — When rain or snow falls from the upper regions of the atmosphere, there is, at the same time, a production of a quantity of electricity, more or less strong: it is only during mild and continued rains that we observe no traces of it: in this case the electricity is sometimes positive, sometimes negative. According to **Schubler's** observations, there are, in south Germany, 100 positive for 155 negative rains: according to those of **Hemmer**, at Mannheim, 100 positive for 108 negative: in the two series the latter are the more common. The direction of the wind is not without influence over these differences. If we designate by 100 the number of positive rains with each wind, we find the following numbers for the number of negative rains with the same winds:—

NUMBER OF NEGATIVE RAINS FOR EACH WIND, THAT OF POSITIVE RAINS BEING EQUAL TO 100.

| | SCHUBLER. | HEMMER. |
|---|---|---|
| N. | 91 | 52 |
| N.E. | 109 | 75 |
| E. | 166 | 95 |
| S.E. | 175 | 95 |
| S. | 260 | 101 |
| S.W. | 232 | 117 |
| W. | 145 | 106 |
| N.W. | 128 | 67 |

(*Vide* Appendix, *fig*. 38.)

With the north winds the number of positive rains is, therefore, relatively greater than with the south winds; the difference of the two numbers obtained by **Schubler** and **Hemmer** are due to local circumstances and climacteric conditions, which are not the same. To sum up: their observations prove that, during the course of one year, most of the rains are positive, whilst they are negative in another. Thus the annual results may be very different from the general mean.

What is the origin of this negative electricity? **Schubler, Tralles, Volta,** and others, explain the phenomenon by the evaporation of drops of water: when they traverse dry air, they partially change into vapours, which carry away the positive electricity, whilst the drop remains in the negative state. This hypothesis is confirmed by the fact of observation, that in the neighbourhood of cascades, where a great many drops are thrown into the air, we always find traces of negative electricity, more or less marked. Several experiments made by **Belli** render this hypothesis improbable. If we insulate an artificial fountain, such as Hero's fountain, and place it in fine weather in an open place, where the atmospheric electricity is strong, the drops will be negative and the vase positive; if the experiment be renewed in dry weather, on points where there are no signs of atmospheric electricity, there will be no electricity either on the vase or the drops, although the evaporation is the same: it is not then to evaporation, but to induction, as **Belli** very well remarked, that the electricity is due. When the fountain rises towards a clear sky positively electrised, it acts by induction; the fountain is positively electrised below, and negatively above: but, as soon as the air is without electricity, the action by induction no longer exists, and there is no trace of electricity. It is the same with a cascade: it is negatively electrised above, positively below; the vitreous electricity flows into the earth, the other remains united to the liquid drops.

Thus, then, although evaporation may develope negative electricity in the drops which fall, the action by induction is much more energetic: clouds have often a strong positive electricity, whilst that of the earth is negative. If there are two strata of clouds in the sky, and the rain falls principally from the lower, both are positively electrised; but the electric state of the lower is modified by that of the earth: it becomes positive in its lower surface, and negative in its upper; the rain is then positive. Soon, not only does the lower face of the cloud become neutral, but also the earth; thus, at the end of a certain time, not the slightest indication of electricity is found until, when under the influence of the upper cloud, the lower one becomes charged with a great quantity of free negative electricity. The drops which fall will then be negative: but, if a breeze condenses anew the vapour of water in the cloud, then we find once more that the drops of water are positively electrised.

Every time I have been able to follow this phenomenon, I was assured of the action of the upper cloud upon the lower. In other cases, the cloud acts on the drops of rain themselves, and changes their electric state. This being well understood, the influence of the winds over the electric state of the rain is easily deduced.

From what we have previously seen, the origin of rain from north and south winds is very different. If, in a clear sky, the temperature rises for several days, the barometer begins to sink, a few *cirri* form in the high regions, at the same time that the south wind becomes predominant; the *cirri* extend, the sky becomes whitish, and positive electricity increases in its lower strata. The barometer continuing to fall, *cumuli* are formed in the lower parts, and the rain begins. At the moment when they are produced, the *cumulus* and the rain are both positively electrised. Soon negative electricity accumulates at the upper part of the *cumulus*, and the rain itself finishes by becoming negative; but as, by the north winds, there is often but one stratum of clouds, this action by induction no longer occurs, and the rain is more frequently positive. In winter, the snow falls generally from a single stratum; it is also almost always positive.

**FORMATION OF STORMS.**—In no phenomenon is electricity manifested in so evident a manner as in this; but there is none in which its part is so difficult to analyse. Storm-clouds are in general at first small, and rapidly become larger, in such a manner, that they seem to grow by the precipitation of the vapours which surround them; in a short time they cover the sky, which is generally of a very pale blue. In other cases, clouds are formed on different points of the horizon, which remain insulated, or finally unite; their characteristics are, that the *cirri* of the elevated parts of the atmosphere pass to the state of thick *cirro-cumulus*, and the *cumuli* form a compact and uniform mass of *cumulo-stratus*: which is clearly to be seen, especially when a storm is formed on the horizon. The entire mass presents very remarkable oppositions of light: in certain points it is of a dark grey, and in others it presents very brilliant colours, approaching to yellow: lengthened striæ may be seen of an ashy grey. When the sun is on the point of setting, these clouds are yellowish towards the west; this colour changes to grey and blue, and it seems as though the landscape were observed through a yellow or orange-coloured glass.

The storm is frequently formed several hours before it bursts forth. In the morning the sky is completely pure, towards noon we remark some isolated *cirri*, which give a whitish aspect to the sky; the sun is pale and dim; there are parhelia or coronæ around the sun. Later, the *cumuli* appear, and, in spreading, they are confounded with the upper stratum. A short time before the storm bursts forth we see a third stratum, which is particularly remarked in mountainous countries. However, I have also observed it in the plains of Germany, although not so well as on the Alps.*

The formation of storms is preceded by a slow and continued fall of the barometer, as must be the case when *cirri* occupy the sky. The calmness of the air and a suffocating heat, which are due to the want of evaporation on the surface of our bodies, are circumstances quite characteristic. This heat does not proportionately affect the thermometer; it is peculiar to the lower strata of the air, for it decreases rapidly with the height. Thus corresponding observations at Munich, and on some mountains in Bavaria, shew that, in the afternoon of stormy days, the decrease was 1° for seventy-eight metres, that is to say, twice as rapid as it is at a mean. The observations at St. Gothard, compared with those in neighbouring towns, prove the same thing; the anomalies of terrestrial refraction, which we then observe, tend to the same result. In the morning, the decrease of temperature being generally very slow, there necessarily results from it in the afternoon a very intense ascending current, which carries off the vapours toward the upper regions of the atmosphere, where they rapidly condense.

**ON LIGHTNING.**—When the instantaneous precipitation of the vapour of water disengages a certain quantity of electricity, then there is a spark, as we see it in our private experiments; this spark goes from one cloud to the other, or from a cloud to the earth. We may distinguish from a distance these two kinds of lightnings. If the lightning joins two clouds, whose height is not equal, then the sky is irregularly illumined. We remark a point where the light is more intense, but it is not clearly defined: on quitting this centre, the light continues to diminish in intensity. If the lightning goes from a cloud to the earth, then we observe a narrow train of dazzling light, very limited and surrounded by a less intense light. We observe this same band when

---

* In his notice on thunder (*Annuaire du Bureau des Longitudes* for 1838), M. ARAGO has shewn that storms may be engendered by a certain number of agglomerated or superposed clouds; but he also quotes several examples, borrowed from MARCORELLE, DUHAMEL DU MONCEAU, and M. HOSSARD, in which the lightning flash is produced from a very small insulated cloud. These facts are contrary to the opinion of FRANKLIN, DE SAUSSURE, and BECCARIA, who do not admit that a solitary cloud can be stormy. This subject, therefore, claims the attention of observers.

it joins two clouds which are equal in height, and which the lower clouds do not hide from our sight; in this latter case we only observe one light, as in the former: shall I add, that these lightnings are identical, but that the immediate view of the former is hidden from us by the clouds which pass before them?

If lightning were immovable, it would appear to us under the form of a globe of fire; strong lightnings often terminate thus at their anterior extremity. Lightning affects the form of a zigzag, like the spark of our machines; perhaps it has really the form of a helix, whose projection seems a broken line. The unequal conductibility of the air explains this course of lightning, and also its bifurcations. During violent storms the principal lightning emits lateral branches, or appears ramified at its origin. In a very strong storm which took place at Halle in June 1834, the lightning had the appearance of a vertebral column, with the ribs that it supports.

In general, the colour of lightning is a dazzling white; I have, however, often seen it verge towards violet. In 1834, several inhabitants of Halle made the same remark; the lightning was very high, and consequently took place in a rarified air. Now, we know, that if we make a spark pass through the receiver of an air-pump, its light is bluer in proportion as the vacuum is complete.

It is generally admitted, that lightning moves from above downwards; however, numerous examples exist of its having followed an opposite direction. The spark probably leaves both bodies at once, as we see it when we bring a ball near to the conductors of an electric machine. I have remarked several times, in two clouds of the same height, that two flashes of lightning have left each of them, and united in the middle of the interval which separated them.*

---

* M. Arago (*Annuaire* for 1838) distinguishes three kinds of lightnings:—

1st. *Zigzag lightning*, which usually describe zigzags in space; sometimes they bifurcate or trifurcate at their extremity. Some facts would even lead us to think that their division went still further. Thus, the 3d June 1765, the thunder penetrated, at the same instant, by four different points and distant from each other, Pembroke College at Oxford; and in April 1718, twenty-four churches were struck with lightning in the neighbourhood of St. Pol-de-Léon, although only three claps of thunder were heard.

2d. *Sheet lightnings*, which present themselves under the form of lights that illumine the outlines of the clouds; these are the more common and more frequent in a storm.

3d. *Ball lightnings*, or *globes of fire*. These move slowly from the clouds to the earth, and are visible for several seconds. M. Arago cites a great many examples of them.[15]

M. Arago then demonstrates, that the lightnings of the first and second classes do not last for the millionth part of a second.

[15] *Vide* Note o, Appendix, No. II.

**THUNDER.**—Sooner or later after the lightning we hear the thunder; this noise results from the displacement of the air by the spark and irruption of the surrounding air, which fills up the vacuum formed, as it happens when we open a case that closes well. Thunder follows lightning, because sound, by travelling 333 metres a second, does not reach our ear so quickly as the luminous sensation.

The noise of thunder is not the same, according as we are more or less distant from the lightning; thus, when thunder falls on the surface of the earth, those who are near hear a dry noise of varying power, which ceases immediately. Observers placed at a greater distance hear a series of noises, which rapidly succeed each other; these last differ completely from the rollings of the thunder, especially when the explosions take place between clouds. The rolling continues for several seconds, even a minute, and does not diminish in force; on the contrary, it seems to gather force from time to time, and appears intermixed with more violent claps, like the noise produced by a mass of something falling down stairs. The weak noise at the commencement increases successively, and does not attain its greatest force till a certain time. It is difficult to explain the rolling of thunder; we can only compare it to the sound produced by a rope put in motion. Ancient philosophers only saw in it a repercussion of sound by the earth, an hypothesis which seemed so much the more probable as the rolling is much stronger in mountainous countries than in plains: however, as we hear it also on the open sea, it was thought that the clouds reverberated the sound. **Deluc** objected, first, that it was improbable that clouds, that is to say fogs, whose limits are scarcely defined, can reflect sound. However, I do not regard this reflexion as quite impossible, although I explain the rolling in another manner. On comparing analogous optical phenomena, we shall find that there is reflexion as soon as the properties of refraction and dispersion of light are on the point of changing. Some facts observed by the academicians of Paris during their experiments on the velocity of sound seem favourable to this hypothesis. In fact, when there were clouds between the two stations, Montmartre and Montlhéry, then the report of a cannon imitated to a certain degree the rolling of thunder, which never took place when the sky was clear.

The nature of lightning plays, according to **Brandes, Helvig,** and **Raschig,** an important part; for it is lightnings that are directed upwards or laterally, which are accompanied by a rolling, whilst the lightning that strikes an object is accompanied by a dry and short noise. If we admit that lightning is composed of a series of small explosions, as the optical experiments of M. **Dove** prove, each of these explosions must produce a noise. In a flash of lightning which falls, the noise caused by the first explosion reaches the ear of the observer at the same time as the last; but, in a horizontal flash of lightning, the noises produced at a greater distance arrive later than the others, and a flash of lightning which lasts a second, but which extends over a length of perhaps 2000 metres in a straight line, will produce a noise that will last seven seconds.

The zigzag form of lightning, on which **Helvig** has insisted, is not of the least importance. He has distinctly seen a flash of lightning arrive on the earth in four leaps, and he has heard four noises of different intensity. Evidently the noises must have reached the ear at different intervals; and as it is at angles that the noise is the strongest, on account of the compression of the air, he thence deduced the unequal intensity of the sound.

As in all complicated phenomena, there are here two acting causes—echo, and the unequal distance of the explosions; but to explain their unequal intensity, and the intervals of silence, followed by a reinforcement of sound, we are obliged to admit the interference of the sonorous vibrations. Sound moving from the point where it is produced in every direction, spherical waves are the result; which are such, that if, in a given moment, the air of a series of these spheres is of a very feeble density, whilst the spheres which separate them have a very strong density, the result is, that in the following moment these series change functions. Let us suppose that, at a certain distance, a second undulatory system, of the same force and height, is engendered, these both cross without contracting their mutual extension; but, on certain determined points in each system, there is a great difference in the intensity of the sound. For, in the points where the two systems render the air alternately more or less dense, the movement is more rapid, and the sound more intense than if there had only been one sonorous wave. In other points these two systems meet and tend, the one to condense, the other, to rarify the air; they act, therefore, in opposite directions. If their actions are equal, their effects destroy each other; if they are unequal, nothing remains but the excess of the stronger over the weaker. We shall, then, find a series of points where the sound will be stronger or weaker, according to circumstances, as if these had but one original sound. We may figure to ourselves these effects in the following manner: draw on a plane two systems of concentric circles, whose diameter regularly increases by the same quantity—of a millimetre, for instance—the 1st, 3d, the 5th, &c., of these circles will be designated by dotted lines; the 2d, the 4th, &c., by continued lines; the latter designate the series of points where the air is more dense, the former the points where the air is rarified. If, at a certain distance, we trace circles around a second centre at a little distance, the sound will be reinforced at the points where the lines of the same kind meet, and weakened at those where the dotted lines cut the continued ones. If we join by lines the different points of the intersection of the circles, we shall see that the points of intense sounds, and those of weak ones, occupy determinate places. We may figure to ourselves the two centres of these systems of undulations, as placed at the extremity of the two branches of a tuning-fork; if we put them in motion, and make the tuning-fork turn at the same time round its axis, we shall hear a very regular increase and diminution of sound.

It is probable that these interferences play a part in this phenomenon; as, in the other sounds, the undulatory motion continues even a certain time after the cause has ceased to act, every point that the lightning strikes becomes the centre of an undulatory system. However we will admit, for greater simplicity, that the angles only of a zigzag are the centres of such systems. The noise of thunder arrives from the nearest angle to the zigzag, then from a second point. If the waves meet, the sound will be reinforced: if that does not happen, it will be weakened or null, and will recommence with a new intensity when the corresponding waves of one or several systems of undulations meet.

I cannot explain all these circumstances in any other way; for, if we take for the point of departure the distance of the source of sound, the thunder would have its greatest intensity at the beginning, since it is the nearest sound which reaches us first. If we suppose that the isolated noises are reinforced by adding themselves together, then the noise of the thunder would be weak at the commencement, would then become stronger and stronger, and attain a *maximum*, and then diminish. It is only in the most favourable circumstances, and consequently very rarely, that we should hear the rolling. We also see why the rolling is much more marked during distant storms than in those which break forth in the vicinity of the observer. In fact, these interferences take place especially when the waves are comprehended in an acute angle; which happens more frequently with distant lightning than when it is near. It is probable, that of two distant observers each hears his own thunder, in that the one hears it with much more force at the same moment that the other hears nothing, and *vice versâ*. If observation should succeed in establishing this as a fact, it would be a proof of what we have just said.*

**EFFECTS OF THE LIGHTNING FLASH.**—When lightning falls on the surface of the earth, it follows, like every entire electric spark, the best conductors: it also attaches itself principally to metals. However, it may happen that it leaves metal for a body that is not so good a conductor, when the latter conducts it more directly to the earth. After metals, damp substances are followed by it in preference: this is why men and animals are often struck by lightning and killed, or only stunned. In the first case, death appears caused by a shock on the nervous system; for dead persons retain the very same position which they occupied before they were struck by lightning. These cases are not very common. At Göttingen, in the space of a century, three persons only have been killed by lightning; and at Halle, only two.† Thus, the fear of thunder is

---

* What is the duration of the rolling of thunder observed in an open country, and corresponding to a single flash of lightning? Such is the question asked by M. ARAGO, in the remarkable notice we have already cited. The observations made by DE L'ISLE, at Paris, give from thirty-five to forty-five seconds for the duration of the longest rollings he has observed.

The interval which elapses between the lightning and thunder varies generally from three to sixteen seconds, but it may be fifty and even seventy-two seconds. The space of time which separates the lightning from the claps of thunder, or from their *maximum* noise, oscillates between twelve and twenty-six seconds, according to the observations made by DE L'ISLE in 1712. ROBERT HOOKE (*Posthumous Works*, p. 424) is the first, according to M. ARAGO, who has well explained the rolling of thunder. "Lightnings," says he, "only occupy a point in space, and give place to a short and instantaneous noise. Multiple lightnings, on the contrary, are accompanied by a rolling; because the different parts of long lines which the lightnings occupy are in general found at different distances, the sounds which are there engendered, either successively or at the same physical instant, must employ times gradually unequal in order to reach the ear of the observer."

† The researches of M. ARAGO do not confirm M. KAEMTZ's opinion as to the trifling number of persons struck by lightning. Doubtless, if we examine but one locality or town, the number of victims is very limited, but it is not thus when we consider a whole country. Thus, in 1819, we have a knowledge of twenty persons being killed in France by lightning. In the United States, according to VOLNEY, there were, in 1797, from the month of June to the 28th of August, twenty-four persons struck, of whom seventeen were killed.

The danger increases, as we well know, for men placed on very high points. The following is a sad example:—M. BUCHWALDER, a Swiss engineer, had established a geodesical signal on the top of the Sentis, in the canton of Appenzell. This summit is 2504 metres above the level of the sea. "The 4th July, 1832," said he, "it rained abundantly towards evening, and the cold and wind became such that they prevented my sleeping all by no means excusable; and it can be only due to the prejudices inculcated in children by ignorant parents, who

night. At four o'clock in the morning the mountain was covered with clouds, and some passed over our heads; the wind was very violent. However, larger clouds coming from the west, approached and slowly condensed. At six o'clock the rain began again, and the thunder resounded in the distance. Soon the most impetuous wind announced a tempest. Hail fell in such abundance that, in a few moments, it covered the Sentis with a frozen stratum, which was four centimetres in thickness. After these preliminaries the storm appeared calmer; but it was a silence, a repose, during which Nature was preparing a terrible crisis. In short, at a quarter past eight o'clock, the thunder growled again; and its noise, approaching nearer and nearer, was heard without interruption till ten o'clock. I went out to examine the sky, and to measure the depth of the snow, at a few paces from the tent.

"Scarcely had I taken this measure, when the lightning burst forth with fury, and obliged me to take refuge in my tent, together with my assistant, who brought some food there to take his repast. We both lay down side by side on a plank. A thick cloud, as dark as night, then enveloped the Sentis; the rain and hail fell in torrents; the wind blew with fury; the near and confused lightnings seemed like a conflagration; the lightning broken into flashes mixed its hurried bolts, which, driving against each other and against the sides of the mountains, indefinitely repeated in space, were at once an acute rending, a distant reverberation, and a deep and long roaring. I felt that we were in the very centre of the storm; and the lightning shewed me this scene in all its beauty or in all its horror. My assistant could not free himself from a sensation of fear, and he asked me if we were not running some danger. I removed his fears by relating to him that, at the time when MM. Biot and Arago were making their geodesical experiments in Spain, the lightning had fallen on their tent, but had only passed over the roof without touching them. I was really at ease; for, accustomed to the noise of thunder, I still studied it when it threatened me closely. These words, however, brought to my mind the idea of danger, and I fully understood it.

"At this moment, a globe of fire appeared at the feet of my companion, and I felt my right leg struck with a violent commotion, which was an electric shock. He uttered a doleful cry: 'Ah! my God!' I turned round to him. I saw on his face the effect of the lightning-stroke. The left side of his face was covered with brown or reddish spots. His hair, eyebrows, and eyelashes, were frizzled and burned; his lips and nostrils were of a brownish violet: his chest seemed still to heave at intervals; but soon the sound of respiration ceased. I felt all the horrors of my situation; but I forgot my suffering, in order to seek succour for a man whom I saw dying. I called him, but he did not reply. His right eye was open and bright; it seemed to me as though a ray of intelligence beamed from it, and I hoped: but the left eye remained closed; and, on raising the eyelid, I saw that it was dull. I supposed, however, that there was still sight remaining on the right side, for I endeavoured to close the eye on that side; an attempt which I repeated three times. It opened again of itself, and seemed animated. I put my hand on his heart; it no longer beat. I pricked his limbs, body, and lips with a compass; all was immovable: it was death, and I could not believe it. Bodily pain at last drew me from this painful contemplation. My left leg was paralysed; and I felt a shuddering, an extraordinary movement. I felt, besides, a general trembling, and oppression and disordered beatings of the heart. The most sinister reflections took possession of me. Was I going to perish like my unfortunate companion? I thought so from my suffering; however, reason told me that the danger was passed. I gained with the greatest difficulty the village of Alt St. Johann. The instruments had been struck in like manner."—(*Ergebnisse der trigonometrischen Vermessungen in der Schweiz*, p. 11.)

In the *Comptes rendus de l'Académie des Sciences*, t. viii. p. 174, we find an example of four sailors being struck by lightning on the top of the mainmast of an English ship of the line, the Rodney.—M.

teach them to see in thunder a sign of the anger of Heaven, whose thunderbolts strike the wicked and the impious. **Lucretius** long ago refuted these absurd prejudices, when he says, book vi. ver. 416, while speaking of the chief of the gods:—

> "Postremo, cur sancta Deûm delubra, suasque
> Discutit infesto præclaras fulmine sedes,
> Et bene facta Deûm frangit simulacra? Suisque
> Demit imaginibus violento vulnere honorem?
> Altaque cur plerumque petit loca, plurimaque hujus
> Montibus in summis vestigia cernimus ignis?"

If lightning, in its course, meets with bodies that are bad conductors, it pierces and breaks them, and scatters them about with irresistible force: thus, on the 6th of August, 1809, the lightning displaced a wall near Manchester, $0^{m}$,9 thick, and $3^{m}$,6 high, placed between a cellar and a cistern. The displaced part was removed from its primitive position $1^{m}$,2 on one side, and $1^{m}$,8 on the other; and its weight amounted to 19240 kilogrammes. To estimate the whole force employed, we must take into the account the cohesion of the parts, which would lead to a very much higher number. A great number of analogous examples have been observed.

When lightning falls on combustible bodies, it inflames them, carbonises their surface, or reduces them to splinters; perhaps, in the latter case, the explosion is so violent that it extinguishes the fire at the same instant, as a powerful electric spark disperses gunpowder, while a more feeble spark ignites it. Need I add that a fire caused by lightning is extinguished as easily as any other?

**LIGHTNING CONDUCTORS.**—Scarcely was **Franklin** convinced of the electric nature of lightning, than he pointed out the means of averting it from edifices: this is the object of lightning conductors, which present to the lightning a more easy route than is presented by stone or wood. Thus, an iron bar is placed at the top, connected with a conductor of twisted iron-wire, which is plunged into a moist soil; experience proves that, under these circumstances, the lightning follows this route without damaging the edifice. I shall not enter into more lengthened details on this subject; they will be found in the instructions published by MM. **Gay-Lussac** and **Arago**.

Experience having shewn that the lightning was then without effect, it was thought that storms might be dissipated if a sufficient number of *paratonnerres* were raised, so as to neutralise the electricity of the atmosphere. But even though it should be certain, which is not the case, that storms are engendered by electricity, I yet doubt whether thousands of paratonnerres would have any influence over storm-clouds. Thus, at Zurich and its vicinity, the houses are studded with paratonnerres, and I am not aware that storms are less frequent there than in any other country.

**ODOUR OF LIGHTNING.**—Near the spot where lightning has fallen, an odour is perceived analogous to that perceived in the neighbourhood of our electrical machines. It has always been said that this is a sulphurous odour; but we must not forget that the mass of mankind designate by this term every disagreeable odour which is not related to any of those with which they are acquainted. Few philosophers have thrown any light on this subject:[16] **d'Allbard** and **Taylor** maintain that they have recognised an odour decidedly sulphurous; **Romas,** in his experiments with the electric kite, says that the odour of the sparks was the same as that drawn from the electrical machine. **Fusinieri's** opinion, that the lightning comes with its finely divided particles of iron and sulphur, remains to be verified; for, if more iron and sulphur have been found in the part of a tree struck by lightning than in the rest, this may happen from the tree's having been partly burned and volatilised; the sulphur and iron that enter into the composition of almost all organised bodies have remained accumulated in a more notable quantity in the woody parts that have remained untouched.

**FULMINARY TUBES.**—When lightning falls upon sand, its course is often marked by tubes, called fulminary tubes, or *fulgurites*. Although they have long been noticed, it is only since **Henzen** observed them in the sandy hillocks of Holstein that they have been attentively studied. **Blumenbach** was the first to attribute them to lightning; **Fiedler** carefully studied their nature and their mode of formation. They are generally composed of tubes of very different lengths and diameters, which contract toward their lower extremity, and terminate in a point; they are generally sinuous, and more or less ramified. Vitrified within, their exterior is covered with agglutinated grains of sand; the vitrified parts of which are of a reddish, or even greenish pearl grey. Their diameter is from 1 to 90$^{mm}$; the thickness of the sides, 0$^{mm}$,5 to 24$^{mm}$. Their length sometimes exceeds 6$^{m}$, and the ramifications are from 2 to 30 centimetres long. All fulminary tubes with thick sides have, according to **Fiedler,** rough surfaces, and are divided into fragments of from 5 to 100$^{mm}$ long. The tubes, whose

---

[16] *Vide* Note *p*, Appendix, No. II.

sides are thin throughout their length, have a smooth surface, and are regularly cylindrical; they present no transverse fractures. All the fulgurites hitherto examined are directed towards reservoirs of water, or bodies which are good conductors of electricity.

Direct observations have shewn that these fulgurites were due to the action of lightning. Thus, **Pfaff** received a tube from the island of Amrum. Some sailors saw the lightning fall upon the sand; they dug and found a tube $6^{mm}$ in diameter, blackened within by the carbon of the burned vegetables. **R. Brandes, Hagen, Rippentrop,** and **Withering,** have related analogous examples; MM. **Beudant, Hachette,** and **Savart,** obtained artificial fulminary tubes by making powerful electric sparks pass into sand mixed with salt, in order to increase its fusibility.

Finally, vitrified particles have been found on the surface of rocks, which are an effect of lightning. **De Saussure** saw on Mont-Blanc* rocks of schistose amphibole, covered with vitreous globules, analogous to those seen on tiles struck with lightning, or on pieces of hornblende, that are dispersed by means of a powerful electric spark. **Ramond** made the same remarks on the micaceous schist at the summit of the Midi, and on the *Klingstein-porphyr* of the Rock-Sanadoire, in the department of Puy-de-Dôme; M. **de Humboldt** saw the same traces on the trachite porphyry of the Nevado de Toluca in Mexico, at the height of 4622 metres. MM. **Buckland** and **Greenough** found a fulminary tube near Drigg, in the county of Cumberland, adhering to a pebble of porphyry that the lightning had melted, and near which were two very thin plates of glass, of an olive colour.

**STORMS WITHIN THE TROPICS.**—Before passing to the other effects of lightning, it is fit to say something on the geographical distribution of storms, and their frequency in different seasons.† Nowhere are they exhibited with such violence as within the tropics during the wet season, and at the change of the monsoons. In the morning the sky is serene, but toward noon it is covered with clouds;

---

* Voyage dans les Alpes, § 1994.

† M. Arago has treated this question greatly in detail in the *Annuaire* for 1838. Not being able to give in this place all his numeric tables, I will content myself with pointing out the places for which they have been drawn up. These are:—Calcutta, Patna, Rio-Janeiro, Maryland, Martinique, Abyssinia, Guadaloupe, Viviers, Quebec, Buenos-Ayres, Demainvillers, Smyrna, Berlin, Padua, Strasburg, Maestricht, La Chapelle near Dieppe, Toulouse, Utrecht, Tubingue, Paris, Leyden, Athens, Polpero, St. Petersburg, London, Pekin, Cairo.—M.

and the electricity is more violent in the low than in the more northerly latitudes; the lightnings succeed each other without interruption, and the rollings of thunder are much more powerful than with us. According to travellers, we, in our climates, can form no notion of the violence of these storms; in the region of calms there is a storm almost every day, so that we might call it the region of eternal storms.

When they are accompanied by a very high wind, they are known by the name of *tornados* or *trovados;* in the Antilles and in India they are called *hurricanes*, and in the Chinese Sea they are designated *typhons*. But these winds present such peculiarities, that we should be very wrong to extend the word hurricane to tempests of the mean and of the high latitudes.

Hurricanes are very frequent on the coast of Sierra-Leone, at the beginning and at the end of the rainy season, when the monsoons change. According to **Winterbottom**, they present the greatest analogy to our storms, and rarely last more than twenty minutes or half an hour; this is also the testimony of **Dampier**. But these storms arrive so suddenly, and are attended by so furious a wind, that ships run the greatest danger. In 1681, **Dampier** observed a hurricane at Antigua (Antilles) which lasted from eight o'clock in the morning until four o'clock the next day. Captain **Gadbury** had landed with his crew; when he wished to return on board he found the ship lying on its side, and the point of the mast buried in the sand. The hurricane then returned with fresh violence; the waves rose to a monstrous height; casks were found a quarter of a league inland: one ship was hurled into a forest, and another on a rock, three metres above the highest tides.—In a hurricane that raged in the end of October, 1831, over Balasore, in India, latitude 21° 32′ N., longitude 84° 30′ E., ten thousand persons lost their lives. The great route from Madras to Calcutta passes through Balasore, at a distance of fourteen kilometres on one side; it was, however, invaded by the sea, and every thing that was there was carried away. A surface of twenty-four myriametres was covered with four or five metres of water. The sea advanced to the doors of the town; the bridge and the wreck of a vessel were found on the highway. A hurricane, of no less violence, ravaged Guadaloupe on 25th July, 1825: cannons, twenty-four pounders, were displaced; one wing of the government-house, constructed with the greatest solidity, was destroyed, and a fir-plank nine decimetres long, two wide, and twenty-two millimetres thick, was hurled through a palm-tree, four decimetres in diameter.

The approach of these hurricanes is sometimes announced by foreboding signs. On the coast of Sierra-Leone, for instance, a thick cloud is observed in the east, which, according to **Winterbottom's** expression, does not appear greater than the hand. At the mouth of the Senegal, a white round cloud, according to M. **Golberry**, is seen to make its appearance in the higher regions of the atmosphere; feeble electrical lights rapidly succeed each other, and the distant rumbling of thunder is heard. In the devoted place the clouds thicken, their bulk increases, and the thunder is heard with louder crashings; the clouds become blacker and blacker; and, finally, all the sky is covered, and the earth seems enveloped in profound night, which contrasts with the purity of the sky in the west. Immediately before the hurricane breaks loose, a slight and almost insensible breeze blows from the west, or the air is even entirely calm; nothing moves; but feeble whirlwinds occur here and there: at the same time, the temperature falls rapidly.

Another circumstance characterises these storms; it is, that they are confined within very narrow limits: at the distance of twenty kilometres, or less, the calm of the atmosphere has not been disturbed for a single moment. They are also attended by changes in the direction of the wind, and it is not uncommon for it to blow from all points of the horizon in the space of a few minutes.[*]

---

[*] M. Espy has given a theory of the tempests, hurricanes, and tornados of America, which has been favourably received. He first noticed the extraordinary fall of the barometer, which accompanies these meteors; then, on examining the direction of the trees thrown down by the wind, and the traces impressed on the ground, he has concluded that, in these hurricanes, the air rushes toward a central space, point, or line: so that, if the wind from one side blows in the east, it blows from the west on the other side; the centre of the meteor shifts its place. He recognises as a cause an ascending column of air, the temperature of which does not vary, because the precipitation of its moisture restores to it the temperature it loses by expansion. This ascending column gives rise to a wind on the surface of the earth, and above to the formation of a *cumulus*, which is immediately resolved into hail or rain. (*Vide* M. Babinet's report on M. Espy's works, *Annales de Chimie et de Physique*, 3d series, t. i. p. 372.)

M. Dove has studied the laws of hurricanes in the equatorial, tropical, temperate, and frigid zones, and, by collecting a large number of observations, has arrived at conclusions differing from those which M. Espy has formularised. He regards hurricanes, tornados, typhons, &c. as whirlwinds, whose direction and diameter vary. In these whirlwinds, says he, the wind does not blow from the circumference to the centre, but it always blows at the circumference, and in a direction perpendicular to the radius. The progressive motion of the hurricane is rectilinear or curvilinear. Chains of mountains on elevated coasts are generally the causes of changes in the direction of the hurricanes. Their origin is due to the meeting of two oppo-

Hurricanes are generally observed at the period of the greatest heat of the day; but in the interior of continents, especially when they are mountainous, there are also nocturnal storms. According to observations made by the intrepid **Caille,** this is often seen in the mountains to the south of the western part of Sahara; and, according to those made by **Eschwege,** in the mountains of Brazil. The latter assures us that no idea can be formed of the violence of a nocturnal storm in the virgin forests of this country.

I am not in possession of sufficient facts for determining the number of storms observed in a year in the different regions of the globe. However, from the observations made by travellers, it appears that they occur for the most part when the regularity of the trade-winds is disturbed, or when the monsoons change.

At sea, in the region of the trade-winds, storms appear to be as uncommon as rain; for I do not remember to have found, in a single traveller, the account of a storm of any violence in this zone. At Madeira, storms appear to be very frequent in winter; and this is also the season when the limit of the N.E. trade-wind passes into the vicinity of this island. During the conflict that occurs between the S.W. wind, which is descending, and the N.E. trade-wind, electric discharges are very common.

**STORMS IN HIGH LATITUDES.**—North of the Alps there are scarcely any storms except in the hot season. As we advance from the shores of the Atlantic into the interior of the continent, a modification is found, in their number

---

site winds, which produce the whirlwind. From his researches, M. Dove draws the following indications for the use of nautical men :—

1st. In the temperate zone of the northern hemisphere, if the wind blows first from the S.E., and turns to the south, and then to the west, the ship should be steered to the S.E. On the contrary, if it blows first from the N.E., and passes to the north and the N.W., the ship must be steered to the N.W. In the former case, we are in the S.E. region of the hurricane; and in the latter, on the contrary, in the N.W.

2d. In the northern part of the equatorial zone, if the wind first blows from the N.E., and passes through the east to S.E., we must steer to N.E. If it blows first from N.W., and turns by west to S.W., we must steer to the S.W. In the first case, the ship is in the N.E., and in the second, in the S.W. of the hurricane.

3d. In the southern part of the equatorial zone, when the wind blows from S.E , and then turns to south and S.W., we must steer to N.W. ; if it blows first from east, and passes through north to N.W., we must steer S.E. In the first case the sailor is N.W. of the tempest, and in the second, S.E.

4th. In the temperate zone of the southern hemisphere, if the wind is first established in the N.E., and then passes through north to N.W., the head must be turned to the N.E. If, on the contrary, it is established in the S.E., to pass to south, and then to S.W., we must steer to S.W. In the first case, the ship is N.E., in the second, S.W. of the tempest. (POGGENDORFF's *Annals*, t. lii. p. 1. 1841).—M.

and distribution, analogous to that of rain. Mountainous countries are an exception to the general law, inasmuch as storms are more frequent on the west side of chains than on the plain. On the west coast of Europe and in Germany, we find about twenty storms in the year; at St. Petersburg and Moscow, seventeen at a mean; at Kasan, nine; at Nertschinsk, two; and at Irkoutsk, about eight. Let 100 represent the number of storms occurring in a year, we have the following distribution in the four seasons:—

RELATIVE NUMBER OF STORMS IN THE FOUR SEASONS.

| | WINTER. | SPRING. | SUMMER. | AUTUMN. |
|---|---|---|---|---|
| W. Europe . . . | 8,9 | 17,7 | 52,5 | 20,9 |
| Switzerland . . . | 0,4 | 20,6 | 69,0 | 10,0 |
| Germany . . . . | 1,4 | 24,4 | 66,0 | 8,2 |
| Interior of Europe | 0,0 | 15,7 | 79,3 | 5,0 |

(*Vide* Appendix, *fig.* 39.)

On the western coast of Europe only a tenth of the total number of storms occurs in winter; in summer, there is the half. In Switzerland and in Germany, a storm in winter is a very rare phenomenon; two-thirds of the total number occur in summer. In the interior of the old continent there are no storms in winter, three-fourths take place in summer, and the small number of these that are observed in spring and autumn occur only during the hottest months of these two seasons; so that we may correctly say that there are no storms during one half of the year.

**STORMS IN SCANDINAVIA.**—As there is not any country where the transition from a sea to a continental climate is so sudden as in Scandinavia, so there is no place where there is so great a difference for storms; we shall be convinced of this, by comparing their number in different towns:—

### RELATIVE NUMBER OF STORMS IN DIFFERENT TOWNS IN SCANDINAVIA..

| MONTHS. | BERGEN. | SŒND-MŒR. | SPYD-BERG. | STOCK-HOLM. | SKARA. |
|---|---|---|---|---|---|
| January . | 1,3 | 0,2 | 0,0 | 0,0 | 0,1 |
| February | 1,3 | 0,2 | 0,0 | 0,0 | 0,0 |
| March. . | 0,1 | 0,0 | 0,0 | 0,0 | 0,0 |
| April . . | 0,2 | 0,2 | 0,0 | 0,2 | 0,0 |
| May . . | 0,0 | 0,1 | 0,7 | 0,8 | 0,9 |
| June . . | 0,2 | 0,3 | 2,7 | 1,9 | 2,0 |
| July . . | 0,8 | 0,5 | 2,3 | 2,4 | 3,8 |
| August . | 1,0 | 0,1 | 1,7 | 3,6 | 1,9 |
| September | 0,5 | 0,1 | 0,3 | 0,7 | 0,4 |
| October . | 0,0 | 0,6 | 0,0 | 0,0 | 0,0 |
| November | 0,4 | 0,6 | 0,0 | 0,0 | 0,0 |
| December | 0,0 | 1,0 | 0,0 | 0,0 | 0,0 |
| Year . . | 5,8 | 3,9 | 7,7 | 9,3 | 9,2 |
| Winter . | 44,8 | 35,6 | 0,0 | 0,0 | 0,1 |
| Spring. . | 5,2 | 8,9 | 8,7 | 10,8 | 10,4 |
| Summer . | 34,5 | 22,2 | 86,9 | 81,7 | 83,5 |
| Autumn . | 15,5 | 33,3 | 4,4 | 7,5 | 5,9 |

(*Vide* Appendix, *fig.* 40.)

The number of storms is very small, for there are not above ten in the year; but their distribution is very different on the coast and in the interior of the country. At Bergen, the winter rains predominate over those of summer; and, at the same time, storms are more frequent there, as also at Sœndmœr, which is in the same district; but, at Spydberg, in the interior of the country, we find the same relations as in Russia: it is the same at Stockholm and at Skara. **Stroem, Arentz,** and **Hertzberg,** have perfectly described these winter storms of the province of Bergen : they arrive indifferently at the end of an intense cold, as after a time of continuous thaw, or after rain. They are always brought by west or S.W. winds. **Stroem** even asserts that a storm may be predicted, if the wind suddenly changes from the S.W. to west or N.W. These storms are violent on the islands along the coast; they are more feeble in the fiords, and almost unknown in the interior of the countries, where storms sometimes burst forth in summer.

Winter storms are formed more commonly on sandy shores. In Iceland, lightning frequently occurs in winter in the neighbourhood of the volcanoes; at the Feroes, the Hebrides, the Shetland, and the Orkneys, it is only during violent gales of wind that thunder is heard to roll. On the west coast of America, and on the east coast of the Adriatic, storms are much more common in winter.

If the number of storms is so small in Scandinavia, compared with Germany and France, it is seen to diminish still more as we advance toward the north, where the quantity of vapours filling the atmosphere is very small. Thus, during a sojourn of six years in Greenland, latitude 70°, **Gisecke** heard thunder but once; and all travellers agree on this point.

**STORMS IN THE NORTH OF THE MEDITERRANEAN.**—The ancients had long ago remarked their frequency in certain seasons. **Lucretius** thought that violent winds squeezed out the fire contained in the clouds: and he hence deduces the causes of their distribution in the different seasons:—

> "Autumnoque, magis stellis fulgentibus, alta
> Concutitur cœli domus undique, totaque tellus,
> Et cum tempora se veris florentia pandunt;
> Frigore enim desunt ignes; ventique calore
> Deficiunt, neque sunt tam denso corpore nubes:
> Inter utrumque igitur cum cœli tempora constant,
> Tum variæ causæ concurrunt fulminis omnes;
> Nam fretus ipse anni permiscet frigus et æstum,
> Quorum utrumque opus est fabricanda ad fulmina nobis
> Ut discordia sit rerum, magnoque tumultu
> Ignibus et ventis furibundus fluctuet aer.
> Prima caloris enim pars et postrema rigoris,
> Tempus id est vernum; quare pugnare necesse est
> Dissimiles inter se res, turbareque mistas,
> Et calor extremus primo cum frigore mistus
> Volvitur, autumni quod fertur nomine tempus;
> Hic quoque confligunt hyemes æstatibus acres:
> Propterea sunt hæc bella anni nominitanda.
> Nec mirum est in eo si tempore plurima fiunt
> Fulmina, tempestasque cietur turbida cœlo."
>
> Book vi. verses 356 *et seq.*

The testimony of other writers agrees with that of **Lucretius**; in Greece, storms are frequent in autumn, and in spring, according to M. **Peytier's** observations. There are probably great differences in their season distribution; unfortunately, we possess but few documents on this point. I associate here those which we have for Rome, Palermo, Padua, and Janina, thanks to M. **de Pouqueville**.

### RELATIVE NUMBER OF STORMS, IN DIFFERENT SEASONS, IN ITALY, AND AT JANINA.

| MONTHS. | PADUA. | ROME. | PALERMO. | JANINA. |
|---|---|---|---|---|
| January . | 0,1 | 1,1 | 0,4 | 1,2 |
| February . | 0,5 | 1,6 | 0,7 | 1,6 |
| March . . | 1,2 | 1,7 | 0,6 | 1,6 |
| April . . | 2,7 | 1,6 | 0,7 | 3,1 |
| May . . . | 5,3 | 3,8 | 0,8 | 7,4 |
| June. . . | 8,5 | 5,3 | 0,8 | 5,8 |
| July . . . | 9,5 | 3,7 | 0,7 | 6,6 |
| August . . | 7,9 | 5,8 | 0,8 | 5,2 |
| September . | 3,6 | 6,4 | 1,5 | 3,1 |
| October . . | 1,8 | 5,4 | 3,0 | 3,7 |
| November . | 0,8 | 3,9 | 2,4 | 3,1 |
| December . | 0,2 | 2,1 | 1,1 | 2,6 |
| Year . . . | 41,9 | 42,4 | 13,5 | 45,0 |
| Winter . . | 9,8 | 11,2 | 14,8 | 12,0 |
| Spring . . | 21,7 | 16,8 | 15,9 | 26,9 |
| Summer . | 61,8 | 34,9 | 21,5 | 39,1 |
| Autumn . | 14,7 | 37,1 | 47,8 | 12,0 |

In north Italy, as well as in Greece, there are about forty storms in the year, that is to say, a number the double of that for Germany. At Palermo, the number is not above a third of that in our climates; the air is indeed purer, and the warm air coming from Africa opposes the precipitation of aqueous vapours. There are only sixty-four days of rain throughout the year at Rome; at Padua, on the contrary, there are 120. At Palermo, storms are very common in autumn, whilst at Rome there is scarcely any difference between autumn and summer; their distribution through the year at Padua completely recalls to mind that of Germany. The observations of the ancients chiefly relate to this town: and, if they have laid stress upon autumn storms, it is because they are more violent, and of longer duration.

**FORMATION OF STORMS.**—All storms may be divided into two classes; the one class are due to the action of an ascending current, the other are a result of the conflict of two opposite winds; the former occur during the hot season, the latter during winter. Let us begin by examining those of the first class.

In our climates, and in summer, three conditions are necessary for the formation of a storm: a great calm in the atmosphere, a soil moist to a certain extent, and serene weather. The calm of the air does not always extend to the limits of the atmosphere, for, in general, the barometer falls slowly for a day or two, a proof that air is passing away in all directions. The *cirri*, which first make their appearance, are drawn along by feeble S.W. winds. Under these circumstances, the masses of air in contact with the ground acquire very great ascensive force, because the high temperature that we then observe only belongs to the lower strata; for, if we compare thermometric observations made at more elevated points, we shall find that, during the days of storm, the decrease of temperature is extremely rapid. The vapours then condense in the higher regions of the atmosphere, and contribute to increase the volume of the *cirri*, by being transformed into flakes of snow; at the same time *cumuli* are formed below, which pass into the state of very dense clouds: the temperature then very frequently falls, and the sun ceases to act powerfully on the ground and on the air.

Under the influence of these circumstances, it may very readily happen that the clouds are again dissolved by currents of hot air rising toward them: if this air is dry, this result is inevitable; but the equilibrium of the atmosphere, if it existed in the outset, may be disturbed by the slightest cause; these causes reside in the atmosphere itself. The mass of air situated below the clouds being colder, because it does not receive the direct influence of the solar rays, there are on the sides currents of hot air directed towards the clouds, and the presence of which is generally betrayed by small clouds; whilst, at the surface of the earth, currents diverge in all directions, setting out from the storm as a centre. If the difference of temperature is very great, then these winds acquire considerable force, and, if the movement extends in height, masses of cold air are precipitated towards the earth, which determine the rapid condensation of vapours, and give place to a very high developement of electricity. If, on the contrary, the mass rises toward the zenith, the barometer ceases to fall, and even rises some tenths of a millimetre, but it begins to fall as soon as the storm departs. These storms frequently take place at the period of the greatest diurnal heat; the air soon recovers its serenity, but the storm is produced again for several successive days; storm-clouds are formed, without thunder occurring every time, until the direction of the winds and the state of the atmosphere are completely changed.

This periodicity of storms, which **Volta** was the first to observe in the north of Italy, but of which traces are found in our climates, does not exist in the second class of storms. The *cirri*, it is true, are developed under the influence of very elevated south winds, which sometimes descend to the level of the earth; but these south winds contend with those from the north; at their point of meeting storms are formed. These clouds occupy long and very narrow bands; and, in this case, violent showers occur. This conflict may occur for several days successively, as was seen at Halle for a whole week of the month of July, 1834; the issue of the conflict determines the physiognomy of the weather. If the south winds gain the pre-eminence, the barometer continues falling, and the weather becomes heavy and rainy; if the north winds, the air is at first cold, and remains serene, and is afterwards heated under the influence of the solar rays.

In all cases, a rapid condensation of vapours is the essential condition for the formation of storms: if electricity is very powerfully developed, there is a storm; if not, there are simply passing showers, accompanied by very marked signs of electricity. If we examine all the circumstances that accompany the developement of electricity, we must consider the condensation of vapours as the cause of its production, and conclude that it is the storm that produces the electricity, and not the electric tension that produces the storm, as is the general opinion. Violent rains without thunder and lightning are distinguished from storms merely by a lesser developement of electricity; whence proceeds the absence of lightning and thunder.

**HEIGHT OF STORM-CLOUDS.**—Storms in summer always commence with *cirri;* when these become thicker, or when one or several strata of *cumuli* exist beneath, then these clouds make a mutual exchange of lightnings. We must, therefore, assign to storms a great height; this assertion is quite in contradiction to the received opinion of the moderate height of electrical clouds. Travellers who have been at the summit of the Brocken, at 1140 metres, and on mountains of less elevation, have assuredly seen them beneath them. Whether the sky was perfectly serene over their heads is what they have omitted to tell us: in a storm they only regard the lightning, and rarely the state of the sky, for several hours before it bursts forth. On the Alps, I never saw storms beneath my feet. The whole mass was often overhead; I was sometimes enveloped in clouds, and the thunders and lightnings burst forth at no great distance from me; but I found myself merely in the lower part of the stormy mass, which exchanged sparks with the higher mass.

Those low clouds that are observed on the summits of mountains of moderate elevation form with extreme rapidity on the approach of the storm. I have frequently observed them. During my stay on the Rigi, at 1800 metres above the sea, the sky remained covered with *cirri* for the whole morning; this *cirrus* thickened about mid-day, and isolated *cumuli* passed over my head. In the afternoon a storm formed in the upper part of the Valley of Sarnen; I heard the gentle rolling of distant thunder, and it rained abundantly in this valley; the Rigi was free from clouds, there were merely a few on Mount-Pilate. After some time the storm was directed toward the north, but it was evidently higher than the summit of Mount-Pilate, which is 2044 metres above the sea. I could see along the sides of this mountain the effects of the descending current of cold air; not only did the clouds increase rapidly around its summit, but isolated masses rolled with extreme velocity along its ridges, like colossal balls precipitated from the top of the mountain; lower down, they disappeared, or else moved horizontally. At the same time the thunder burst forth with greater violence. A few minutes afterwards, the portion of the Lake of Quatre Cantons, comprised between the Gulf of Alpnach and that of Lucerne, was agitated; this agitation was propagated with the storm toward the Rigi, and I observed several clouds on the Rigi-Staffel, which were not long in disappearing. Meanwhile, the wind had become more violent on the summit that I occupied, the clouds rose along the west side, the storm approached my zenith; it was at a great height. At the end of a few minutes the clouds descended to a level with me, and I found myself enveloped in fog; the thunder rolled, and the lightnings shone at a very little distance. Travellers afterwards assured me of having found clouds at more than 300 metres below the summit. Considering merely these lower clouds, we cannot attribute to this storm a height greater than 1300 metres at the utmost; but what we have seen above proves that it surpassed that of Pilate.

If storms were as low as the majority of travellers maintain they are, they could not so easily travel through the lofty chains of mountains. The inhabitants of the valley of Chamouni assure me that storms frequently pass above the summit of Mont-Blanc (4810$^m$). I have seen a storm from the Faulhorn (2683$^m$) that was arrested by the Haut Valais; the higher boundary of the clouds overtopped the point of Finsteraarhorn (4362$^m$). During another storm the lower plain of the clouds was very uniform: the

Faulhorn, Schwarzhorn, Pilate, and the Niesen (2365$^m$), were free from clouds. The silver horns (*Silberhoerner*) of the Jungfrau were not enveloped in it: we may, therefore, assign to this storm a height of 3300 metres at least.

It is sometimes possible to determine approximatively the height of a storm. When lightnings pursue a horizontal course, we measure the interval separating the thunder and the lightning; now, as sound travels 333 metres in a second, we have only to multiply by 333 the number of seconds that have elapsed, in order to estimate the distance of the lightning from the observer. If, at the same time, we measure the angular height of the lightning, we can hence deduce its vertical height. Thus, in 1834, when there were several very elevated storms at Halle, I found, on the 5th of June, that the lightnings were at a height varying from 1900 to 3100 metres. On the 21st of July, the *minimum* of certain lightnings traversing the zenith was 1300 metres.

When storms also are not very elevated, we must admit that the clouds we see are formed after the more elevated strata, that principally constitute the storm. The rapidity with which the lower clouds are condensed give rise to a strong electric tension that is manifested by repeated discharges; it is due to the inductive action of the higher masses acting on the lower.

**ELECTRICITY OF STORMS.**—Notwithstanding the numerous researches that have been undertaken on this subject, it is still enveloped in great obscurity. Place yourself near an electrometer, and observe it during the whole course of a storm, and you will see how variable its indicacations are. The lightnings are actually very near without the most delicate instruments giving the least sign of electricity; suddenly the latter increases at the moment of a very powerful flash. Another day the storm arrives with all the signs of a very powerful electric tension, lightnings play in the clouds, the two straws of the electroscope collapse, and it is some time before they open again. At one time, the electric tension will vary for every clap of thunder, at another time it will remain the same for a quarter of an hour, although the lightnings rapidly succeed each other. In one storm the straws separate rapidly; a flash of lightning occurs, and they collapse; during another, they fall together, and then diverge rapidly to approach slowly, until a fresh clap of thunder makes them diverge again. The electricity may be for a long time positive, its force alone varies; but soon, while the rain, the clouds, the wind, and the lightnings, remain the same, the straws separate sometimes under the influence of positive, at other times under the influence of the fluid of the contrary sign.

If we compare all that has been written upon storms, we do not hesitate to conclude that they are the most complicated phenomena of Meteorology. I suspect that a long time will elapse before we can account for all the circumstances by which they are accompanied. First, a single observer is insufficient to collect all the data; we ought to note the electricity, the direction of the wind, the movements and the form of the clouds, the size of the drops of rain, and the direction in which they fall, the form and place of the lightnings, and the divergence of the straws of the electrometer; each of these phenomena requires all the attention of an observer, who also loses valuable time in writing his remarks. Several additional observers are necessary, who, being dispersed over the whole surface where the storm is visible, should each notice all the indications in his station, and compare them with the rest.[17]

All the capricious indications of the electroscope are due to its being influenced by several strata of superposed clouds, which act and react on each other and on the earth, so that the electricities are developed and neutralised alternately.[18] We are accustomed in storms to see the most powerful developements of electric tension, and it is difficult to conceive how lightnings and claps of thunder could occur without there being a very notable electric tension. However, the electricity of induction offers analogous effects on a small scale. Insulate a charged Leyden jar, and bring the most sensible electroscopes near its outer coating; it will not give the least sign of electricity; and yet it contains a large quantity, which is retained by the electricity accumulated on the inner coating: this latter contains free fluid; for, if we bring the finger near, a spark is produced, and the superabundant electricity passes away to the ground. But, then, a portion of the electricity of the outer coating becomes free, and acts on the electrometer, while the inner coating does not act, and only begins doing so when the outer coating is again touched. These alternate contacts may be repeatedly renewed; the part, which formerly seemed in the neutral state, becomes electric as soon as the other is touched. If we suspend a jar horizontally by silk threads, and place an electroscope near it, its straws act as they do during a storm, with this difference, however, that there are not merely two coatings, but several; for each gust of wind condenses fresh

---

[17] *Vide* Note *q*, Appendix, No. II.

[18] *Vide* Note *r*, Appendix, No. II.

vapours which liberate electricity: hence we can understand how complicated the phenomenon is.

All storms furnish a proof of these successive condensations. A flash of lightning passes the zenith, and before the clap of thunder, but rarely afterwards, the rain or hail escapes in torrents from the cloud; the drops at first fall in a line inclined to the horizon, and then return to a vertical direction. It is commonly stated, that the rain is an effect of the lightning tearing the clouds;[19] but it is the gust of wind condensing the vapours into large drops, having first driven them into an almost horizontal direction: hence, the escape of electricity and the claps of thunder. As a proof that this condensation precedes the lightning, the rain often falls before the noise of the thunder is heard: now, the latter travels 333 metres per second; if, therefore, the rain were an effect of lightning, it would follow that the drops of water would have fallen with a velocity at least equal,—a velocity which they never have, even at the end of their fall.

Add to this, that storms are frequently heard over a surface of many thousand square myriametres, and that the electricity of each of their parts reacts on the other. The observer, who is situated on the plain, has not a sufficiently extensive view to embrace the whole, and he who is on a mountain is most commonly enveloped in clouds. In a storm that I observed on the Faulhorn, August 13, 1833, the lower clouds did not exist, and I was able to contemplate the phenomenon in all its grandeur. Many times during the day it had rained in the distance, and also near me. About seven in the evening, the mass of clouds, composed of several strata, presented a stormy appearance; their lower surface was at an elevation of about 3300 metres. Beyond the Diablerets in the Bas-Vallais, and Glaernisch in the canton of Glarus, nothing was visible. In this storm, which had an extent of more than 150 kilometres, the lightnings distinctly came from five different points: beyond the Diablerets, in the country of Vaud; to the right of Rinderhorn, perhaps in Simmenthal; in the direction of Berne; in that of Lucerne, behind the summit of Mount-Pilate, and in that of Schwitz. Many hours of observation convinced me that the electricities from these five points acted and reacted on each other. Out of at least one-third of the lightnings I drew the following conclusions: in the Pays de Vaud, a flash passed between two strata of clouds, for the lower stratum was very little illuminated; immediately afterwards, frequently

---

[19] *Vide* Note *s*, Appendix, No. II.

at the same time, a zigzag flash, directed from above downwards, was seen in the neighbourhood of Rinderhorn. Some instants afterwards, electric lights shone above Berne, and a zigzag flash replied to them in the neighbourhood of Lucerne, and then in that of Schwitz. When the atmosphere became very dark, I also saw lightnings in the east; but they were too far off for me to be able to study them. It is evident that the first flash, which passed in the neighbourhood of Vaud, disturbed the equilibrium of the whole system: an observer, placed at Schwitz, would, therefore, have observed oscillations in the electrometer, the prime cause of which depended on a flash of lightning that had occurred in the neighbourhood of Lake Leman.

**RETURN STROKE.**—It is not uncommon to see two storms separated by a part of the sky almost entirely serene; a flash of lightning in the one is followed by a flash in the other. But, the earth being by induction in a state opposite to that of the cloud, the electricity may recombine with that of the cloud and produce a violent shock. Few events of this kind have made so much stir as that of July 19, 1785; of which **Brydone** has preserved all the details. After a fine morning, clouds appeared in the north-west at 11 o'clock; between 12 and 1 o'clock they exchanged lightnings, which were succeeded by claps of thunder after intervals of twenty or thirty seconds. Suddenly **Brydone** heard a loud detonation, as if several guns had been discharged at short intervals; this detonation was not preceded by any lightning. At a short distance from the house a man named **Lauder**, driving a cart of coals, was killed, as were also his horses; another carman, seated on a cart that followed the former, saw the horses fall without perceiving any lightning or feeling any shock. Several pieces of coal were scattered about. At five decimetres behind each of the cart-wheels, there was a hole in the earth five centimetres in diameter, the middle of which corresponded with the tire of the wheel. These details were confirmed by ocular testimony. In the neighbourhood, a shepherd, who was feeding his sheep, saw a lamb fall dead, and he himself felt a flame pass before his face. This accident preceded that of **Lauder's** by about a quarter of an hour, and it occurred about 2700 metres from the place where the latter was killed. A woman, who was cutting grass at a short distance, experienced a violent shock in the feet, and fell. **Bell**, the shepherd, asserts that he felt the ground of his garden tremble beneath his feet.

These phenomena result from the action of clouds on each other and on the earth; we may imitate them by means of our machines. Electrise positively a conductor which I will call A, then arrange in its neighbourhood two small cylinders, B and C, placed one behind the other; if A and B are sufficiently far apart so that the spark cannot pass between them, B will be electrised by induction, the extremity nearer to A will be negative, the other positive, and a great number of sparks will pass from B to C. The same thing happens after a flash of lightning among several clouds, or between a cloud and the earth. Suppose that a large cloud electrises the earth by induction; if, at one of its extremities, a flash of lightning falls on the ground, the electricity of the opposite side, becoming free, unites with that of the earth. If the latter is moist, the passage is easily made; if not, there is a shock, because the earth conducts the electricity badly.

**LINES OF THE SEPARATION OF STORMS.**—In mountainous countries storms are generally more frequent and more violent than in the plain, because the winds produce a more rapid condensation of vapours; at the same time, the mountains oppose the movement of the clouds, and the electricity produced accumulates, as it were, in a single point. In some countries, mountains are actual lines of separation; often, indeed, a storm, formed in the plain or in a valley, is driven by the wind toward a chain of mountains; it stops there, whence it is afterwards drawn in another direction, and ramified in various ways. In every village, they will shew you the spot whence storms come; however, these operations must be subjected to scrutiny, which does not generally confirm the received opinion.

Mountains oppose to storms a purely mechanical obstacle; the storm is frequently drawn onward by a wind of moderate power, but the cold air below the cloud is precipitated with extreme rapidity, and passes away in all directions; while the warm air above moves in all directions toward the cloud. If the current of cold air meets a chain of mountains, it experiences a resistance, and arrests the movement of the cloud by reacting on it; if the direction of the progress of the cloud is perpendicular to that of the chain of mountains, it may remain clinging to them for a long time. If its direction makes an acute angle with that of the chain, it then follows it until it finds a valley whose direction is parallel to that which it had in the outset, it penetrates this valley, and then discharges itself. Isolated summits frequently separate storms into two parts, each of which pursues a separate course.

**STORMS IN WINTER.**—The formation of storms, as I have said already, is accompanied by a slow and continued fall of the barometer, which proves that south winds prevail in the higher regions of the atmosphere. When the ascending current elevates the vapours to a great height, they are rapidly condensed. The wind draws them along with it; wherefore, storms in winter always come with a S.W. wind. In other cases, the storm is formed at the point where two opposite winds meet; it is then very violent, and the state of the atmosphere is troubled for a long time. When east winds have been constantly blowing, and the S.W. obtains the pre-eminence, the weather becomes rainy. During these storms, there is so much confusion between the aërial currents, that it requires the most attentive observation to unravel them. I have rarely been able to observe them so well as during the storm of July 21, 1834; east winds had been prevailing for a long time, the sky was serene, and the temperature high, but the barometer fell slowly. On the morning of the day of the storm there were interlaced *cirri* in a sky with a heavy aspect, especially in the west. The *cirri* gradually condensed, the brightness of the sun became paler and paler, whilst in the east the sky remained serene. After four o'clock its azure hue disappeared behind thick *cirri;* and bluish clouds, the precursors of a storm, ascended from the west toward the zenith, which they passed. Thunder was soon heard, rain and hail fell in abundance, but the clouds moved with variable velocity. It was for a long time evident that clouds were moving from west to east, although the principal mass moved toward the west. Vapours coming from the west mingled with air coming from the east. Those which were lower were condensed, but were always driven back toward the west. Although the entire phenomenon was a consequence of the contest of opposite winds, yet it was easy to see that the combat was more violent in certain spots, and was accompanied with a condensation of vapours and a developement of electricity. Indeed, the clouds moved with velocity in one point; they turned on themselves, and became more and more opaque. The lightnings in this point succeeded each other with rapidity, and occurred less frequently in the other parts of the sky. This phenomenon was soon produced in another part of the sky, very distant from the former, and the lightnings ceased in the first point.

Thus it is that all the winter storms are formed, when two opposite winds contend together, and especially when a storm arriving, from the west, is driven back by an east wind. At the moment when the storm breaks out, the barometer generally begins to rise. But storms are seldom very violent in our countries, for the air is not sufficiently charged with vapours for a notable quantity of electricity to be developed. They are very common in the neighbourhood of the coasts, where the temperature in winter is higher, and the evaporation more abundant than in the interior of the country; but their duration is not so long, for the electricity produced is soon exhausted, and equilibrium is immediately re-established.

**LIGHTNINGS WITHOUT THUNDER.** — When a storm is situated below the horizon, we observe in the evening, and during the night, very brilliant flashes of lightning, while no thunder is heard, because the storm is too far distant from the observer for the noise of the thunder to be able to reach his ear. But, when the lightnings attain an angular height of 20°, it may sometimes happen that the thunder is scarcely heard. This is particularly the case when they are very high in the atmosphere; for then the sound produced in a highly rarified air is weakened, more and more as it traverses strata of greater density.

On a serene evening we often see after sunset intermittent lights that illumine a great portion of the sky; these are called *heat-lightnings*. They are observed within the tropics, as well as with us. At Demarara, they occur at the commencement of the rainy season, for then it is that storms are very common among the mountains in the interior, whilst the sky is serene all along the coast. We regard these lights as reflections of the lightnings of distant storms. Every one may convince himself that lightnings are reflected through the air with great intensity on a dark night. When a storm is in the west, and the rest of the sky remains serene, we have only to turn our back to the storm to see the lightning reflected in the east part of the heavens; and yet, in this case, the conditions for reflection are far less favourable than in the preceding example.

We may in this way perceive storms at enormous distances; but, as the observer has not always the opportunity of obtaining evidence of the existence of these storms, it has followed that various hypotheses have been given in order to explain these lights. Some have thought them a phosphorescence of the atmosphere; others have admitted electric sparks in a serene sky. But we commit here the same fault as for storms; they are observed at the moment they break forth, and all that precede them is neglected. In almost all cases when I have observed violent heat-lightning, the sky has been dull throughout the day, interlacing *cirri* have been perceived here and there; every thing has made us fear the approach of a storm; sometimes there have been also on the horizon *cumulo-stratus*, which seemed suddenly to disappear after sunset, but the lightnings betrayed their existence by illuminating their forms. In this case, we also very frequently perceive long horizontal bands of *cirrus*. The barometer begins to fall or rise; and in the majority of cases, in which I have observed heat-lightnings, I have found in the public journals that storms had broken forth at a distance of twenty or twenty-five myriametres. Many times these distant lightnings were followed by a violent storm during the night.

M. **de la Rive** of Geneva, and several Swiss philosophers, having maintained the opinion that these lightnings were not the consequence of distant storms, I may here add certain facts observed in the Alps, to which I may subjoin many others of which I was a witness in Germany and elsewhere.

On the 18th of June, 1832, from the summit of the Rigi, I perceived storms in different directions; toward evening, the sky was illuminated; and at nine o'clock there were no clouds except on the mountains of the south; these also were not long in disappearing. At ten o'clock, I observed brilliant lightning between the south and the S.E. beyond the Alps; a low and almost horizontal band of clouds, the upper border of which was visible only when illuminated by the lightning, was seen in the same direction. Beyond that, all the mountains were relieved. The lightnings passed the zenith. Had I not perceived the border of the storm-cloud, I might have believed them heat-lightnings. Travellers afterwards related to me that violent storms occurred almost daily in north Italy. On July 12, I saw, together with M. **Horner**, at Zurich, at the south of the lake, very vivid heat-lightning; there were *cirri* in the sky, and the lights illuminated even the streets of the town.

In the middle of the month of August, 1832, heat-lightning was very frequently observed at Geneva; during the day the sky had a dull and dim appearance. On August 16, the subject was actively discussed in the *Société de Physique et d'Histoire Naturelle*. After the sitting, heat-lightning illuminated the whole of the north horizon, as though to put to the test the opinions that had been advanced. During the day the sky had been dull; toward the north I had perceived *cumulo-stratus* about the horizon; and after sunset there still remained clouds in the sky. Some days after, the newspapers were filled with the account of ravages caused by storms in Baden, Wurtemberg, and Bavaria; even in the country of Vaud, the lightning struck several houses.

If the newspapers had also mentioned the storms that had occurred in this neighbourhood, without causing mischief, we might have seen that there were some even closer still.

The next morning, August 17, 1832, light clouds covered the sky; toward mid-day *cirri* appeared, and the sky acquired a dull appearance. In going toward Chambesy along the Lake of Geneva, I saw very distant *cumulo-stratus* at several points of the horizon, for their borders were red. Clouds concealed the summit of Mont-Blanc and the neighbouring mountains. M. **Theodore de Saussure**, with whom I passed several agreeable hours, told me that for some days the dryness of the air had been extreme, and the electrical signs were almost null. In returning to Geneva in the evening, I saw lightnings at the horizon in all directions; the brilliancy of the stars was diminished, and the clouds seemed to have disappeared, although I had distinctly seen them a quarter of an hour before the commencement of the lightning. It is not very probable that clouds so thick as these were thus dissipated in a quarter of an hour. On August 21, I saw beyond Bex very vivid lightnings in the Haut-Valais, as well as clouds, that I had observed during the day; all the sky was illuminated, even when I turned my back to the storm. I shall not add any other facts; for, in my opinion, it is certain that the so-called heat-lightnings are due to distant storms.

**SAINT-ULMO FIRES.**—When storm-clouds are very low, there is frequently no lightning; the electricity produced by induction is so powerful, that it escapes by salient points in the form of flames, as we see at the points of our electrical machines. This phenomenon, which was known to the ancients under the name of **Castor** and **Pollux**, has been since named St. Ulmo's Fire. The ancients relate several instances of it, which Titus Livy ranks among his prodigies. Flames, accompanied with a hissing noise, and leaping from point to point, had been seen at the extremity of the lances of soldiers and of the masts of ships. St. Ulmo's Fire is more commonly seen in winter; at least, the greater part of the accounts I have perused refer to that season. The following account by M. **de Forbin** may furnish an idea of this phenomenon; it occurred in 1696:—"The sky," said he, "was suddenly covered with thick clouds. Fearing a gale, I had all the sails reefed. There were more than thirty of St. Ulmo's Fires on the ship; one of them occupied the vane of the mainmast, and was about five decimetres long. I sent a sailor to fetch it. When he was aloft, he heard a noise like that which is made when moist gunpowder is burned. I ordered him to take off the vane; he had scarcely executed this order when the fire quitted it, and placed itself at the apex of the mainmast, whence it could not possibly be removed. It remained there for a long time, and then gradually disappeared. The storm terminated by a shower, which lasted for several hours."

On mountains this phenomenon is still more common when electrised clouds pass near them. **De Saussure** saw it on the Alps, and I have myself also observed it. Need I add that this flame, notwithstanding its analogy to fire, does not burn the objects it touches; the points of our machines are not heated even when the greatest quantity of electricity passes through them.

If there exist between the cloud and the earth other bodies that may be electrised by induction, then the latter may also part with electricity, which will be visible in the form of flame. A shower of phosphorescent snow has frequently been seen to fall to the earth; and, in this case, there is always a strong charge of electricity in the air.

We have now examined the most important phenomena that accompany a powerful developement of electricity. The observations which prove their connexion are still far from complete; and, in order that they might be thoroughly convincing, they must be repeated continually, and at different parts of the globe. However, it appears to me demonstrated that electricity is not the cause of the modifications of the atmosphere; and its most formidable manifestations occur, because the electricity liberated by the precipitation of the vapour of water cannot be neutralised except by a spark. A great many philosophers do not share in this manner of viewing the subject; but I should be carried too far were I willing to refute their opinions.

**HAIL.**—From the origin of Meteorology, a multitude of different explanations of this phenomenon have been given; and even now philosophers are far from agreeing with each other. How are we to understand that, during the fine season, and the hottest days, considerable masses of ice fall? Why certain countries are ravaged by hail almost every year, whilst adjacent localities are almost entirely spared? Is hail formed at a great height in the atmosphere, or at a moderate distance from the surface of the earth? Such questions as these have been often raised, but never solved.

Three species of hail, founded on the different sizes of the hailstones, are generally distinguished. But, to prove that this distinction has no scientific importance, it will be sufficient for me to observe, that no attempt has ever been made to distinguish the microscopic flakes of snow, which occasionally float during winter in the lower regions of the atmosphere when the weather is serene, from the large flakes which fall during moist weather. Every one knows, too, that between the fine rain which escapes from a moist fog and the showers of large drops from a storm-cloud there are all imaginable transitions.

Very small hailstones are termed *sleet*. Generally spherical, or almost spherical, they rarely attain a diameter of two millimetres; though they may reach three, or even four. Isolated hailstones are opaque, frequently soft, and of a whiteness approaching that of snow. The largest are sometimes surrounded with a slight film of ice; they fall in winter and in spring, during gusty weather; they rarely accompany storms.

Forms of Hailstones.—True hail has generally the form of a pear or of a mushroom, terminated by a roundish surface. It is an opaque mass, analogous to hardened snow. The large hailstones are surrounded by a thick coat of ice, and are composed of alternate layers of snow and ice. No observer has seen hailstones formed of transparent ice; all make mention of a snowy nucleus. The grains frequently resemble spherical pyramids or pyramids with three faces, terminated by a base, that is a portion of a sphere. Thus MM. **Delcros, Noeggerath**, and other observers, think that the primitive form of hail is a sphere that breaks to pieces in falling.* I think, however, that the pyramidal form is the primitive form of hail; for the nuclei of snow, sur-

---

* Descartes put forth analogous ideas on this subject. We read as follows in his sixth *Discours sur les Météores*:—"That if the snow is not yet so melted, but merely a little warmed and softened when the cold wind that converts it into hail arrives, it will not become entirely transparent, but remains white like sugar. And, if the flakes of snow are sufficiently small, as the size of a pea or less, each is converted into a tolerably round hailstone; but, if they are larger, they melt and divide into several hailstones, all pointed, and in the form of pyramids. For the heat that retires into the pores of these flakes, at the moment when the cold wind begins to surround them, condenses and presses together all their parts, acting from their circumferences toward their centres, which makes them become very round; and the cold, penetrating them immediately after, and freezing them, renders them much harder than snow. And because, when they are somewhat large, the heat they contain within still continues to make their interior parts press together and condense, by always acting toward the centre, after their outer surfaces are so hardened and congealed by the cold that they cannot follow, it is a necessary consequence that they must break within, along plains in straight lines tending toward the centre, and that the cracks shall increase the more, in proportion as the cold penetrates more onward; finally, they burst, and are divided into several pointed pieces, which are so many hailstones."

MM. Elie de Beaumont, Virlet and Airy, have also observed hailstones having the forms of a spherical pyramid. They assign to them the same probable origin as Descartes had previously mentioned (Vide *Comptes rendus de l'Acad. des Sciences*, t. iv. pp. 749, 801, and 922).—M.

rounded by a stratum of ice, frequently present this appearance; and, on the Alps, I have found that sleet generally affects this form. Grains of sleet form the centre of hailstones; and I think, with **de Saussure**, that sleet is changed into hailstones, as it descends in the atmosphere, in consequence of the addition of new layers of ice.

Hailstones formed of transparent ice are rain-drops, falling from clouds, brought by south winds, which freeze in traversing cold strata of air in contact with the earth.

SIZE OF HAILSTONES.—It is often very notable; but we should inquire whether the masses mentioned in authors are not due to the agglomeration of a great number of hailstones which have united in falling. Every year we find accounts in the newspapers of enormous hailstones that have fallen in various places. Let it suffice to mention a few instances. April 29, 1697, according to **Halley**, there were picked up, in Flintshire, hailstones weighing 120 to 130 grammes; and May 4, of the same year, **Taylor** measured some hailstones, in Staffordshire, that were three decimetres in circumference. **Parent** assures us, that on May 15, 1703, hailstones were found at Perche as large as the fist. **Montignot** and **Tressan** collected some at Toul, July 13, 1753, the form of which was that of irregular polyhedrons, and the diameter eight centimetres. **Musschenbroeck** observed at Utrecht, in 1736, a heavy hail-storm, of which all the hailstones were as large as a pigeon's egg; some, formed by the agglomeration of several others, were as large as a hen's egg. In North America, according to **Olmsted**, hailstones fall every year larger than hens' eggs. May 7, 1822, **Noeggerath** collected hailstones, the weight of which was 190 grammes. In 1811, **Muncke** found, in Hanover, a great number of hailstones, weighing 120 grammes. In a hailstorm, that committed great ravages on the banks of the Nile, August 13, 1832, the heaviest hailstone found by **Voget** at Heinsberg weighed ninety grammes; at Randerath, in the district of Geilenkirchen, the hailstones weighed from 120 to 240 grammes; some are said to have been picked up weighing 500 grammes. At Elberfeld, the hailstones were as large as a hen's egg. During a hail-storm, October 5, 1831, masses of the size of the fist fell at Constantinople. Half-an-hour afterwards some weighed as much as 500 grammes. Analogous masses are mentioned as having been picked up in the end of the month of May 1821, at Palestrina in the Roman States. Add to this, June 15, 1829, the hail beat in the roofs of the houses at Cazorta in Spain; the blocks of ice are reported to have weighed two kilogrammes. It is probable that they were agglutinated hailstones; we cannot doubt this in regard to a mass that fell in Hungary, May 8, 1832, which was one metre in length and width, and seven decimetres in length. Another block, equally large, fell near Seringapatam about the end of the reign of Tippoo Saib.

Relics of straw have sometimes been found within hailstones; and, in Iceland, volcanic ashes have been found. Much has been said also of hailstones containing sulphuret of iron and hydrated oxydes of iron; but the information collected at Orenburg by M. **Gustave Rose** would tend to induce our belief that this assertion is controverted.

**EPOCHS OF HAILSTONES.**—It is generally admitted that it only hails during the day. To test this assertion, I have collected together the dates of all the hail-storms in Germany and Switzerland that have happened within my knowledge, and have constructed the following table:—

**SEASONS AND HOURS OF HAIL-SHOWERS.**

| HOURS. | WINTER. | SPRING. | SUMMER. | AUTUMN. | YEARS. |
|---|---|---|---|---|---|
| Noon. | 1 | 8 | 10 | 5 | 24 |
| 1 | 4 | 18 | 8 | 6 | 36 |
| 2 | 10 | 38 | 15 | 13 | 78 |
| 3 | 4 | 19 | 11 | 8 | 42 |
| 4 | 5 | 14 | 17 | 1 | 37 |
| 5 | 4 | 16 | 13 | 3 | 36 |
| 6 | 1 | 9 | 8 | 5 | 23 |
| 7 | 1 | 6 | 10 | .. | 17 |
| 8 | 1 | 3 | 3 | 4 | 11 |
| 9 | 2 | 18 | 6 | 3 | 29 |
| 10 | 3 | 2 | 3 | 1 | 9 |
| 11 | 1 | .. | .. | 1 | 2 |
| Midnight | .. | .. | 2 | .. | 2 |
| 13 | .. | .. | 1 | .. | 1 |
| 14 | .. | .. | 2 | .. | 2 |
| 15 | .. | .. | .. | 1 | 1 |
| 16 | 1 | .. | .. | .. | 1 |
| 17 | 2 | 2 | .. | 1 | 5 |
| 18 | 1 | 1 | .. | .. | 2 |
| 19 | 7 | 13 | 3 | 6 | 29 |
| 20 | 4 | 3 | 1 | 2 | 10 |
| 21 | 3 | 6 | 2 | .. | 11 |
| 22 | 2 | 8 | 3 | 1 | 14 |
| 23 | 1 | 10 | 4 | 5 | 20 |

(*Vide* Appendix, *fig*. 41.)

This table shews, that hail falls at all hours of the day; but that it falls more commonly about mid-day or soon after, at the moment of the greatest diurnal heat. The numbers then diminish in a very regular manner; but at the hours nine and nineteen they are greatest, which might be supposed *à priori*.

These figures, it is true, are borrowed from the *Ephémérides de Mannheim*, and the hours indicated are those at which the instruments are observed. It is probable that the hail which fell in the intervals was registered at the time when the instruments were observed. The exact moment is only mentioned in those cases where the hail-storm occurred several hours before.

Nocturnal hail is not very uncommon. I have related a great many instances in my *Treatise on Meteorology*.

**HAIL IN THE DIFFERENT SEASONS.**—Hail, like rain and storms, does not occur with equal frequency in all seasons. Associating with it sleet, which does not sensibly differ from hail, we find that, in Europe, it is less common as we recede from the sea-coasts. Representing the number of times it hails in a year by 100, we find for the different seasons the following proportional numbers:—

DISTRIBUTION OF HAIL-SHOWERS IN THE FOUR SEASONS.

| | WINTER. | SPRING. | SUMMER. | AUTUMN. |
|---|---|---|---|---|
| England . | 45,5 | 29,5 | 3,0 | 22,0 |
| France . . | 32,8 | 39,4 | 7,0 | 20,7 |
| Germany . | 10,3 | 46,7 | 29,4 | 13,6 |
| Russia . . | 9,9 | 35,5 | 50,6 | 13,0 |

(*Vide* Appendix, *fig*. 42.)

Thus, in England, sleet or hail principally falls in winter; and the number of summer hail-storms is relatively very small. In France, the sleet, known by the name of *giboulées*, is very frequent in spring. In summer the number increases; and, in the interior of Europe, half the total number of showers of hail occurs in summer.

**OF HAIL IN THE HIGHER REGIONS OF THE ATMOSPHERE.**—It would be very interesting to the history of this meteor to compare observations comprising several years and made in neighbouring localities; for there are countries that are frequently ravaged by hail, whilst this is rarely the fate of other neighbouring countries. Thus, **Scheuchzer** affirms that, in the Swiss valleys, which run east and west, as Le Vallais and that of Glarus, twenty years sometimes elapse without hail. More recently, M. **de Buch** has said, that hail is rare in all the valleys where the *goître* and the *crétins* are observed; but, at the opening of these valleys, where they are confounded with the country called the plain, in opposition to the High Alps, hail is very common. Thus, Borgofranco, at the mouth of the valley of Aosta, is devastated by hail almost every year: and **de Saussure** had long ago remarked, that countries situated within a certain distance from high mountains are afflicted with this scourge more frequently than those placed at the foot of the Alps or at a great distance from these mountains. M. **de Buch** also believes that hail is not so common in high regions. At Cressier, above the lake of Neuchâtel, the vines are often beaten down with hail. In the village of Lignières, which is 390 metres above, rain falls, whilst hail is ravaging the vineyards on the shores of the lake. During the summer, storms come out from the valley of Travers, and discharge themselves in the form of rain in the elevated regions, and of hail in the lower countries. Near Clermont in Auvergne, at the foot of the mountains, storms are frequent, and they are always accompanied by hail. The villages of Blanzat, Châteaugué, and Sayat, appear to be condemned annually to these ravages. On the other hand, M. **de Savigne**, curé at Vernet in the mountain, affirms that these showers are rare between Mont-Dore and Puy-de-Dôme, and that he has seen hail fall but once in twenty-three years. This region is not far from the villages that we have named; it is merely situated 400 metres higher.

These observations, which would seem to establish a presumption that hail is formed, or increases in the lower regions of the atmosphere, are difficult of explanation. We should not forget that these notices reach us from cultivators who merely remark the hail-storms that diminish their harvests, and make no mention of the rest. Local circumstances must have a great influence over the frequency of hail. If the clouds are arrested by a chain of mountains, hail is more common. Some observers have very frequently seen it fall in elevated regions; the following are some examples:—

**De Saussure**, during his stay of thirteen days on the Col de Géant, at the height of 3428 metres, was struck with the frequency of hail and sleet, which he observed eleven times. **Balmat** experienced a shower of hail during the night that he passed on the summit of Mont-Blanc; and **Paccard** found much hail beneath the snow with which the summit is covered. **De Saussure** hence concluded that sleet is formed in the highest regions of the atmosphere, and that it is transformed into hail during its fall. **Zumstein**, in his ascent of Mont-Rose, June 12, 1822, experienced it at the height of 4550 metres; and **Welden** says that rains in the plains are hail or sleet in the mountains. The same observations apply to Glarus. The shepherd, **Heer**, at Matt, has assured me that the pasturages of the High Alps were frequently covered with hail; and his son, **Oswald Heer**, communicated to me the following accounts: "I was with some friends on the glaciers of Glaernisch, at about 2000 metres above the sea: suddenly, a black cloud, coming from the east, deprived us of the sight of Bachistock, which rises in the neighbourhood. Soon afterwards, several formidable claps of thunder re-echoed among the mountains of Glaernisch, and we saw several hailstones fall. We descended rapidly about 300 metres before the cloud burst. We were surrounded with lightning and thunder, and inundated with hail and rain. We took refuge under a rock; the clouds soon rose in the west, and formed a semicircle, beneath which we saw the country of Uri, lighted up by the rays of the sun. On coming out from our retreat, we perceived a second cloud, which soon burst over our head with a terrible crash. Hail, mixed with rain, followed us for several hours. Some cabins, constructed by shepherds, offered us an asylum, where we passed the night. In the valley of Serutti, at the foot of Glaernisch, at 715 metres above the sea, as also at Glarus (468 metres), no rain fell, but it hailed in the whole mass of Glaernisch. I regard our Alps as being excellent *paragrêles*. In the plains, it hails frequently; but in the valleys, at Matt, for instance, hail is very rare: on the contrary, it frequently falls on the summits. At some Alpine pasturages above Ammon, near the lake of Wallemstadt, they say that hail occurs several times during every summer."

These observations seem to prove that hail, or, at least, sleet, frequently falls in the Alps, whilst it rains in the plain; this evidently arises from the melting of the hailstones before they reach the plain. M. **de Charpentier**, at Bex, entirely shares in this opinion. He regards the larger drops of rain that so frequently fall during storms as melted hailstones. Although hail rarely falls at Bex, the mountains in its neighbourhood are frequently covered with a bed of hail that is readily distinguished from the snow, by its less brilliant white tint. On the Faulhorn, and on the Rigi, I have frequently seen sleet or hail fall, whilst it was raining in the plain. On the south summit of the Bagnères, about 2924 metres high, **Ramond** experienced a heavy shower of hail, followed by sleet and snow, which covered the mountain to about 200 metres below the summit. During his geodesic operations in the Pyrenees, M. **Peytier** was frequently interrupted by hail.

On examining meteorological registers kept in the Alps and their environs, we see that hail is no uncommon phenomenon in these mountains. The following are a few from among a great number of facts borrowed from the *Ephémérides de Mannheim.*

On the 10th and 31st of May, and the 9th of August, 1782, there were storms and hail in Bavaria, and snow on Mount St. Gothard. The 26th and 27th of May, 1783, there was a storm and hail in Bavaria, and hail on Mount St. Gothard, when the thermometer was still below zero, at 7 A.M. The 10th of August, hail in several countries; on the St. Gothard the thermometer did not rise above freezing point. Snow. August 23d, the same phenomena. May 29th, 1787, storm and hail all day at Padua; snow on St. Bernard and Monte-Baldo. May 27th, same thing at Geneva and on St. Gothard. June 7th, 1789, hail in the north of Italy; snow on the Alps. Same phenomena on the last days of June, the 14th of July, 1790, and the 28th of July, 1792.*

**HAIL BETWEEN THE TROPICS.**—It is very rare, and altogether unknown at Cumana. The hail which fell at Martinique in 1721, according to **Chanvallon,** excited the greatest astonishment. **Denham** and **Clapperton** saw hail fall in the interior of the African continent. At Tatta, near the mouth of the Indus, **Burnes** experienced a hailstorm; and he saw hailstones fall near Peschawer of the size of bullets.

At 500 or 600 metres higher, hail becomes more common, according to the observations of MM. **de Humboldt,** at Ca-

---

* From the 27th to the 31st of July, 1842, the weather was tempestuous and very variable on the Faulhorn. During the days of the 27th and 30th, M. PELTIER observed at least twenty alternations of snow and sleet on each of these days. Every time that the cloud or fog enveloping the mountains was white, the electricity was powerfully positive, and snow fell in abundance. This cloud was soon followed by a grey cloud that gave forth sleet, and the electricity of which had so great a negative tension, that no instruments could measure it. M. PELTIER thinks that sleet must be regarded as distinct from the true hail, which falls in the plains, and which always has asperities. — M.

raccas; **Pentland**, in Peru; **de Heyne**, at Mysora; **Bruce** and **Ruppel**, at Habesch. Moreover, on the 17th of August, 1830, so abundant a fall of hail occurred in Mexico, that, in the streets of the city, the horses were knee-deep. Thus, then, if rain is so rare in the plains, it is because the hailstones melt during their fall.

**NOISE DURING HAIL.**—Some ancient authors, such as **Aristotle** and **Lucretius**, have said that a very loud noise is heard when a cloud charged with hail approaches the zenith. Modern observers have confirmed this assertion. This noise is neither that of a tempest, nor yet the rolling of thunder; it is sometimes so loud that it drowns that of thunder. **Tessier** says that he observed this in France, on July 13th, 1788; and **Kalm** observed it at Moscow, April 30th, 1744. **Thienemann** asserts that he never heard this noise before the fall of hail; others affirm the contrary. It is probably either due to the hailstones beating against each other, or to the conflict of contrary winds; the latter are often so violent, that the hailstones are transported in a horizontal direction. It is often observed that the wind blows in puffs, and that each of them is accompanied by a torrent of hail. If the hail falls as usual at intervals, we see that hailstones, which are at first driven horizontally, finally mingle with the drops of rain; in the end, there is nothing but rain; the drops of which fall vertically to the surface of the soil.*

**MARCH OF STORM-CLOUDS CHARGED WITH HAIL.**—It is frequently observed that, notwithstanding their violence, and the storm which accompanies them, showers of hail are circumscribed by a very limited space. At a few myriametres from the place where the hail has fallen, not even wind has been felt. The hail frequently covers a long and narrow belt. **Musschenbroeck** has mentioned this circumstance, and the limited number of complete descriptions in our possession confirms this idea. A storm of hail that occurred in the Orcades, July 24, 1818, was of this kind. The storm of August 13, 1832, came from Holland; it traversed the Meuse, and destroyed all the crops along the Rhine for a space of 9 or 10 myriametres, with a width of from 1 to 1½ myriametres. A storm, described by M. **Tessier**, made a great impression on the mind. It commenced in the morning in the south of France, and in

---

* At the approach of a storm, while M. PELTIER was at Ham, in the department of La Somme, he heard so loud a noise, that he thought a squadron of cavalry had arrived full gallop on the *Place* of the town. It was nothing; but, twenty seconds afterwards, a terrible hail-storm fell on this town.—M.

a few hours reached Holland. The places destroyed by the hail formed two parallel lines from S.W. to N.E. ; one was 70 and the other 80 myriametres long. The mean width of the west line was 16, and that of the east line 8 kilometres. The space comprised between the two lines, the width of which was 2 myriametres, was spared; there merely fell a heavy rain. It also rained much on the east and the west of the two lines. The storm was preceded by an obscuration of the light of day; it travelled about 66 kilometres per hour, and its velocity was the same in both the zones. In the west zone the hail fell at La Rochelle, after a storm that had lasted all the night; at $17^h\ 30^m$, in Touraine, near Loches; at $18^h\ 30^m$, near Chartres; at $19^h\ 30^m$, at Rambouillet; at $20^h$, at Pontoise; at $20^h\ 30^m$, at Clermont, in Beauvoisis; at $21^h$, at Douai; at $23^h$, at Courtrai; at $0^h\ 30^m$, and at Flessingue, about $1^h\ 30^m$. In the west zone, the storm reached Artenay, near Orleans, at $19^h\ 30^m$; Andouville, in La Beauce, about $20^h$; the Faubourg St. Antoine, Paris, $20^h\ 30^m$; Crespy, in Valois, about $21^h\ 30^m$; Cateau-Cambresis, $23^h$; Utrecht, $2^h\ 30^m$. At each place the hail only fell for seven or eight minutes, but with so much violence, that all the harvests were cut to pieces. Of all the great hail-storms, there is not one of which we have such exact information, and yet it is still insufficient; thus the direction of the wind, and that of the clouds before and after the storms, and on the two sides of the space where the hail fell, have not been pointed out.

**ATMOSPHERIC PRESSURE DURING HAIL.—Du Carla** was the first to say that hail was entirely a local phenomenon. M. **de Buch** is of the same opinion. But, though the fall of hailstones be local, the storms and rain by which they are attended are not so. It follows, from all the descriptions of hail in our possession, that it must be attributed to the mutual conflict of north and south winds, and that, at the point where the shock is most violent, there is the greatest fall of hail. The state of the barometer proves this. I have extracted from the *Ephémérides of Mannheim* the seventeen heaviest hail-storms that have occurred in south Germany, and have compared them with the height of the barometer. In three cases the barometer rose from the evening before until the time when the hail fell; but the maximum of this rise was $1^{mm}$. In all other cases it fell; and the mean of the seventeen cases gave a fall of $2^{mm},5$. From the day of hail to the following day, it remained stationary in three cases: in two others it fell beyond $1^{mm},3$; in all other cases it rose, but never more than $2^{mm},86$. We should conclude, from these oscillations, that hail is brought by south winds entering into conflict with those from the north.

This explains to us a fact that would remain altogether incomprehensible were hail to be regarded as an entirely local phenomenon. It is often observed that, after hail, the weather remains unsettled for whole weeks; in particular, it is followed by cold. But, as the hail itself is produced by the conflict of two opposite winds, that which drives the other back changes the weather for a long time. The rise of the barometer proves that the north wind usually obtains the predominance; and the more so, as in melting the hail absorbs a very notable quantity of heat.

We are the more struck by this contrast, because hail is frequently preceded by great heat. At a mean, the temperature observed during hail-storms at Geneva, Munich, and Padua, during the space of six years, was higher than 20° at about two P.M. Once it even rose to 30°. A short time afterwards the hail fell. Whence, it may be asked, does this very low temperature originate, so as to produce such large masses of ice; for a rigorous calculation apparently shews that the cold of the higher regions cannot be very intense? We must in fact ascend about 195 metres, in order that the temperature may fall 1°; and, consequently, if the heat is only 20° in the plain, it is not until the height of 3900 metres that a freezing temperature will be found. Now, storm-clouds being frequently much lower, we do not comprehend how hailstones can be formed at this elevation. But, if we had studied more carefully the decrease of temperature during the time of hail, we should find that this high temperature is limited to the lower zones of the atmosphere, whilst those above are much colder. Out of six hail-storms that occurred at Padua during the summer months, the mean temperature on St. Gothard, at two P.M. was only 3°,5, that is, several degrees below the mean of the month. Several times during the afternoon the thermometer fell below zero, and, in the evening, it frequently fell 5° below the freezing point. It never rose above 9°. If we inquire how high we ought to ascend in order to have a fall of 1° in the temperature, we find for the afternoon :—

| | |
|---|---|
| Geneva and St. Gothard . . . . | 114$^{m}$,4 |
| Padua and St. Gothard . . . . . | 114 ,4 |
| Munich and St. Gothard . . . . | 111 ,2 |
| Mean . . . . . . . . . . | 113$^{m}$,3 |

Sometimes the decrease of temperature is still more rapid; thus, on June 27, 1790, the thermometer at Munich was at 26°,5; on St. Gothard, it stood at 5°,1; and the decrease of temperature was 1° for 73 metres. On the hottest day of hail at Padua, the temperature was 29°,4; on St. Gothard, 5°,8, which gives a decrease of 1° for 87$^{m}$,8. On this day, at a mean, the temperature of zero was found at the height of 2600 metres. The same day, there would prevail, at the height of 3900 metres, a temperature of —9°, and at 5850, that of —26°,5, numbers which differ greatly from those generally adopted.

**VOLTA'S THEORY OF HAIL.** —This theory being the only one that includes all the circumstances of the phenomenon, I will give it at some length. In order to explain how hail can be formed below the region of eternal snows, and during the hottest season, he admits that it is due; 1st, to evaporation favoured by the solar rays striking the upper part of the cloud; 2d, to the dryness of the air above, and which **de Saussure** and **Deluc** have repeatedly established; and then to the tendency of vesicles of vapour to pass into the elastic state, since they repel each other; 3d, and then to the electric state of the clouds, which, he says, favours evaporation. The dryness of the air above the clouds is an essential condition to the formation of hail; but for this the elastic vapour condenses as fast as it is formed, and, disengaging a quantity of latent heat, the cooling is not so intense. **Volta**, moreover, admits the condition that the sun strikes the upper surface of the cloud, and this way explains why hail almost always falls during the day. Under these influences flakes of snow are formed, which are as it were the embryo of hailstones. In order to explain their increase, he admits the necessary existence of two superposed clouds; the upper cloud is formed by the condensation of the vapours proceeding from the lower stratum. The two strata are charged with the opposite electricities; the higher becomes positive, and the lower, whose particles are undergoing evaporation, becomes negative. To explain the formation of hailstones, **Volta** relies on the well-known experiment of the dancing figures. We know, indeed, that if a copper plate is fixed horizontally to the conductor of an electrical machine, and at some distance another plate is placed in connexion with the earth, light bodies between the two plates, being alternately attracted and repelled, dart continually from one plate to the other. According to **Volta**, the same thing happens between the storm-clouds.

The snow-flakes of the lower stratum of clouds are in the same electrical condition with it; they are, therefore, repelled, and attracted by the upper stratum. As soon as they touch it, they partake of its electricity, are repelled, and fall to the lower cloud into which they penetrate; they are again repelled, and so on. These attractions and repulsions may last for several hours; during which time the grains unite in masses, and condense around them the surrounding vapours, which they convert into ice. They strike against each other; and hence originates that noise, which according to the account of some observers, precedes storm-clouds. When the hailstones have attained a certain size, the lower cloud can no longer retain them and resist the action of gravity; they traverse the stratum, and fall to the earth.

Notwithstanding the favour with which this theory was adopted, it met with several who doubted its truth. **Prechtl,** in particular, remarked how improbable it was that evaporation alone could produce so great a degree of cold in full sunshine; then again, how could it be credited that the hailstones which fell from the upper cloud could be retained by the lower, and not pass through it, by virtue of the velocity they had acquired? If it is unlikely that the formation of hail is due to electricity, we can comprehend the inutility of *paragrêles*, which are tall posts erected for drawing off the electricity of the atmosphere, and opposing the formation of hailstones. Are not forests a collection of living *paragrêles*;[20] and yet they are not spared by hail?

**FORMATION OF SLEET.**—This is more easily explained, because it is more commonly observed in the cold season. At a small height in the atmosphere the temperature must be below zero. Sleet always falls during gales, and when the weather is variable. Even when the air is quiet on the surface of the earth, we see that the clouds move rapidly, and that there is wind in the higher regions of the atmosphere. I consider these gusts as a necessary condition for the formation of sleet. On the Alps, I have seen that snow is transformed into small spherical bodies or pyramids, when the wind blows in squalls. At the moment when the latter cease, the snow falls in flakes; the observations I have made in the plains of Germany seem to confirm those of the mountains. We might think that this formation of particles of sleet is due to the particles being rolled in space, and increasing like a snow-ball by the addition of fresh flakes of snow. I would rather compare it to

---

[20] *Vide* Note *t*, Appendix, No. II.

the crystallisation of salts; for their form more frequently approaches that of a pyramid with three faces. In like manner, as differences of temperature during crystallisation determine the appearance of different forms, so also the crystallisation in the present case, which occurs in a plane in quiet weather, follows the radii of a sphere during agitation of the air; and hence arise spheres or pyramids. Minerals with a mamellated surface also present in their interior radii starting from a central point.

**ORIGIN OF HAIL.**—All the hypotheses which have been made on the origin of hail are defective, in supposing the clouds already completely formed; now, at this period of the phenomenon, the higher clouds are completely concealed by the lower. The following explanation is, no doubt, liable to several difficulties, yet it accounts for a greater portion of the circumstances of the phenomenon; but, in order to complete it, we ought to be in possession of a long series of observations.

As **Volta** was the first to observe, the existence of two strata of clouds is the condition indispensable to the formation of hail. I have quite verified this; and we frequently see these clouds travel in two or three directions, an evident proof that they are not in the same atmospheric zone. But, while **Volta** attributed the formation of the upper cloud to that which is placed below, I think I am right in concluding, from all my observations, that it is the upper cloud which is first formed, and which plays the most important part.

From the morning of the days of hail, the sky presents a peculiar appearance. The blue is not clear or deep as on a perfectly fine day, and *cirrus* is observed in the form of very fine filaments. Sometimes the *cirri* are even much more developed; great white masses are dispersed hither and thither, and their boundaries are lost in the blue of the sky. Coronæ and parhelia are often seen,—phenomena, which are due, as we shall presently see, to the refraction of luminous rays by frozen particles. These appearances precede showers of hail in places where the observer is, and at points at greater or less distances.

The same atmospheric state prevails over a great space; and, as the barometer falls slowly, we are right in concluding that the south wind prevails above. However, this wind is not felt on the surface of the ground, when the air is perfectly calm; or, if there are some currents, they are altogether local, for, at small distances from each other, the vanes take opposite directions. Under the influence of these circumstances, the earth, and then the strata of air in contact with it, become highly heated. But this temperature rapidly decreases with the height, because the strata of air do not mix; and, even though a burning heat should be raging below, at 2500 or 3000 metres, the thermometer is below zero. A very energetic ascending current is, therefore, produced; and, even though the air should not be very moist, yet the higher strata of the atmosphere are rapidly saturated. Clouds are formed; and, at first sight, it would seem that they are *cirri* condensing, because the ascending current elevates them still higher.

If we reflect that *cirri* float at a height of 6000 metres, and more (for I have never seen them below the high summits of the Alps), we can understand that the region in which these flakes of snow are suspended is at a temperature very much below zero. The heating of the ground being very unequal, the ascending currents have also a force and extent differing very much; hence the horizontal winds in the higher regions of the atmosphere.

The ascending currents acquire their greatest degree of velocity at the moment of greatest diurnal heat; and the rupture of the atmospheric equilibrium easily determines the formation of storms. In proportion as the higher stratum of *cirrus* becomes denser, *cumuli* are also formed, which increase with extraordinary rapidity. We then recognise that the wind presents opposite directions—a result of the unequal distribution of the clouds in the sky, and of the fall of temperature accompanying their presence. These clouds are sometimes dissipated and resolved into rain or hail; but the most trifling circumstance may prevent their resolution. They frequently increase, when strata of cold air are descending toward the earth, and determining precipitations of aqueous vapours, and a very notable developement of electricity.

These precipitations are much more evident when north winds at a low temperature contend with those from the south. A circumstance which proves that this is frequently the case is, that it is not an uncommon thing to see the barometer rise after a fall of hail. On the line, where the winds meet, the condensation of vapours is brought about with great energy; superposed strata of clouds are formed, of which the lower are frequently very dark. These clouds are not very high, and resemble sacks or bunches of grapes, which seem every moment about to fall; we often recognise gyratory motions. Sometimes they have a clearer tint than the higher strata, and they generally move in an opposite direction. Should the violence of the higher or the lower wind suddenly increase, whirlwinds are propagated from below upwards in the cloudy mass, the volume of the flakes of snow floating in the atmosphere increases rapidly, they acquire the form of particles of sleet, and are driven horizontally by the wind, until they reach the ground. Enough electricity is then liberated to produce a clap of thunder; but almost all the sleet reaches the ground before this is heard. Fresh gusts favour the formation of large hailstones; so that the hail does not fall for any length of time: frequently, for a few seconds only. This new shower of hail is preceded by a flash of lightning. At the same time, the fury of the gusts gradually diminishes, and, at last, the hailstones fall almost vertically.

We have shewn how the flakes of snow, of which the *cirri* are formed, may be converted into hailstones. The form even of hailstones, their fall on low countries, or on elevated places, depends on the constitution of the rest of the atmosphere. If the hailstones are small, if the temperature of the higher regions of the atmosphere is still sufficiently elevated, it may then happen that the hailstones melt during their fall. Sometimes the drops of rain that are the result condense on their surfaces a great quantity of the vapour of water: hence those large rain-drops, that frequently precede storms, and which fall in small showers like hail. At the same time, the mountains are covered with snow or sleet. Thus, on the Rigi, I have frequently seen snow or sleet fall, whilst it was raining in the plain; this is a very common phenomenon, if I may credit the assertions of the host and of the guides.

If the temperature is very low in the high regions of the air, then hail falls in the plain in a solid state. If the hailstones are driven horizontally, a fresh quantity of water is incessantly precipitated at their surface, and their volume continually increases. Their internal structure depends on the state of the air through which they pass. A pyriform or pyramidal body moves either horizontally or vertically; but the larger end is always downward or in advance: on this surface the vapour of water will condense, unless the hail is driven into whirls, and turns rapidly upon itself. If the air that is traversed by the hail is free from clouds, or if the latter are not very thick, the vapours are condensed at the surface of the hail, as occurs with white frost: in this case, the entire mass resembles hardened snow; but if it traverses very dense clouds, where the vesicles of water are intermixed with drops of rain, transparent ice is then formed, in the interior of which we find a particle of sleet. It is the same mode of formation as that of the drops of frozen water that fall during winter, when a thaw suddenly succeeds a hard frost. If a hailstone of this kind traverses several strata of clouds, separated by spaces not filled with the vapour of water, and if the clouds are not charged with drops of rain, then concentric layers are formed, alternately composed of snow and ice, as we have very frequently observed.

The rapid decrease of temperature is, therefore, the principal condition for the formation of hail; and it follows from this that, in the fine season, and during the hottest days, it must specially be formed, because then the ascending current is very energetic. However, hail may fall in other seasons; for, if south winds prevail with a certain continuance, the *cirri* increase in the evening or during the night; if north winds then begin to blow violently, hail will fall during the night, a rare circumstance, because there is no ascending current. This explains to us why hail is less common between the tropics than in mean latitudes; it is because, in the vicinity of the equator, the decrease of temperature with height is not so rapid.

The conflict of opposite winds also explains certain peculiarities of storms, accompanied by hail. Every thing that tends to put the air in motion favours the formation of hail. This is why it is more common in the mountains, where the rapidity of the atmospheric current increases in the valleys. If the march of storms were known by observations embracing a series of several years, by comparing local peculiarities, we might discover why certain countries are frequently ravaged by hail, whilst others are almost entirely spared. Narrow valleys, surrounded by high mountains, as the Vallais and the vale of Aoste, are rarely visited by hail: these valleys are so warm, that the hailstones melt before reaching the ground. Moreover, the high mountains that hang over them prevent the conflict of opposite winds, or limit it to the high regions of the atmosphere, which prevents the hailstones acquiring any considerable volume. But, at the mouth of valleys, in the plain, storms, accompanied with hail, are the more violent (principally on the south side of the Alps), as the south winds are arrested by the mountains, while the north winds, when they have traversed them, rush impetuously to the plain.

It remains for us to explain why the majority of hailstones extend over a very long and narrow space, as the storm of 13th July, 1788, which traversed western France to Holland. Observations are wanting for the solution of this problem, However, on consulting the *Ephémérides de Mannheim*, we almost arrive at the conclusion that there was a conflict between north and south winds. Even from 11th July the barometer fell, and the more so, as it was nearer to France. In Bavaria, the fall from the 11th to the 12th was, at a mean, only $0^{mm}$,4; at Brussels, Middleburg, La Rochelle, $1^{mm}$,3. From the 12th to 13th, the barometer fell in Bavaria $3^{mm}$,4, but at La Rochelle it had risen even $2^{mm}$; whilst it fell at Brussels and Middleburg $2^{mm}$,2. From the 13th to 14th, the barometer rose every where in Bavaria more than $2^{mm}$; in Holland, $3^{mm}$,3. It is, therefore, probable that the south wind was driven back by the north wind, and throughout the whole line where the conflict occurred there were brisk and violent gusts, which precipitated hailstones, and rooted up large trees. This association of phenomena is rarely evidenced along a greater extent; it is commonly circumscribed within narrow limits; but the hail is always formed at the point where the two opposite winds meet. Like as, during one year, the rain chiefly falls from clouds heaped up by the north wind, and, in another year, from those brought by the south wind, so the conditions for the formation of hail do not occur every year; hence the frequency of hail during certain years, and its rarity during others.

**WATER-SPOUTS.**—Whirlwinds, manifested at the approach of storms, have often great violence; they are described under the names of water-spouts (*trombes*) *wasserhosen*, *sandhosen*, *sandwirbel*, Germ. These whirls possess great analogy with those observed when two currents of water run beside each other with different velocity. During a feeble wind, we often observe small whirls near a house or other isolated object. The air being still at one spot, and agitated at a little distance, the particles at the limits are acted on by different forces. Imagine a horizontal line, perpendicular to the plane of separation; among the particles situated on this line, there are some which are altogether motionless, whilst others are drawn along by the wind with a certain rapidity. However, there are certain transitions between the last motionless molecule and that which is drawn along with the same velocity as the wind: hence the whirls, which are partly drawn along by the predominant wind. We recognise the whirls, because they raise light bodies, such as dust, leaves, straw, several metres in height. Water-spouts are analogous phenomena on a much larger scale. The whirlwind not only exists in the cloud, but even in the water, which rises and joins the cloud that descends to meet it.

Water-spouts are not equally common in all parts of the ocean. In the middle of the equatorial sea we only find them when the trade-winds do not blow in a regular manner; they are only manifested in the region of calms. They are commonly met with near the coasts, or in straits, and they are more frequently formed at the time when the monsoons change: something analogous occurs in the high latitudes, where they frequently coincide with storms.

From the facts collected by myself and others, water-spouts almost always occur when two opposite winds pass side by side, or when a very brisk wind prevails in the higher regions of the atmosphere, while it is calm below: I saw a remarkable example on the Rigi in 1832. Being on the summit of the mountain, I examined masses of fog which were proceeding towards each other in the valley of Goldan, whilst around me the air was calm and the sky serene. At the end of a few moments the masses united, and I observed a gyratory movement in the midst of them; the fog extended with inconceivable rapidity, and violent gusts drew from it rain and hail. In the meantime the temperature had fallen, so that the water between the teeth of the wheels of my **Woltmann's** anemometer was congealed. A physician of Dantzig, who arrived in the evening, told me, that on the lake of Quatre-Cantons he had experienced a violent storm, during which the clouds had been driven in different directions; at the same time he saw a water-spout.

If the currents that meet in the high regions of the atmosphere are violent, if their temperature and the quantity of vapour of water with which they are charged are very different, then the vapour is rapidly condensed. In proportion as the whirlwind increases, it descends, and the diameter of the column decreases; we cannot decide whether the vesicles of water are drawn from above downwards, or whether the condensation occurs in the opposite direction. Finally, the whirlwind reaches the surface of the earth, the latter is agitated, and rises resembling a boiling caldron. While the sea rises the cloud descends, and finally they both unite; it also sometimes happens, that the sea rises in the form of a cone, while an inverted cone descends from the cloud without their both uniting. In the majority of cases, the column is thinner in the middle than it is above or below; under other circumstances, the first trace of the water-spout is evidenced on the sea, a cone rises from the surface of the waters, and it is not till after some time that the vapours from above condense in their turn.

A fact, which proves that the water-spout is in a great measure formed of condensed vapours, is, that the water escaping from it is never salt, not even in the open sea.

If the air is very dry, then these whirlwinds do not always determine the condensation of vapours, and the violence of the wind is the only thing remarkable. Thus, two of my friends were one cloudy day going from Halle to Giebichenstein; on a sudden they were separated by a gust of wind, and one was driven against a wall and the other thrown into a field, while the people who were near had not perceived the least disturbance in the atmosphere.

Almost all observers say, that the water-spout moves slowly onward, turning on its axis; if the current rises, as we see in the whirlwinds of sand, it may draw up enormous masses. **Wolke** relates, that a shepherd near the Jever saw, near Repsolt, a place situated three myriametres from the sea, a water-spout pass before him, and instantly dry up a pond and throw the fishes in all directions. All descriptions prove that in these cases the wind possesses extraordinary force. Thus, Dr. **Mercer** observed two or three water-spouts in the port of St. Jean of Antigua on the surface of the sea; he saw a circle of about sixty metres in diameter, within which the water was agitated and darted towards the sky. A small wooden house was carried away entire, and transported to the distance of thirteen metres without being overturned or destroyed. It is remarkable, that the house was carried from east to west, although the water-spout travelled from west to east. I borrow from the public newspapers another example of the same kind:—Oct. 25, 1820, a large quantity of linen had just been spread out in a meadow in Silesia; the workmen were at dinner, when the tempest announced itself a few minutes after noon, and raised such thick clouds of dust that the day was converted into thick darkness. The doors and blinds of the bleaching establishment were torn down with a terrible crash, the doors were carried off their hinges, and the wind overturned a heavy cart, so that the wheels were placed upwards. The linen was seized upon, and rolled up, and the largest mass was carried fifteen metres above the house, and deposited at 150 paces distant in a ditch in the midst of some bushes. They had to work for several hours in order to disentangle this immense skein; it consisted of twenty-seven pieces, each of which weighed eleven kilogrammes; and in the middle was found a post two metres long, thirty centimetres wide, and six thick, which was used as a bridge for crossing a ditch at a little distance. The water-spout had carried it away with the linen, which it had rolled round and carried over the house, although its weight, without calculating that of the plank, was about 297 kilogrammes.*

When we call to mind the force with which small water-spouts raise water, we are not astonished that a great one can produce such effects. Some authors have attributed these effects to electricity; but if we merely rest on the fact, that this fluid determines such effects as these on the surface of water, we should not forget that purely mechanical forces could produce it as well. Other philosophers have thought that a partial vacuum was formed, in which the water rises as in the body of a pump; but, to suppose the existence of this vacuum, the water would only rise to the height of ten metres, and the helical motion would not exist. It has also been said, that gases suddenly escape from the earth where the water-spout is formed, and raise the water; such an hypothesis as this requires no refutation.†

---

* The water-spout that devastated the village of Châtenay, near Paris, June 18th, 1839, brake, near their base, elm-trees 1m,50 in circumference. M. L. LALANNE, civil engineer, who drew up the plan of the place after the disaster, estimates at 456 kilogrammes per metre the effort exercised against certain parts of the walls that were overturned.

According to M. RENAUX, architect, the water-spout that passed over the town of Courthezon (Vaucluse), May 30th, 1841, overturned a face of a rampart, twelve metres long by eight high and one thick. A great part of the materials were carried to the other side of the Seille, to the distance of about eight metres. In the Faubourg d'Orange, a newly constructed façade was demolished.—(*Comptes rendus de l'Acad. des Sciences*, t. ix. p. 219, and t. xiii. p. 223.)

† In the *Traité des Trombes*, which M. PELTIER published in 1840, we find an account of 137 water-spouts. In this number we notice thirty-three that existed in the midst of calm, twenty-five which had no migratory movement, thirty-seven which occurred with this motion. The silence of the accounts upon the rest of the water-spouts is a presumption in favour of the negative, because, as M. PELTIER says, a relation is the indication of *that which is*, and not of *that which is not*. Ten occurred in a sky without clouds; seven are multiples, that is, there were several branches from the same trunk; three were formed within the clouds, &c.

In addition to this, we find fifty-two relations of stormy phenomena which produced effects analogous to those of water-spouts; finally, this treatise contains the details of experiments by which the different parts of this meteor were produced by means of electricity. The sum of the facts does not appear favourable to the theory that attributes this order of phenomena to whirlwinds.—(*Vide* also, on water-spouts, the article by M. OERSTEDT, in M. SCHUMACHER's *Annuaire* for 1838.)—M.

# VII.

# OPTICAL PHENOMENA

# OF

# THE ATMOSPHERE.

HITHERTO we have only studied the heating power of the sun; we have seen that the diurnal and annual range of temperature depends on the revolution of the earth around this body. The unequal heating of the different regions of the earth has disclosed to us the origin of winds, the changes in the aspect of the sky, and the differences in the pressure of the atmosphere, changes which are interwoven with a rupture of equilibrium in atmospheric electricity. We are now about to examine the phenomena to which the sun gives rise, when regarded as a luminous body, after having prefaced them by a few general observations upon light.

**NATURE OF LIGHT.**—Light and heat are so intimately connected with solar rays, that it is difficult to separate these two manifestations; we shall not enter deeply into this subject, which belongs to the domain of experimental philosophy; nor shall we seek to penetrate farther into the intimate nature of light. Two hypotheses have been put forth. In the first, light is composed of material molecules sent forth by the luminous body; by acting on the retina, they enable us to see the body from which they emanate. In the other supposition, which appears much more probable, the luminous impressions are due to the undulations of a very subtle fluid spread throughout the universe and in the interior of all bodies, a fluid known by the name of *ether*. There exists, therefore, in luminous bodies a force which puts the ether in motion, as the string of a violin, when put in motion, makes the air vibrate, and produces a sound. The undulations of light are transmitted through the ether, as those of sound are through air; and they excite in the eye a sensation analogous to that produced by the others on the ear. In passing from vacuum into the air, these undulations undergo the several modifications that we are about to study.

**REFLECTION AND REFRACTION OF LIGHT.**—The ether being only a hypothetical fluid, the properties of which cannot be recognised by aid of experiment, we can say nothing positive as to its nature in the interior of bodies; however, if we conclude from analogy with that existing in the air, we may admit that its density in the interior of bodies is greater than *in vacuo*, and that this density is different in the different bodies in nature. Take, for example, pieces of glowing carbon and allow them to cool *in vacuo*, then place them in a small capsule swimming on a surface of mercury, and cover them with a small bell-glass; in a short time, the quantity of air contained in this bell-glass will diminish, it will be absorbed by the carbon; and, as the mass of air that has disappeared is greater than that of the carbon, we must conclude that the air has been condensed within the carbon. This absorption of air is so considerable, that fifty kilogrammes of newly prepared carbon, when exposed to the air, will weigh, after a certain time, 52,5 kilogrammes. Almost all bodies exercise an analogous influence, but with a different intensity, according to their nature: it is probable that the same occurs with respect to the ether.

When light passes from vacuum to a transparent body, the undulations change with the density of the ether; their nature remains the same, but the amplitude of the oscillations is less, as a wave diminishing in height. Light is divided into two parts; one is reflected, the other penetrates into the interior of the body. Sound presents analogous phenomena: if sonorous waves strike against a wall, one part of the sound is propagated through the wall, and we hear it behind the wall; the other is reflected and produces echo.

Experiment proves that the reflection of a ray is not made in the same direction as that of its incidence. Indeed, let it be made to fall upon a flat and perfectly polished surface, and suppose a perpendicular to be raised at the point of incidence, we shall see that the reflected ray and the incident ray are both in a plane perpendicular to the reflecting surface, but the reflected ray makes with the normal an angle equal to that of the incident ray. If the body on which the light falls is perfectly polished, and approaches as much as possible to a geometric plane, then the quantity of light thus reflected is very considerable; and the body reflected appears to us in its perfect form, as is the case when we look into a mirror. However, very few bodies are thus terminated by surfaces almost mathematical; the majority have unequal surfaces, which may be regarded as composed of a great number of little planes diversely inclined to each other. The incident rays, therefore, are dispersed in all directions, and we do not obtain a clear image; the objects simply become visible.

The second portion of the incident ray penetrates into the interior of the bodies, and traverses them, if they are transparent; but if the ray, which falls on a body from air, or from vacuum, is not perpendicular to the surface of incidence, it is deviated from its primitive direction, it then continues its course in a straight line, as long as it remains within the body, until it is again deviated at its egress: this phenomenon is known by the name of *refraction*. The angle made by the incident ray, and the refracted ray, depends on the inclination of the incident ray on the surface of the refracting body, and on the nature of that body: however, there exists a constant relation between the incident and the refracted ray; and, if this relation is determined for a single incident ray, it is determined for all the rest. It is on this principle that telescopes are constructed; and the deviation of an object, when looked at through a triangular prism, has no other means of explanation.

**ON COLOURS.** — However varied the phenomena of colours may be, they all depend on a principle discovered by **Newton**, namely, that the white light, that comes to us from the sun, is composed of a multitude of coloured rays, the refrangibility of which is not the same. If we pass a ray through a circular hole, and receive it on a glass prism, the emergent ray makes with the incident ray an angle depending on the angle of incidence of the ray, and on the nature and form of the prism. Moreover, the circular form and the white colour of the illuminated spot have disappeared, and we see a spectrum, the length of which is greater than the width, and which is red at one of the extremities and violet at the other; between these extremities are the colours of the rainbow, which melt insensibly into each other. The angle made by the violet rays, as they leave the prism, with the incident ray, is always greater than that of the blue rays; and this angle continues diminishing as we consider the green, yellow, orange, and red. If one of these coloured rays is made to fall on a second prism, there will be no further decomposition of the light; but the refrangibility of the violet rays will always be greater, and that of the red rays less than all the others. Two consequences flow from these facts: rays of different colour have not the same refrangibility, and the white light of the sun is composed of coloured rays, which form white by their union, but which are separated by the prism.

Almost all the rays that reach us from terrestrial objects are coloured: these objects decompose white light, absorb some colours, and reflect others; and hence it is that the objects themselves appear to us coloured. If we look through a glass, coloured by cobalt, it will absorb in preference the red rays, those of the other extremity of the spectrum will pass through, and the glass will appear blue; here, again, the prism serves to prove the composition of white colour. Indeed, if we allow a pencil of light to pass through a narrow opening and a piece of cobalt glass, and then receive it on a prism, the succession of colours will not be the same as with white light; but several rays will be wanting in the spectrum, and will be replaced by black stripes.

As the eye is fatigued, like every other organ, when the sensation lasts too long, and this sensation is prolonged some time after the cause has ceased, there results a succession of colours that are called subjective or physiological. Look attentively at a green circle on a white ground, then close the eyes; you will continue to see a green circle on a white ground, because the sensation continues for some time on the parts of the retina that have received that of the green circle on the white ground; but if, instead of closing the eyes, we look at a white surface moderately illuminated, we shall see a red circle on a clear ground. Indeed, the portion of the retina, on which the image of the green circle fell, is at last fatigued with this sensation, and becomes more susceptible to the other colours of the spectrum; now, if we eliminate from the spectrum green and the analogous colours, those which remain form red. Inversely, if we had been considering a red circle, we should have perceived green on a white ground: hence it is that we so frequently imagine that we see colours which do not really exist; or, at least, the colour of one object changes that of another object situated near it. Every one is aware of the benefit painters derive from these contrasts of colours.

Take a book, the paper of which is very white, but the edge green, turn it over so that the green and the white pass alternately before the eyes: the white will soon be coloured red, and with the more intensity as you continue to turn it over for a longer time; because the eye will become more and more fatigued by the green, and the impression of the red rays will be the more vivid. This phenomenon is sometimes presented in the atmosphere. When the sun is near the horizon, and isolated red clouds are spread over a whitish sky, then the sky appears green after a few moments,—a subjective colouring, which is for the most part seen in autumn, and of which traces are found almost every evening.

**ABSORPTION BY TRANSPARENT BODIES.**—After having traversed transparent bodies, such as glass or water, light is still very intense; however, accurate measurements prove that a part has been absorbed. The quantity depends on the nature and the thickness of the bodies. We know of no body perfectly transparent; but all bodies, when sufficiently thin, allow a small quantity of light to pass, as, for instance, a sheet of leaf gold. The thicker a body is, the more molecules does the ray of light find opposing its passage. Experiment and theory lead us to a very simple law, which points out to us the dependence of this reduction of light on the thickness of the body. Suppose the body divided into a certain number of slices of the same thickness, and let us examine experimentally the quantity of light absorbed by one of these slices: the loss in each slice will be equal to a similar fraction of the incident ray. Suppose experiment to have proved that, out of 100 luminous rays, 10, or 0,1 of the whole are absorbed by a plate of glass $1^{mm}$ thick, so that only 90 pass out of the body: we can know the quantity absorbed by a plate $4^{mm}$ thick, by supposing it divided into four slices, each $1^{mm}$ thick. The first plate absorbs 0,1; so that the second only receives $100 - 10 = 90$ rays; a tenth of this quantity, namely 9, is then absorbed; the third only receives $90 - 9 = 81$ rays; the tenth of this quantity, namely 8,1, is absorbed by the third: the fourth, therefore, only receives $81 - 8{,}1 = 72{,}9$ rays; and as the tenth of this quantity is absorbed by this latter plate, only $72{,}9 - 7{,}3 = 65{,}6$ rays pass out of the plate, and the light is reduced in the ratio of

100 to 65,6. This calculation shews, moreover, that the most transparent body may so reduce the incident light that it scarcely makes any impression on the organ of sight.

The light which does not pass out from a body is in part really absorbed by the body, and raises its temperature; it is also partly reflected, and renders the body and its interior visible to the eye. According to the nature of bodies, the phenomena may be very varied; and this partly explains to us the extreme diversity of colours. Whatever material is employed, a part of the rays is always lost; it is less as the material is more transparent, but there is no body that acts on the rays of white light with equal intensity;—some rays are absorbed more than others, and the light is coloured. There are bodies that entirely absorb certain rays, whilst others pass through them, or are reflected; these bodies have the same colour whether seen by reflection or transmission: glass coloured blue by cobalt is of this class. Others reflect some rays and allow others to pass; they then present, with reflected, and with transmitted light, two colours, the union of which forms white. Thus certain milky glasses are blue when seen by reflection; but, if a white flame is looked at through one of these glasses, it appears reddish or yellowish. Other bodies entirely absorb certain rays, and reflect some, and allow others to pass. Thus gold appears yellow by reflection; but a white object, seen through a thin leaf of gold, seems green. The yellow rays, therefore, are for the most part reflected, the green rays transmitted, and the rest absorbed.

**TRANSPARENCY OF THE ATMOSPHERE.**—The atmospheric air is one of the most transparent bodies known; when it is not loaded with fog, or obscured by other bodies, we can see objects placed at a very great distance: mountains do not disappear from our view until they are below the horizon. But, notwithstanding its feeble absorbing power, the air is not a body altogether transparent. If it were so, the vault of heaven would be black, and the sun and moon would appear as luminous discs accurately defined. At all places, where the rays of the sun could not penetrate, either directly or reflected by terrestrial objects, there would be complete darkness; and, at the moment when the sun sets, night would suddenly succeed day. As all this does not happen, we must necessarily conclude that the particles of atmospheric air absorb a portion of the light that they receive, allow a portion to pass, and reflect the third portion; hence it is that they illuminate the vault of heaven, light up terrestrial objects on which the sun does not shine directly, and determine an insensible transition between day and night.

We may convince ourselves by daily observations of the reduction of the light of the sun in its passage through the atmosphere. If for several days we take notice of the same object, situated near the horizon, we shall see that it is sometimes very visible, at other times much less so. Small objects disappear, as we recede from them; this partly arises from their apparent size diminishing with the distance; but this is not the only cause, for the distance at which they disappear is sometimes less, at other times greater: we may convince ourselves of this by direct measurements, and express the transparency of the atmosphere by these numbers, as **de Saussure** did, by means of his *diaphanometer*. He had several white surfaces placed one beside the other, so as to be equally illuminated by the rays of the sun. On the white grounds, he traced black circles of different diameters: namely 5 cent. for the first, and 6 deci. for the second. He receded until the second circle became invisible, and measured the distance; if the air were perfectly transparent, the large circle ought to disappear in its turn at a distance, the relation of which to the first was the same as that of the two diameters: experiment constantly shews that this relation is not the same, but smaller. Thus, in one of **de Saussure's** experiments, the diameters of the circles were to each other as 1 : 12; the distances, at which they become invisible as 1 : 11,427, a difference due to the absorption of luminous rays by the atmosphere.

We need scarcely add, that objects employed to measure the transparency of the atmosphere should be altogether identical in respect to form and illumination; for the distance at which objects disappear does not depend simply on the visual angle, but likewise on their mode of illumination, and on the contrast made by their colours with surrounding objects. This explains why stars, notwithstanding their small diameter, are so visible in the vault of heaven. It is the same with terrestrial objects: there is a difficulty in distinguishing a man when he is projected on fields or black surfaces; but he is very visible when placed on an elevation, so as to be projected on a light sky: hence the optical illusions so common in mountainous countries.

Whilst the chain of the Alps seen from the plain, at a great distance, is distinctly visible in its minutest features, the spectator placed on one of its summits scarcely distinguishes any thing in the plain: all travellers agree in this fact. During my stay on the Faulhorn, in September 1832, the weather was very fine; I distinguished with great clearness the chain of the High Alps, but every thing was confused on the plain. The country, extending beyond the Lake of Brienz seemed covered with a veil; only the summits of Pilate, Forêt-Noire, and the Vosges, at a great distance, were clearly defined, whilst nothing was distinct in the plain between the Alps and the Jura. It was with much difficulty that I could distinguish, during serene weather, the town of Berne through a glass; and yet the Faulhorn is very visible from that town. This is easily explained: indeed, while mountains make a contrast by their opacity and their deep colour with the transparency of the sky, and are very distinctly defined, all the objects on the plain are clad in a sombre and uniform greenish tint: so that at a certain distance an isolated object is not relieved from among those surrounding it.

But it is not only rays coming from terrestrial objects that are partially absorbed by the atmosphere; it is the same with those coming from the sun. The curved surface that bounds the atmosphere being parallel to that of the earth, and its thickness being nothing when compared with the mass of the terrestrial spheroid, we may suppose, without sensible error, that the plain of the portion of the atmosphere, which the eye can embrace, is sensibly parallel to the horizon. If the sun were in the zenith, its rays would traverse the shortest road to reach us; the more the sun approaches the horizon, the greater is the thickness of atmosphere to be traversed by its rays, and, consequently, the more is the brilliancy of the rays enfeebled: experience proves this every day. The light of the sun or of the moon in their passage to the meridian is dazzling, whilst we can gaze at these bodies when they are near the horizon; for the same reason, the regions situated near the horizon appear devoid of stars. The latter are actually invisible, because their rays cannot reach us through the thick stratum of atmosphere that they have to traverse; but they become perfectly visible as this part of the vault of heaven rises above the horizon. If it were possible to measure the intensity of solar light at different elevations, we might also indicate the quantity of this absorption; but the methods employed to measure this intensity, and the results obtained, are still subject to very grave difficulties.[21] The actinometer, or the heliothermometer, described in p. 149, may be employed for this purpose. The absorption of solar rays is such, that in the plains of Germany, if the sun were in

---

[21] Vide Note 21, Appendix, No. II.

the zenith, and the sky perfectly clear, the earth would only receive two-thirds of the rays that arrive at the upper surface of the atmosphere; all the rest is partly absorbed, and partly reflected by the air and the particles of vapour: but the numerical value of these elements is still unknown.[*]

**BLUE COLOUR OF THE AIR.** — One part of the luminous rays is absorbed, the other reflected by the air; the latter, however, does not act equally on all the coloured rays, of which white light is composed; it acts like a milky glass, it rather allows the rays of the red extremity of the spectrum to pass, and, on the contrary, reflects the blue rays; but this difference is not sensible, until the light has traversed large masses of air. **De Saussure** has shewn that the blue colour of the sky is due to the reflection of light, and not to a peculiar colour belonging to the aërial particles. If the air were blue, he said, mountains that are very distant, and that are covered with snow, ought to appear blue, which is not the case. An experiment made by **Hassenfratz** also proves that the blue ray undergoes the greatest reflection. Indeed, the thicker the stratum of atmosphere in which the ray traverses, the more do the blue rays disappear, which make the red ray visible: now, when the sun is near the horizon, the ray traverses a greater thickness of the atmosphere; thus this body appears to us red, purple, or yellow. The predominance of red, and the absence of blue, when the sun is near the horizon, have been confirmed by an experiment of **Hassenfratz**: he passed the solar light through an opening, and received it on a prism; he then measured the width of the prism at a certain distance; the observation was repeated when the sun was at different heights above the horizon. In the long days of summer, at mid-day, the length of the prism was 185 parts; and in winter, during the shortest days, at sunset, only 70 parts. All the rays of the extreme violet were wanting; for the spectrum was only composed of red, orange, and green: an evident proof that all the blue rays had been absorbed. The blue rays also are often wanting in rainbows that appear a short time before sunset.

In order to measure the intensity of the blue, **de Saussure** invented the *cyanometer*. Imagine a band of paper divided into rectangles, of which the first is of the deepest

---

[*] It follows, from Bouguer's experiments, that while the barometer is at 760 millimetres, if we take as unity the intensity of a star, when it enters into the atmosphere, its intensity, when it reaches the observer, and when the star is at the zenith, is reduced to 0,8123. (Laplace, *Exposition du Système du Monde*, t. i. p. 191.)

cobalt blue, whilst the last is almost white, the intermediate rectangles presenting all imaginable shades, between deep blue and white. If we find that the blue of one of these rectangles is identical with that of the sky, we then express this identity by a number corresponding to one of the rectangles, and every thing is obtained for drawing out the scale of the instrument. To accomplish this, **de Saussure** rested on this principle, that the difference between two very similar colours disappears the farther we recede, so that finally they are confounded. **De Saussure,** therefore, takes two shades of blue that are very similar, and lays beside each other two sheets of paper coloured with these shades; then he recedes until a black circle, four millimetres in diameter, painted on a white ground, and placed beside these sheets of paper, becomes invisible; if the differences of the shades disappear at a distance greater or less than that at which the circle disappears, one of these must be exchanged for another, until the required shade is obtained. In this manner, **de Saussure** obtained between white and black fifty-one shades, and consequently 53 degrees in all. The white was marked 0; and he satisfied himself, by other experiments, that these degrees corresponded to combinations of white and deep blue mixed in definite proportions.

Other apparatus have been devised, but all are intended for measuring the intensity of the blue. Now, as the atmosphere presents other colours, such as yellow, red, greyish blue, &c., instruments should be constructed for each of these colours. The following apparatus might serve to indicate the shade of colour; but I leave others the care of verifying by actual experiments the utility of this idea. The colour of objects is due to the want of certain of the colours of white light; thus, then, if we knew the principal elementary colours in white, and in the light coming from any body, we might know the colour of that body. In order to determine the number of elementary colours, we should select a perfect prism of flint-glass, and fix it at the extremity of a tube three or four decimetres long. The light of a body whose colour we desire to know is received through a narrow opening, and the prism decomposes it; but, in order to distinguish the colours well, they are received, as they pass out from the prism, on the achromatic object-glass of an astronomical telescope. By means of a micrometer-screw, the length of the spectrum and the width of each colour is measured: in this way, we may not only indicate, with great accuracy, the different shades of the sky, but, on repeating the experiment, when the sun is at different heights above the horizon, we arrive at a positive knowledge of the number and the nature of the different elementary colours of solar light.

The mere contemplation of the sky at once proves to us that its colour is not the same at all points of the same vertical; it is generally deeper in the zenith; then it becomes brighter toward the horizon, when it is frequently completely white. This contrast becomes still more striking by the use of the cyanometer. Thus, **de Saussure** found one day that the colour, corresponding to No. 23 of his cyanometer, was in the neighbourhood of the zenith, and that corresponding to No. 4, near the horizon; M. **de Humboldt** arrived at analogous results. But the colour of the same part of the sky changes very regularly during the day; in that it becomes deeper from morning to mid-day, and becomes clearer from this time until evening.

When we ascend from the plain to mountains, the sky appears deeper and deeper; the chamois-hunters and shepherds have long known this. **Deluc** was the first to direct attention to this fact, which **de Saussure** verified in the Alps, and M. **de Humboldt** on the Cordilleras. In our climates, the sky has the deepest blue colour when, after several days' rain, the east wind drives away the clouds. According to M. **de Humboldt** the sky is bluer between the tropics than in the higher latitudes; but paler at sea than in the interior of countries.

The colour of the sky is modified by the combination of three tints: blue, which is reflected by the particles of air; the black of the vault of heaven, that forms the ground of the atmosphere; and finally, the white of the vesicles of fog and flakes of snow that swim in the atmosphere. Indeed, the tint of the blue rays is darkened by the black colour of space; and, on the other hand, it is made lighter by the white of the vesicles of fog; when we ascend in the atmosphere, we leave a great portion of the vesicles of vapour beneath us. So that, while rays reach the eye in less proportion, and, the sky being covered with a lesser number of particles reflecting its light, its colour becomes of a deeper blue. For the same reason, the blue in the neighbourhood of the horizon is less intense than at the zenith. If the sky is paler in the open sea, and in high latitudes, than in the interior of the continents, and in the neighbourhood of the equator, it must be attributed to the vesicles of fog.*

---

* ON THE POLARISATION OF SERENE AIR.—A luminous ray is *completely polarised*, when, even under perpendicular incidence, it cannot pass through

**TWILIGHT.**—During a serene day, as the sun approaches the horizon, the neighbouring portion of the sky is coloured yellow or red. The rays, which have been traversing a great thickness of the atmosphere, lose, on their way, a great portion of the blue rays, and we receive only the red rays.

a thin film of tourmaline cut so as to contain the axis of this crystal, and placed in a situation perpendicular to this radius. The plane passing through this radius and this axis is named the plane of polarisation. The polarised ray also possesses other characters, by which it is defined; but this is sufficient.

If the plate of tourmaline is turned 90°, its surface remaining perpendicular to the luminous rays, these rays pass through the plate; the plane of polarisation is then perpendicular to the axis of the crystal. So that the polarised ray can no longer be considered as symmetrical with reference to exterior space: hence its name.

Light may be *partially polarised*; it may then be regarded as constituted of natural light not polarised, and light completely polarised. All possible intermediate conditions may be observed between these two states of light.

The act of reflection polarises luminous rays; the plane of the polarisation of a reflected ray is that in which the reflection takes place; but, if the incidence is normal, the light is not polarised.

From these principles we may explain the polarisation of the light of a clear sky. If we imagine a plane passing through the sun and the observer, the light coming from the sun, which reaches the eye of the latter, along a certain line, situated in this plane, has been reflected by the aërial molecules situated in the course of this line. This light would, therefore, be polarised in a plane passing through the sun; now, this is actually what we observe. If M. Arago's *chromatic polariscope*, or Savart's *fringe polariscope*, (instruments which are described in most treatises on Natural Philosophy) is directed toward the sky, we recognise that the intensity of the polarisation is very great near the zenith, that it goes on increasing until *about* 90° degrees from the sun; after which, it progressively diminishes to a distance of 150° from this body, at least, if the place of this latter is a little above or a little below the horizon. At this place the polarisation is insensible. This point, which is situated in the sun's vertical, has been usually designated the *neutral point*. Beyond this, the polarisation begins to increase; but the plane of the polarisation, instead of coinciding with the vertical of the sun, has become perpendicular to it. MM. Arago, Biot, and Forbes, attribute this latter phenomenon to the secondary reflections that occur between the aërial molecules taken two and two. It is evident that, with respect to one molecule of air, the rest of the atmosphere plays the part of an illuminating body in the form of a horizontal ring surrounding it on all sides. The portion of light that the molecule borrows from this source must, therefore, be polarised in a horizontal plane, or, at least, in a plane but little inclined to the horizon; and in all cases, on account of its symmetry, this plane must be perpendicular to the vertical of the sun, if the molecule is itself situated in this plane. In proportion as we examine the parts of the sky that are nearer to the point of the horizon opposite to the sun, polarisation in a horizontal direction must go on increasing, and end by predominating over vertical polarisation, which, on the contrary, continues diminishing, until the incidence of the solar rays approaches more and more toward being normal with the same molecules.

M. Babinet found a second neutral point, in the neighbourhood of the sun; its height is 17° 30′ above the centre of the sun. Mr. Forbes explains it by the preceding theory, namely, the predominance of reciprocal horizontal reflections.

The angles 159° and 17° 30′ are the mean result of numerous observations made by M. Bravais, on the summit of the Faulhorn, in 1842; we may believe that, in the plain, the situation of these neutral points is somewhat different. The presence of clouds in the sky is even sufficient to displace them from their natural positions.—M.

The sky becomes pale in the neighbourhood of the zenith, and the clearness goes on increasing towards the western horizon. We gradually observe in the east of the sky, situated opposite to the sun, a red tint, that attains its *maximum* intensity at the moment when the sun descends below the horizon. This colouring is the effect of the last rays of the setting sun, that sends into this region of the sky only its red rays, which, after their reflection, again traverse the atmosphere, and reach the eye of the observer entirely deprived of their blue rays. According to the state of the atmosphere, this colour varies between fiery red and deep purple; in like manner, in the west of the sky, the twilight presents all the intermediate tints between gold-yellow and deep red; the red, however, is never so deep as that of the eastern sky.

When the sun descends a little below the horizon, we may observe in the eastern sky a segment, more or less clearly defined, of a deep blue colour, above which the red colour, of which we have spoken, is constantly shewn. The separation between the blue and the red segment is frequently very plain; but, under favourable circumstances, we may distinguish between them a white or yellow stripe: **Mairan**, who was the first to draw attention to this subject, named it *second twilight* or *anti-twilight.*

Its culminating point is situated opposite to the sun; and an attentive observation proves that this segment is due to the shadow of the earth projected on the sky. This point is no longer illuminated by the direct rays of the sun, but merely by a diffused light; and, as the latter is blue, it communicates this tint to the entire segment. So long as the upper limit of the shadow of the earth is not very high, the red tints in the western and eastern sky are confounded in the higher regions; when the air is very pure, and not charged with the vapour of waters, the zenith is blue; but if, during the day, the sky has a whitish colour, then it is entirely covered with a purple tint; because the eye not only receives the blue rays reflected by the zenith, but also the red rays derived from the particles of vapour that are situated lower. The anti-crepuscular arc gradually rises towards the zenith, where the sky appears blue, the redness of the western sky becomes deeper, and a few isolated stars become visible; sometimes a second red coloration is again shewn in the eastern sky. In proportion as the sun descends, the red segment of the western sky, which descends with it, becomes better defined, and above it is seen a white space in the form of an arc, which we might call with

Brandes *crepuscular light.*[*] The more the sun descends, the more does darkness increase, and finally the greater portion of the stars begin to shine; the moment when stars of the sixth magnitude become visible may be considered as the end of twilight. This is called astronomical twilight, in order to distinguish it from ordinary twilight, which terminates when darkness compels us to suspend labour that is going on in the open air (*vide* Note F).

Daybreak and twilight depend on the rays that come

---

[*] When the crepuscular curve, formed by the shadow of the earth projected on the high regions of the atmosphere, sets in the evening on the western horizon, we may still, under very favourable circumstances, perceive a feeble and whitish light illuminating the sky towards the N.W. and which sometimes rises to a considerable angular height. This light is incontestably due to secondary illumination, thrown on the higher points of the atmosphere by strata of air situated at that time below the horizon and directly illuminated by the sun; the light of this atmospheric space is due to rays that have already undergone a first reflection, which M. BIOT (*Mémoire de l'Académie des Sciences*, t. xvii.) names the *second crepuscular space*.

It does not appear that this second twilight can be observed from our valleys; but on high mountains it is very frequently visible: DE SAUSSURE observed it when on the Col de Géant; the light attains to as much as 30° above the horizon; the depression of the sun below the horizon of the illustrious philosopher was at the time 22°. M. BRAVAIS observed it several times on the summit of the Faulhorn (canton of Berne), 2683 metres above the level of the sea, during the years 1841 and 1842. The following table contains the results of his measurements. The column on the left indicates the zenithal distance of the sun at the moment of observation; the column on the right gives the angular limit in height, beyond which the light ceased to be distinct.

ZENITH DISTANCES OF THE SUN AND CORRESPONDING ANGULAR HEIGHTS FOR THE SECOND CREPUSCULAR SPACE.

| | | |
|---|---|---|
| Aug. 2, evening 1842 | 107° 4′ | 17°,6 |
| „ 12, morning 1842 | 107 25 | 20 ,5 |
| „ 5, evening 1842 | 108 34 | 16 ,4 |
| „ 5, „ 1842 | 111 3 | 25 ,2 |
| „ 13, morning 1842 | 112 5 | 16 ,0 |
| „ 9, evening 1842 | 112 13 | 16 ,6 |
| „ 16, morning 1842 | 113 23 | 12 ,5 |
| „ 5, evening 1841 | 116 4 | 9 ,0 |
| „ 16, „ 1842 | 116 6 | 7 ,0 ? |

These measurements are perfectly compatible with the explanations that we have just given; if it were true that the ordinary crepuscular curve exactly coincided with the curve of the passage of the earth's shadow out of our atmosphere, this second crepuscular curve ought itself also to be interpreted in an analogous manner, and we might use it with advantage to determine the height of our atmosphere; but our knowledge on this subject is still much too imperfect for such deductions to be at present at all legitimate.

The light of the second twilight is faint, without any marked colour, and analogous to the Milky Way in brilliancy; it, therefore, does not prevent our seeing the small stars, even those of the fifth and sixth magnitude.—M. T from the sun meeting the higher strata of the air, and being reflected by it and dispersed in all directions, when the sun has for some time disappeared below the horizon; these rays are again reflected, and illuminate the eastern side of the celestial vault. From this we can understand that an intimate connexion exists between the descent of the sun below the horizon, the state of the atmosphere, and the light of which we are speaking: so that astronomers have endeavoured to indicate this relation, by calculating the duration of twilight for different countries and different seasons; but they have been too much preoccupied with the mathematical elements of the question, and have in some degree neglected the physical conditions. All of them have endeavoured to determine the moment when the sun is 18° below the horizon, and have not inquired whether this angle every where corresponds with the end of twilight: so that, in my opinion, the question is no farther advanced than at the period when a cardinal induced the Portuguese **Nonius** to enter upon this question.

Twilight terminates at the moment when darkness attains a certain determinate degree. Ancient astronomers gave, as a rule, that we should see stars of the sixth magnitude in the neighbourhood of the zenith; but these stars do not become visible until the moment when the reflected light that is spread in the atmosphere is very faint, and when the rays from the stars are not too much reduced, in their passage through the atmosphere, to produce a luminous sensation on the eye. The more vapour there is condensed during the day, the more dull does the sky appear, and the more enfeebled also is the light that passes through the atmosphere, whilst the reflected rays amount to a large number: under these circumstances, twilight is very long. In the interior of Africa, where the air is sometimes so pure and so transparent that **Bruce**, when in Sennaar, saw the planet Venus in broad daylight, night immediately succeeds sunset. On the other side of the Alps, in Dalmatia for instance, night occurs half an hour after sunset. Between the tropics twilight is still shorter: it lasts a quarter of an hour at Chili, according to **Acosta**; and a few minutes at Cumana, according to M. de **Humboldt**; the same phenomenon occurs on the coast of Africa. These results differ very manifestly from those obtained by calculations, according to which twilight ought to last at least an hour. We are, therefore, obliged to admit that between the tropics the sun is not so far below the horizon at the end of twilight as it is in the very high latitudes. When the air is filled with vesicular vapours and particles of snow, the sun may descend as much as 30° below the horizon without darkness being complete, as the long twilights of Greenland and other polar countries prove.* Its duration must vary according to seasons; in summer, when the vesicular vapour is higher than in winter, the sun, according to **Riccioli**, is at a greater distance below the horizon at the end of twilight than in winter: in like manner, in the morning, at the commencement of daybreak, it is higher than in the evening, probably because a part of the vapours of water is precipitated to the surface of the earth.

When the vapours are very high, while the lower strata of the atmosphere are very transparent, twilight may last for a very long time. The summer of 1831 was remarkable in this point of view; very prolonged twilights were seen from Madrid to Odessa, and the newspapers of the period were filled with observations of this kind. These twilights were very remarkable on the 24th, 25th, and 26th of September. On the 25th, the setting of the sun presented nothing extraordinary; but the colour of the sky very soon became of a very deep orange tint; the brilliancy of the crepuscular light slowly diminished and passed to red; the illuminated portion of the sky contracted more and more, and exactly corresponded to the point where the sun was beneath the horizon; it was still seen as late as eight o'clock, an hour at which the sun was 19° 30′ below the horizon: it was the same on the following evenings; and the mornings also presented extraordinary phenomena. M. **Nees d'Esenbeck**, who was contemplating the phenomenon from the summit of the Hampelbande, says that the morning of the 24th had not its usual brilliancy, and rather resembled a winter twilight. On the 25th, immediately after sunset, a deep red tint, veiled in vapour, covered all the sky, enveloped the horizon, and seemed to be lost in the zenith, in the form of red rays. At this moment, a violent storm rose in the S.W.; it lasted all night with diminished violence; and the red colour disappeared about nine o'clock.

This phenomenon depends, as I have said, on vapours elevated in the atmosphere. From the 24th, the barometer fell at Halle, the sky was not of a deep blue, although it was clear; the sun had the dead brilliancy of the moon. This state of the atmosphere, analogous to that which pre-

---

* It has not been proved that the long twilights of the north are not due simply to the obliquity of the diurnal march of the sun, inasmuch as the height of the atmosphere there is probably less than at the equator, a circumstance which has a marked influence over the duration of twilight.—M.

cedes storms, when *cirri* float in the high region of the atmosphere, extended over a great part of Europe. The long twilights attended by storms were remarked in northern and southern Europe, as is proved by a violent hurricane that burst over Messina on the 27th of September. During the entire summer of 1831, storms were very frequent, and there were hurricanes in the West Indies. On the 3d of August and following days, the brilliancy of the twilight was remarked at Odessa, in Germany, at Rome, and at Genoa; but, at the same time, violent storms burst in many countries, in Navarre, in Aragon, at St. Giorgo, and in Silesia. In Switzerland and in the Tyrol, the S.W. wind, that accompanies storms, was so violent that there were serious inundations. In the sea of Antilles, terrible hurricanes desolated Barbadoes, on the 11th of August; and Jamaica, Hayti, and St. Vincent, on the 14th. They were connected with violent storms from the north, which made great ravages at Cuba and in Louisiana on the 16th and 17th.

**DAWN AND TWILIGHT.**—We have already seen that their duration and colouring depend on the state of the atmosphere. If the air is filled with vesicular vapour, and the sky during the day has presented a whitish aspect, then the red is more or less dead and mingled with grey striæ, sometimes of a deep carmine colour; and, even during the day, the part of the sky below the sun appears more or less red. It is, therefore, certain that these vapours are so arranged as to allow only the red rays to pass. Thus in winter, in our latitudes, the sky is frequently red throughout the day; and in summer, during rainy weather, when fine *cirri* are floating in the atmosphere, the same occurs several hours before the culmination of the sun; but, when the sky has been of a deep blue throughout the day, then the twilight presents a yellowish tint. If light *cumuli* or *cirro-cumuli* are in the atmosphere, they are beautifully coloured; and in the intervals between them are observed the green tints, of which we have already spoken.

This red colouring of the clouds is connected with a phenomenon that I have frequently observed in Switzerland, and which is named the rose-tint of the Alps (*das Glühen der Alpen*). A short time after sunset, the snowy peaks of the Alps appear of a rose colour; the colour then becomes deeper, and finally disappears, when the shade of the earth reaches to their summits; the snows then assume a bluish grey appearance. Sometimes the Alps are coloured afresh, but in a less marked manner, and not for so long a time as at first. This phenomenon occurs for the most part when light *cumuli* or *cirro-cumuli* are floating in the west; the bare surfaces of the rocks then resemble masses of incandescent iron. Here again, the reflected red rays reach the eye in the greatest numbers, and this reappearance of the rose-tint certainly arises from the red rays, which, being reflected by the atmosphere, illuminate the summits of the mountains a second time.

The appearances of twilight depend on the state of the sky; it, therefore, follows that they may serve to foretell, to a certain extent, the weather of the following day; when the sky is blue, and, after sunset, the western region is covered with a slight purple tint, we may be sure that the weather will be fine, especially, if the horizon seems covered with a slight smoke. After rain, isolated clouds coloured red and well illuminated announce the return of fine weather. A twilight of a whitish yellow, especially when it extends to a distance on the sky, is not a sign of fine weather for the following day. In the opinion of those who live in the country, we must expect storms when the sun is of a brilliant white, and sets in the midst of a white light, which scarcely permits us to distinguish it; the prognostication is still worse, when light *cirri*, that give the sky a dull appearance, appear deeper near the horizon, and when the twilight is of a greyish red, in the midst of which are seen portions of a deep red, that pass into grey, and scarcely permit the sun to be distinguished: in this case, vesicular vapour is very abundant, and we may calculate on wind and approaching rain.

The signs drawn from daybreak are somewhat different; when it is very red, we may expect rain, whilst a grey morning announces fine weather. The reason of this difference between a grey dawn and a grey twilight is because, in the evening, this colour mainly depends on *cirri*, in the morning, on a *stratus*, which soon yields to the setting sun, whilst the *cirri* become thicker during the night. If at sunrise there is enough of vapours for the sun to appear red, it is then very probable that, in the course of the day, the ascending current will determine the formation of a thick stratum of clouds.

**HEIGHT OF THE ATMOSPHERE.** — The pressure that the particles of the atmosphere undergo diminishes as we rise above the level of the sea; the density of the air diminishes in the same proportion. If we could observe the barometer and thermometer at this elevation, it would be easy to deduce the density of the atmosphere; but it is important to know to what extent this diminution of density can go, whether the air is rarified indefinitely, or whether this refraction has a limit. Under the last supposition, the limit of the atmosphere would be found at a point, when the air would be so rarefied that this action could not be carried farther; if this rarefaction could go on *ad infinitum*, then the air would be diffused throughout space, and each planet would form an atmosphere for itself. It is difficult to know experimentally which of these suppositions is true; for we cannot expose highly rarefied air to a degree of cold equal to that which prevails in the limits of the atmosphere. It appears more probable that this rarefaction of the air is limited; for, as each planet draws to itself a part of the atmosphere, refraction, according to a remark made by **Wollaston**, would be very marked in these planetary atmospheres. Observations shew nothing resembling this. When a planet passes near a fixed star, the apparent position of the star undergoes no change; its rays are not divided by the atmosphere of the planet, at least, so far as the most attentive observation has demonstrated.

If the atmosphere is limited, at what height is this limit found? We have sought to deduce this from the phenomena of twilight. Indeed, from the apparent height of the illuminated segment, and from the known distance of the sun below the horizon, we may deduce the height of the last aërial particles, capable of reflecting light. Supposing the sun 18° below the horizon, we find from 60,000 to 80,000 metres as the height of the atmosphere; but if we make more accurate measurements, taking from moment to moment the height of the illuminated segment, and comparing it with the depression of the sun below the horizon, we find, as **Brandes** and **Lambert** have proved, that this mode of determination is very inaccurate. At the moment after the sun has set, the observer sees very clearly the anti-crepuscular segment in the east; for the eye is less dazzled by light coming from other parts of the sky. When the anti-crepuscular segment ascends to the zenith, all the sky situated over the head of the observer is illuminated by the light, which the aërial particles reflect from west to east, and it is then more difficult to recognise its limits clearly. The farther the sun descends below the horizon, and the more the light is limited to the west, the more also does the quantity of diffused light increase. If, therefore, we wish to deduce the height of the atmosphere from a series of measurements of this kind, we shall obtain higher values, in proportion as the sun descends below the horizon.

Barometric and thermometric measurements cannot lead to any result; for we neither know the laws of the decrease of temperature at a great height, nor the nature of the aërial particles, subjected at the same time to a feeble pressure and a very great degree of cold. All, therefore, that has been said respecting the height of the atmospheres is still subject to doubt; but we may affirm that, at between fifteen and twenty kilometres above the surface of the earth, the density of the atmosphere is almost nothing (*vide* Note G).

**CREPUSCULAR RAYS.**—When a cloud intercepts the light of a part of the atmosphere, it projects a shade that obscures a part of the sky. In the fine days of summer, if a few *cumuli* are floating in the sky, we may follow the shade they cast to a great distance. The converse phenomenon is much more common. Indeed, when a great portion of the sky is covered with clouds, especially by *cumulo-stratus*, interrupted by light spots, then the sun shines through, and the air, the vesicular vapour, dust, and other bodies, floating in the atmosphere, seem rays with various degrees of luminosity. If the sun is not very high above the horizon, these rays come from the sun; if, on the contrary, it is about to set, they rise in the atmosphere under the form of arcs of great circles, which would cut each other in a point situated below the horizon, and on the right line, that joins the centre of the sun and the eye of the observer. These rays are parallel to each other; and their apparent curvature, as well as their divergence in the neighbourhood of the zenith, are merely a consequence of the effects of perspective; the more distant they are from us, the less does their deviation seem, because the visual angle becomes less: it is a similar illusion to that which we experience in an avenue bordered by two parallel rows of trees, which yet seem to approach at the farther end.*

It is commonly said that crepuscular rays announce rain, an opinion which is not devoid of reason. This phenomenon occurs for the most part when the sun is near the horizon; but, on fine days, the clouds have there disap-

---

* Readers, who are interested in this subject, will find, in the *Annales de Chimie et de Physique*, t. lxx. p. 122, a memoir by T. Necker de Saussure, in which this philosopher treats in detail the phenomena of crepuscular rays, and of the second rose colouring of the snowy peaks of Switzerland. His explanation of crepuscular rays is the same as that of M. Kaemtz; but the second colouring of the Alps appears to him an effect of contrast. The white peaks of the Alps, being first projected on an illuminated sky, and then on the shades of the earth, *appear* to be again coloured, although their whiteness remains the same.—M.

peared, or are ready to disappear. When the atmosphere is loaded with vapours, all the circumstances that may produce this phenomenon are united; but, in these cases, there are also great chances of rain. Between the tropics, where showers generally fall at the moment of the greatest diurnal heat, this phenomenon appears to be more rare than in the high latitudes.

**REFRACTION OF LIGHT.**—Although the air has only a feeble influence over light, yet observations carefully made prove that a ray of light does not reach our eye without a deviation, except when it comes from a point situated at our zenith, or from a terrestrial object at the same height as the eye; because then all the thickness of atmospheric stratum that it traverses is of uniform density. In all other cases the ray is refracted, and in such a manner that, if we imagine the different strata to be of different densities, the rays, in passing from a less dense into a denser medium, approach a perpendicular raised on the refracting surface. If, therefore, a ray from a star reaches us, it traverses strata, the densities of which continue increasing; it approaches the vertical, and the star appears to us higher above the horizon than it actually is. This displacement is greater as the angle of height is less. Rays coming from the zenith do not undergo any deviation, because they are perpendicular to all the separating surfaces of the strata. The refraction is as great as it can be when the star is in the plane of the horizon, for then it appears elevated 0° 30′ above that plane; in like manner, when the sun sets, it is elevated about 30′, and, as this angle is equal to that which its apparent diameter subtends, it follows that in reality its upper edge is already tangent to the horizon, when its lower edge apparently touches it.

In all observations on the height of stars, refraction must be accounted for; and astronomers have endeavoured to determine exactly the value of this angle for the different heights of the barometer and thermometer. There is often a notable difference between the refraction observed and the refraction calculated from these elements; but we should not forget that our instruments merely indicate the density of the air at the surface of the earth, and that winds, or other causes, may modify the laws of decrease of density, so that it may be very different from that found by analysis. These exact measures of astronomic refraction will render great service to Meteorology, in that they will throw a bright light upon the more or less rapid decrease of temperature.

**ON THE SCINTILLATION OF THE STARS.**—In our countries the stars do not always appear motionless in their place, they sometimes seem to oscillate around the point they occupy in the celestial vault. At the same time the intensity of their light changes; it increases or diminishes by very short intervals; sometimes, also, their colour varies, the red, green, and blue rays in turn become predominant, especially when these stars approach the horizon. This scintillation is much more remarkable in the fixed stars than in the planets; which latter rarely present it. However, when the scintillation of the stars is very great, the planets also scintillate, as I have seen Jupiter do, when situated near the horizon.

The scintillation is not equally vivid, whatever be the position occupied by the star. It is frequently in the neighbourhood of the horizon that the scintillation is the greatest possible, whilst it is nothing in the zenith; nor is it the same under all circumstances. **Musschenbroeck** relates that in Holland it is very vivid during intense cold and with a clear sky: it is the same in other countries. From my own observations, it is very marked when violent winds prevail in the atmosphere, and when the sky is alternately serene and cloudy.

As this phenomenon is, for the most part, manifested when aërial currents of different temperatures are moving one over the other, it follows that its intensity is not always the same. Between the tropics, when the trade-wind blows with great regularity during the dry season, the stars scintillate, according to M. **de Humboldt,** near the horizon. **La Condamine** confirms this testimony; but he adds that, in Peru, this scintillation is less vivid than in Europe. In Persia and Arabia, it is observed in winter; however, it is not so great as in our countries.

The cause of this phenomenon resides in the unequal refraction which light undergoes in strata of air alternately colder and hotter: **Vitellio** had long since explained it, by movements of the air, but **Hooke** was the first to shew that it is due to the mixture of strata of air unequally heated. We may convince ourselves of this, adds he, by looking beneath a piece of warm glass at a distant object: the latter seems to change. Indeed, if the light of a star, S, pl. v. fig. 1, reaches the upper surface of the atmosphere, in the direction S C, it is refracted in its passage through each of the strata C C, D H, &c., and the ray C D E F reaches the eye of the observer placed at E; the latter, therefore, sees the star in the direction FE. Suppose now that the stratum of air DE is suddenly displaced, and replaced by another of different density, then the ray CD will not be refracted in DF, but in DI, and will not reach the eye; it is the ray CHF that arrives there, and the star that appeared to be in the direction FD is found in the line FH. If this new mass of air has no great volume, or if its temperature differs but little from that of the mass which it replaces, then the displacement and the change in the intensity of the light are not very notable. Planets scintillate less than stars, because, as the latter appear to us as points, the least displacement, were it merely 5 seconds, would be sensible to our eye. The planets having an apparent diameter of 30 or 40 seconds, it is more difficult to appreciate their apparent change in volume; however, through telescopes we frequently see the edges scintillate, especially if they are near the horizon. Under certain circumstances, the same phenomenon is observed on the circumference of the limb of the sun. We can easily imagine, that the light passing from stars situated near the horizon, which has a much longer course to traverse, may on its way meet with a mixture of strata of air of more variable density than those do that are placed above the head of the observer.

Scintillation not only consists in the displacement of the star, but also in changes in its brilliancy and colour. M. **Arago** deduced these two orders of phenomena from the interference of luminous rays. Luminous rays that form together a small angle, and cut each other, may be mutually reduced and increased; under certain circumstances they destroy each other, and this fact, which is inexplicable if we consider light as a material emanation, is a very simple consequence of the system of undulations, and even the best proof that may be given of its reality. Throw a stone into quiet water, there will be formed a system of concentric circular waves, the common centre of which will be the point where the stone fell. Now, throw two stones at the same time, at a certain distance from each other, each of the systems of circular waves will extend as if it were isolated, and, at the point where the two waves meet, their form is not changed, merely their height is increased. When the hollow interval between two waves, or the furrow that separates two successive waves, meets the interval of two waves of the other system, the furrow becomes deeper; but if on a certain point the wave of one system tends to raise the water, while the wave of the other system tends to lower it, these two opposite movements destroy each other, and the water is quiet, or much less agitated than if there were only one system of concentric circles.

The system of undulations teaches us that the intensity of light increases when the luminous particles oscillate greatly around their mean position, as a bell or a chord resounds more powerfully at the moment when they are moved, because their oscillations are then greatest. The amplitude of these oscillations, that is to say, the deviations of two successive waves, are not the same for the different rays of the spectrum; as in the different tones of the musical gamut, one of them makes in a second a number of oscillations less by one-half than that which is an octave higher: hence it follows that the amplitude of the oscillations of the first is double that of the second. Exact measurements have proved that the deviation of two waves is less as we advance from the red toward the blue end of the spectrum.

These principles being established, we may easily deduce from them the changes in the intensity and colour of a star. Among the rays which leave it simultaneously, and which are differently refracted, a great number unite either in our eye, or in their course through the atmosphere. If they so meet each other that their waves are united, they mutually reinforce each other; but, if a wave is added to an interval, then they weaken or destroy each other: hence the alternate increase and decrease of light. As, in the atmospheric state that we have described, the refraction changes at every moment, the rays also meet and reinforce or reduce each other every instant. As the light that comes from the stars is susceptible of decomposition into its elementary colours, like that coming from the sun, we must attribute its increase and its diminution to the meeting of its elementary rays. It may, therefore, happen that the red is annihilated by the meeting of two rays of this colour, whilst the blue becomes more intense: the star will then appear blue; a second afterwards, the contrary may occur, and the star will assume a red tint.

**MIRAGE.**—Like as the rays that come from the stars are refracted so that they appear to us more elevated, so also those that come from terrestrial objects undergo an analogous deviation. This consideration is of the highest importance for the measurement of mountains by land-surveying. It is only when the object is in the zenith, or in the same horizontal plane as our eye (supposing the stratum containing both to be of the same density), that there is no refraction: this last condition is seldom realised, on account of the action of the ground on the aërial strata with which it is in contact.

Look at distant objects during calm and fair weather, or at the shadow projected by trees on a surface heated by the sun, you will see their form continually oscillating; this effect is much more marked, if we look through a telescope at objects situated in the horizon. Very frequently pieces of the horizon seem to be detached, and to float in the air, and then fall again. If the object is small, it will appear double or multiple: thus M. **Biot**, on looking through a telescope at a very distant light, saw it double, the coloured and extended image was placed vertically above the real light. An instant after, instead of two lights he saw several, which appeared and disappeared at regular intervals; the lowest, which were nearest to the real light, were the largest and most brilliant. Sometimes objects situated in the middle of a plain appear double, and several images are formed above and beneath them: this phenomenon is known under the name of *mirage*, on the north coast of Germany it is called *Kimmung*.

Let O (pl. v. fig. 4) represent the eye of the observer: the line HH′ represents the horizon. If the ray OH traversed a stratum of air of equal density, the object H would be seen in the place it really occupies; but, if the weather is calm, and the earth highly heated, the temperature diminishes rapidly from the surface of the ground, and the change of density in the lower strata, which is the consequence, changes the refractions. The ray H′C, in passing at C from a hotter into a colder, and consequently a denser stratum of air, approaches the vertical: and, as this effect takes place in each stratum, it follows that it describes the curve H′CA, and does not reach the eye: but another lower ray describes the curve HDO, and reaches the eye, and, the object seen at H appearing inverted, we might imagine that it is reflected on a transparent liquid. The illusion is the stronger, as the rays from the points intermediate between H and H′ do not reach the eye, and it appears as if there were a void space in the neighbourhood of the inverted image;—a space, which we are the more tempted to regard as water, because the currents of air that mix make the objects tremble, and resemble a surface agitated by wind. If the air is colder at the surface of the sea, or of fields of ice, than it is a few decimetres above, the inverted image is above the object; and above the first image is a second that is not inverted. **Wollaston** points out a very simple experiment, by which this phenomenon is realised: a cubical vessel with plane surfaces is selected; into this is poured first water and then sulphuric acid by means of a funnel, the extremity of which touches the bottom. When the experiment is carefully made, the sulphuric acid occupies the bottom of the vessel, but its strata go on diminishing in density as they approach the surface of the water. If now we place behind the vessel a paper covered with a few letters, and the eye is on the same horizontal line, we may see the object directly and by refraction.

The mirage for the most part occurs in extensive plains, when the weather is calm, and the ground heated by the sun; the plains of Asia and Africa have become celebrated in this respect: thus, during the expedition of Egypt, the French army frequently experienced cruel deceptions. The ground of Higher Egypt forms a plain perfectly horizontal; the villages are situated on small eminences. In the morning and evening, they appear in their proper places, and at their real distance; but, when the ground is highly heated, the country resembles a lake, and the villages appear built on islands, and reflected in the water. As we approach, the lake disappears, and the traveller, devoured by thirst, is deceived in his hope. This phenomenon is so common in these countries, that the Koran designates every thing deceitful by the word *serub*, which means mirage. It says, for example: "The actions of the incredulous are like the *serab* of the plain; he who is thirsty takes it for water, and finds it to be nothing." Although it is more common in the East, yet the mirage exists in our plains much more frequently than is imagined, expecially when we bring the head near the surface of the ground: I have observed it in the neighbourhood of Halle, in the country of Magdebourg, and on the coasts of the Baltic, where I often have thought myself in the midst of a large bed of water.

If the ground is colder than the air in contact with it, then the temperature of the aërial strata rapidly increases with the height, and we not only see above the object its inverted image, but the visual circle of the spectator is singularly augmented. **Scoresby** made a great number of observations of this kind in the seas about Greenland. June 19, 1822, the sun was very hot, and the coast suddenly appeared to come 25 or 35 kilometres nearer; the different eminences were so raised that they were seen as easily from the deck of the ship as they were before from the fore-top. The ice in the horizon assumed singular forms, the larger blocks seemed columns; icebergs and fields of ice, a chain of prismatic rocks; and, in many places, the ice appeared to be in the air at some minutes above the horizon. Ships, that were in the neighbourhood, assumed the most whimsical forms; in some, the mainsail seemed reduced to nothing, whilst the foresail appeared four times larger than it really is; the topsail appeared shortened. There were also other whimsical appearances. Above the topsails was seen a sail resembling top-gallant-sails loose from the bolt-rope; in others, the topsail seemed divided into two, inasmuch as the true sail was separated from its image by an interval. Above distant ships, their own image was seen inverted and magnified; in some cases, it was very high above the ship, and then it was always smaller than the original. The image of a ship, that was itself below the horizon, was seen for several minutes; a ship was even surmounted by two ships, one in the right position, the other inverted. Some days later, **Scoresby** saw the same appearances: "The most curious phenomenon," said he, "was to see the inverted and perfectly distinct image of a ship, that was below our horizon. We had observed similar appearances; but the peculiarity of this was the distinctness of the image, and the great distance of the ship it represented. Its outline was so well marked, that, on looking at this image through one of **Dollond's** telescopes, I distinguished the details of the rigging, and of the hull of the vessel, I recognised it as being my father's ship; and, when we compared our log-books, we saw that we were then 55 kilometres apart, namely, 31 kilometres beyond the real horizon, and many myriametres beyond the limit of distinct vision."

There is a mirage, in the proper acceptation of the term, when we see below the object its inverted image; and then the air is hotter in the neighbourhood of the ground than at a certain height. This phenomenon evidences an anormal state of the atmosphere, and the calm, indispensable for its production, is often troubled by ascending currents and violent gales of wind: so that several observers say that the mirage is the precursor of a tempest.

**CORONÆ AND HALOS IN GENERAL.**—When the light coming from the stars falls on condensed vapours in the vesicular state, or on icy particles, it experiences different modifications; thence follow phenomena known under the name of *coronæ* and *halos*; generally these two words are used to designate phenomena that are very different in their aspect and their origin. When the sky is covered with light clouds, we often see a coloured circle, in which red predominates, surrounding the moon or the sun;

its diameter only comprises a few degrees; at other times, several concentric rings are observed, separated by intervals, in which green predominates: we shall designate these rings by the name of *coronæ* (*Lichtkranz* or *Kranz*, Germ.); some authors call them *small halos.* I also range among the coronæ that phenomenon in which, when the shadow of the observer falls on a cloud, the head appears surrounded by a glory, or by coloured circles. In the description of the Rigi, the geographer **Keller** designates this phenomenon by the name of *Nebelbild* (fog-image), which it bears on the Alps. On the Brocken it is termed the spectre of the Brocken (*Brockengespenst*); it is sometimes called *glory;* we shall name them *anthelia* (*Gegensonne*). The second class of this phenomenon constitutes the *halos properly so called*, which may be named large halos; under this name we comprise the great circles that surround the sun or moon, and the diameter of which comprises nearly 44°: they are attended by circles of a double diameter, by parhelia (*Nebensonnen*), and by other circles. These two classes of phenomena have a very different origin, the former are formed in vesicular vapours, the others in crystals of ice.

**OF CORONÆ.**—When light clouds pass before the sun and weaken its rays, the corona is more or less regular. As we are generally too much dazzled by the rays of the sun to distinguish the colour surrounding the disc, the phenomenon is more frequently noticed round the moon; in order to examine it round the sun, we should use a mirror blackened on one of its surfaces: the reflection then so reduces the brilliancy of the rays, that we can study the colours surrounding the sun.

All clouds that are not too thick to prevent the light passing through, the *cirrus* and the *cirro-stratus* excepted, present traces of coronæ: but the brilliancy of the colour is not always the same. I have never seen them so beautiful as fogs that are formed during the night in the valleys, and rise about mid-day to the summit of the mountains. When fragments of clouds passed between myself and the sun, then the colour had a brilliancy such as I had rarely seen; they are no less beautiful on the *cirro-cumulus*, especially when they are in small masses of a dazzling white, and the edges of which are so confounded that we can scarcely trace out their outline on the sky. Clouds of the same form, the edges of which are more jagged, and which I class among the *cumulo-stratus*, only give rise to incomplete coronæ: we frequently see in them a red of an undecided tint and badly defined. In true *cumulus*, the mass of vesicles is often so great, that light cannot traverse them in sufficient quantity to produce the phenomenon; but we often see the colours in the slight flakes that are detached from the principal cloud and approach the sun: this phenomenon, therefore, is by no means rare, for it may be observed every time that light clouds pass before the sun.

If the corona is complete, several concentric circles are observed. Near the sun they are of a deep blue, the second circle is white, and the third red, which terminates the first series; in the second we see, still going in the direction from the centre to the circumference, purple, blue, green, pale yellow, and red; the series is rarely thus complete. More frequently we observe near the sun, blue mingled with white, then a red circle clearly limited within, but confounded without with the others. If a second red circle exists outside this, then green is observed in the interval, by which they are separated. The distance of this circle from the centre of the sun varies according to the state of the clouds and the atmosphere; I have found it from 1° to 4°.

According to the faithful researches of **Fraunhofer**, these coronæ are due to modifications of light, known by the name of diffraction; and although it is impossible for us thoroughly to analyse the laws of the phenomenon, without having recourse to mathematics, I will yet endeavour to explain them as clearly as possible.

Let us look through a slit made with a penknife in a very firm sheet of paper at a luminous point, such as the image of the sun, or that of a distant taper reflected by a blackened watch-glass, or the bulb of a thermometer, we shall see, on both sides of the luminous point, a series of coloured images. If, instead of white light, we had operated on a coloured ray, such as that obtained by making it pass through coloured glass, we shall obtain a series of objects, separated by dark intervals; but, all things else being equal, the deviation of the red will be less than that of the blue rays. This phenomenon is due to the waves continuing their course through the slit; but the edges of the latter become the point of departure for fresh undulations, which act by interference, either upon each other or upon the direct waves; so that, in certain points, there is darkness, in others, an increase of light; hence follows the alternation of light parts and dark bands. The distance of these images from the luminous point depends on the length of the wave of light employed. Let us take a white light, the dark band of the red ray will fall where two blue rays are added together: this point, therefore, will appear blue. The exact calculation of the position of each of these isolated colours gives intervals that perfectly accord with experiment.

The phenomena are still more remarkable, if, instead of a single slit, we consider several of equal size and equidistant; the effect of each is augmented by the others. Trace with a diamond on a plate of glass several equidistant lines, and then look through it at the flame of a candle: you will see around the flame coloured rays, the direction of which is perpendicular to that of the scratches. If a series of lines had been traced perpendicular to the former, two systems of images would have been obtained, crossing each other at right angles; these effects may be seen, although somewhat imperfectly, by looking through a piece of very thin muslin. If the transparent parts were not, as in this case, in parallel series, but arranged arbitrarily in space, although grouped symmetrically round a point, the image would form circles, of which the centre would be the luminous point: this is what **Fraunhofer** saw on looking at a distant luminous point through a great number of thin films, or small glass balls placed between plates of the same substance. The luminous point, when examined through this apparatus, was surrounded with coloured rings: it may be seen, but not so well, by dimming a glass with the breath, and looking through at a distant light; as the different parts of the plate have different transparency and refracting properties, a multitude of systems of waves result, which act on each other by interference, and thus produce the different colours. When windows have not been cleaned for a long time, a slight film of dust and smoke is formed on their surface; and, as these opaque particles are rarely of the same thickness, the flame of a taper, when examined through this glass will be surrounded by a coloured corona, which will be circular, because the particles that impart the light are arranged symmetrically around an ideal line joining the light and the eye. The phenomenon is produced with reflected as well as with direct light. Had we, in the latter case, examined the image of the flame of a taper reflected by a plate of glass dimmed with the breath, we should also have seen around it a circular corona, in the same manner as we see on scratched glass coloured bands on both sides of the reflected image. The deviation of the image depends here, as in the preceding cases, on the deviation of the rays.

If the vesicles of fog are not too numerous, and are of equal diameter, then they act upon the light of the sun in the same manner as the smoke on a plate of glass does; the sun is surrounded by a luminous circle, the diameter of which depends on that of the vesicles. These two sizes are so intimately connected, that the measure of the diameter of the corona is the best means for knowing that of the vesicles of fog; and it is the means that is employed in order to obtain the numbers given in p. 111. If the vesicles of vapour in the atmosphere have not the same size, then, according to the laws of diffraction we shall not obtain luminous coronæ, but merely a luminous aureola.

Whoever has studied these phenomena is convinced of their variability. Let it suffice to allude to the rainbow colour of clouds. When white clouds, the edges of which are parallel to the horizon, and which have the form of *cirro-cumulus*, are in the neighbourhood of the sun, we observe, by means of a blackened mirror, vivid prismatic colours under the form of parallel fringes at the edge of the cloud, and often at ten degrees distance from the sun. These fringes are generally green within, and bordered by two red lines, they are regularly distributed in the cloud, and at different distances from the sun. The vesicles have probably, at certain points, very unequal dimensions, which destroy the symmetry of the circle, and foretell approaching rain.

**ANTHELIA.**—If the sun is near the horizon, and the shadow of the observer falls on grass, or a field of corn, or any other surface covered with dew, then he observes a glow, the light of which is vivid, especially near his head, but which diminishes from this centre. This light is due to the reflection of light by the moist stubble and drops of dew; it is more vivid around the head, because the stubble, situated in the neighbourhood of the shadow of the head, shew to it all their illuminated portion, whilst those that are more distant shew to it parts that are illuminated and others that are not, which diminishes their brilliancy in proportion to the diameter of the head. As the stubble has a cylindrical form, it follows that the glory is a little elongated in the vertical direction.

The anthelia seen by **Bouguer** in the Cordilleras, and since by several travellers in other countries, is always experienced in this manner. **Scoresby** has, however, described it in detail; according to his observations, the phenomenon is seen in the polar regions every time that there is fog and sunshine simultaneously. I have verified this fact on the Alps. As soon as my shadow was projected on a cloud, my head appeared surrounded by a luminous glory. In the polar seas, when the stratum of fog that is not very thick is resting on the sea, and rises to the height of 90 or 100 metres, an observer placed on the foremast, twenty-five or thirty metres above the sea, perceives one or several circles on the fog. These circles are concentric; and their common centre is on the straight line which goes from the eye of the observer to the fog on the side opposite to that where the sun is. The number of the circles varies from one to five; they are generally numerous and well coloured when the sun is very brilliant or the fog thick and low. On July 23d, 1821, **Scoresby** saw four concentric circles around his head: the first was white, yellow, red, and purple; the second blue, green, yellow, red, and purple; the third, green, whitish, yellowish, red, and purple; the fourth, greenish, white, and deeper on the edges. The colours of the first and second are very vivid; those of the third, only visible at intervals, were very faint; and the fourth presented only a slight tinge of green. The semi-diameters of these circles were of the following lengths:—semi-diameters of No. 4, internal edge, 36° 50′, external edge, 41° to 42°; semi-diameter of No. 3, 6° 30′; semi-diameter of No. 2, 4° 45′; of No. 1, 1° 45′. The circle, No. 4, to which **Scoresby** assigned a diameter of about 40°, appeared to be very uncommon; however, I have never seen it more than two or three times in the Alps, perhaps because the clouds were too small. We must consider it as a rainbow formed in the small drops, so that I need not in the present place dwell on it at greater length.*

**Bouguer** thought that the phenomenon of the anthelia was due to the passage of light through frozen particles. This is likewise the opinion of M. **de Saussure** and **Scoresby**; but **Ramond** mentions that he has seen it in the Pyrenees, at

---

* The author seems to admit here that the greenish white circle, or SCORESBY's circle, No. 4, is an ordinary rainbow, appearing white, because its colours are very pale; but it is difficult to be of this opinion, if we regard the measurements that have been made of this arc. The observations of BOUGUER and ULLOA, in Peru, give 33° 30′ as the radius; that of SCORESBY, 38° 50′; the mean of the two observations of M. KAEMTZ, 39° 48′; M. BRAVAIS found 45° as a measurement made at Bell Sound (Spitzbergen), and 38° 54′ from the mean of five measurements made on the Faulhorn in 1841. The general mean of these five numbers is 37° 12′. This angle is very different from the angle 41° 30′, which represents the mean radius of the ordinary rainbow, in order that this circle may be considered a vertical rainbow.

SCORESBY remarked, that this circle presented a slight greenish tinge. In the three appearances that occurred to M. BRAVAIS, he never saw any thing like this: but once only he thought he distinguished a very feeble reddish tint in the exterior part of the circle.

The cause of this phenomenon is not yet well understood. Is the cloud on which it is produced formed of liquid water, or of frozen particles? The former of these two opinions is the more probable. It is remarkable, that this cloud is more frequently situated very near the observer, and sometimes at a few metres distance. The circle to which we here alluded sometimes bears the name of the *circle of Ulloa* or the *white rainbow*.—M.

temperatures during which we could not suppose that there were frozen particles in the air; he reverts, at the same time, to an observation made by M. **Omalius d'Halloy**, August 27th, 1807, in the neighbourhood of Spa. My own observations in the Alps confirm this opinion, for I have frequently had a temperature of 10° in the neighbourhood of the fog. The whole of the phenomenon may be deduced, as M. **Fraunhofer** has very well shewn, from the diffraction of light. This theory is confirmed by the observations in which I first saw a corona, when the cloud was between myself and the sun, and then an anthelia when it was in a direction opposite to that of the sun. The light is reflected more powerfully in the neighbourhood of the head by the vesicles of fog as by blades of grass, for we then receive the light sent to us by the posterior and anterior faces: thus, therefore, the brilliancy of the light must go on decreasing from this centre. When these reflected rays, before reaching the eye, pass through other vesicles, they are then diffracted, and coloured rings are produced.

**HALOS.**—These optical phenomena are so complicated that it is even a difficult task to describe them; few observers have seen them completely; and even during the observation their appearances often change. I will here relate the description given by **Lowitz** of the one he observed at St. Petersburg, June 29th, 1790. For a long time we had no other exact description; but, on the 12th of May, 1821, **Hoff** and **Kries**, at Gotha, described a second very complete one; and March 27th, 1826, **Schult**, **Hansteen**, and **Segelke**, saw similar phenomena in Norway.

At St. Petersburg, the air was loaded with haze, and the phenomena lasted from 7 hours 30 minutes A.M. until 12 hours 30 minutes, though it has not at all periods the same intensity. The following are the principal facts (pl. v. fig. 3):—

1st. A ring, 22° in diameter, the centre of which was occupied by the sun *a*; it was coloured red within, and of a pale blue on the exterior. It is generally a single circle. **Lowitz** saw, in place of it, two circles *c d b e*, which cut each other above and below; in Norway, three have been seen. According to **Æpinus**, who considered these circles to be ellipses, they would be very common.

2d. A circle *z z z*, of which the sun is the centre, and which is also coloured. In general, it presents more decided colours than the former; its diameter is about double.

3d. An horizontal white circle *a b z g h f c*, passing through the sun, and taking the course of the horizon.

4th. There were on this circle five parhelia, two of them, *z* and *y*, a little beyond the small circle; they are generally found at the point of intersection of this vertical circle with the horizontal. They appeared coloured, and their red side was turned toward the sun; they had brilliant elongations, that extended in the direction *xz* and *yz* on the horizontal circle; the coloured arcs, *xi* and *yk*, that came from them, have never been seen again by any one.

5th. The third parhelion *h* was placed on the large horizontal circle, opposite to the sun: it was of a pale white.

6th. The fourth and fifth parhelia, *f* and *g*, were, in like manner, white: all observers agree on this point. They are seen more rarely; they appear to exist at the points of intersection of a circle with a radius of about 90° (of which the sun is the centre), with the horizontal circle.

7th. Above, at *d* the interior circle shone with so much brilliancy, that the eye could scarcely support it. Vertically above the sun, the interior circle is also more luminous; and a convex arc is frequently observed in it towards the sun.

8th. **Lowitz** saw a similar arc in *r e f*, at the lower part of this circle; it was very large and extremely brilliant, but of a semi-diameter less than that of each of the others.

9th. At the culminating point *z*, of the great vertical circle, he saw the arc *p z q*, which was convex toward the sun; it was as brightly coloured as the circle *z z z*. It is always placed vertically above the sun, and at the same distance as the circumference *z z z*.

10th. **Lowitz** saw also two arcs *h l a* and *h m a*, which passed through the parhelion *h*; and which he has drawn as passing also through *d*, the culminating point of the interior circle; they were white, and so pale, that many persons could not distinguish them. **Lowitz** says that they cut each other in the brilliant region near *d*; but, as **Schult** makes them pass through the sun, **Brandes** thinks that that body is their true point of intersection, but that there is a difficulty in following them so far. These two arcs are rarely seen; nevertheless, other observers have pointed them out, and say that they cut each other at an angle of 60°.

11th. Finally, **Lowitz** saw two other circles, *tt′* and *vv′*, tangents to the great vertical circle; their tangental points *oo* were distant about 60°; their size and colouring were those of the rainbow: they are also very rare.*

Lunar and solar halos are more common than we are apt to imagine; there is often a doubt in the public newspapers, where observers describe them as rainbows. We shall see presently that the origin of the rainbow and its position relative to the sun are very different from that of halos. Halos, indeed, generally exist between the observer and the sun; the rainbow, on the contrary, is formed in the part of the heavens opposite to the sun, to which latter

---

* The plate in the frontispiece represents a solar halo observed at Piteo in Sweden, by M. Bravais and myself, 4th October, 1839. Although this halo was far from being so complete as that given by the author (pl. v. fig. 3), it yet produces the appearances that are less rarely seen, with the arrangement of colours, proper to the different parts of the phenomenon.

The height of the sun, during the observation, varied from 13° to 20°; but, not to increase the size of the figure too much, this height has been considerably diminished in the drawing.

The projection of the phenomenon is made on a vertical above, perpendicular to the vertical plane containing the sun and the observer; this circumstance explains why the different circles present elliptical or extended hyperbolic forms.

The arc tangent to the halo of 47°, *the circumzenithal external arc*, was very brilliant during our observation; and the different tints of the solar spectra were as distinctly evident as in an ordinary rainbow. This arc extended considerably either to the right or left. On ideally joining its two extremities with the zenith of the place, a section of about 90° was formed; it was the *azimuthal amplitude* of this arc. Moreover, it appeared horizontal to the eye.

This result is conformably to the theory of these circumzenithal arcs (*Berührungsbogen*), given by M. Galle in Poggendorff's *Annales*, t. xlix. pp. 261–272.

We observed that the two parhelia opposite to the sun were placed a little beyond the ordinary halo, which accords with the theoretical explanation given by meteorologists.

The phenomenon lasted from 9 A.M. till 3 P.M.

About two o'clock, I observed on the horizontal circle two new parhelia, situated about 45° from the sun. They were visible for only a few moments on a group of white *cumulus*, and disappeared with the arrangement of clouds, by which they had been rendered visible.

The plate on the frontispiece, beginning from above downwards, represents:—

1st. The external circumzenithal arc, presenting the tints of the spectrum; it corresponds with the arc *p z q* (pl. v. fig. 3).

2d. The extraordinary halo, or exterior vertical circle of 47°, corresponding to the arc *z z z*.

3d. An arc tangent to the ordinary halo, or interior circle, which in fig. 3 would be tangent at *d*.

4th. The ordinary halo, or interior vertical circle, of 22° radius, replaced in fig. 3, by two circumferences, *d c c* and *d b c′*, cutting each other at *d* and *e*.

5th. The sun placed in the centre of the ordinary halo, and supposed at *a* in fig. 3.

6th. The horizontal or parhelic circle, passing through the sun, and corresponding to the circle *a z f h g z a* of fig. 3.

7th. The two parhelia placed a little beyond the point of intersection of the ordinary halo, and the horizontal circle, corresponding to the point *x* and *y* of fig. 8.—M.

the observer turns his back. Frequently there are but portions of the halo, which can only be seen by the assistance of a blackened mirror, and not by looking at them directly.

Lunar halos are visible when the stars are not very brilliant; during the day, the sky has a dull appearance, and the horizon is white. The appearance of the sky is, therefore, that which accompanies coronæ. The arrangement of clouds is not the same in the two cases. The coronæ occur in the middle of *cumulus*, halos in *cirrus;* there are not any clouds that do not present traces of them; and, although the opinions of different observers are at variance, every thing I have seen convinces me of the correctness of my own.

Some authors insist that they have seen halos and coronæ at the same time round the sun or the moon; but, from my own observations, this coexistence is very rare, and then even, on taking all circumstances into the account, we find that coronæ are found in *cumulus*, floating in the lower regions of the atmosphere, and which are frequently so attenuated, that they cannot be seen without looking at the sky with much attention: thus, therefore, these two phenomena are distinct. Moreover, in coronæ, the red is more distant from the sun than the blue; the contrary is the case with halos: we are forced to conclude that halos are an effect of refraction. **Mariotte** had admitted that light is refracted in small crystals of snow; all the observations, made since his time, have given the highest degree of probability to this opinion. Not only are the dimensions of halos precisely those given by calculation on this hypothesis, but we may in winter convince ourselves directly of this. In this season, when small transparent crystals are floating in the atmosphere, they frequently appear tinted with prismatic colours; if their distance from the sun is measured, we find that it is the same as that of the halos. As all mathematical considerations are excluded from this work, I must refer to my *Treatise on Meteorology.*

**Brandes,** who made the most assiduous researches on halos, and in which he developes the ideas of **Venturi** and **Fraunhofer,** divides the circles, that he has seen during a halo, into three categories: 1st, the circles of which the sun occupies the centre; 2d, circles, that pass through the sun; 3d, and tangent to the circles of the first class.

**CIRCLES, OF WHICH THE SUN OCCUPIES THE CENTRE.**—Let us begin by studying the circles of the first class. When a ray of the sun is refracted by an immovable prism, the incident and the refracted rays make together an angle depending on the substance, on the angle of the prism, and also on that under which the ray is incident; if the angle of incidence varies, that of the refracted ray varies with it. However, calculation and experiment prove, that there is a position of the prism in which the angle of incidence may vary without the direction of the refracted ray being sensibly changed. Take a glass prism, and present it to the incident ray of the sun in such a manner that the refracted ray deviates as much as possible from the incident ray; turn the prism slowly round its axis, measuring the angle of rotation; the direction of the refracted ray continues to increase in deviation from that of the incident ray, and this change is very rapid. But, if we continue to turn the prism, it finally takes such a position that the prism may be turned several degrees without the direction of the refracted ray being sensibly changed. In this position, the incident and the refracted rays make together the smallest possible angle; it is the position of the *minimum* of deviation. This *minimum* of deviation is important for consideration in these and in the following researches.

Imagine now a series of identical prisms, placed one above the other, so that their axes are on the same straight line; but that, on the lower one, the incident ray coincides with the vertical, whilst in the second, it deviates 1°, in the third, 2°, &c.; we shall see, on a white surface placed behind these prisms, a series of spectra, the horizontal distance of which increases from below upwards, so that it is scarcely sensible for the lowest in the neighbourhood of the *minimum* of deviation. If the axes of these prisms were not in a straight line, but so inclined, that all the spectra coincided with a horizontal line, some of them would cover each other, and form white light; in this point, therefore, we should see a band of white light. It is only in the neighbourhood of the *minimum* of deviation that these spectra do not completely cover each other. Furthermore, the same colours of the different spectra would coincide, and the result would be a single prism very deeply coloured, in which the red is generally very intense; because the red of the extremity of the spectrum is less mingled with foreign tints than the blue, which receives some red rays from the strongly refracting prisms, and forms white. In the interval between this red and the space, where the direct light of the sun falls, there is only diffused light, and this interval appears dark.

Instead of a single series of prisms arranged vertically above each other, let us imagine a great number differently inclined to the horizon; each will produce the same phenomenon: only the spectra will not only cover each other in the horizontal direction, but on a line, the inclination of which depends on that of the prisms. If the number of these series is very great, there will finally result a luminous circle in which the red colour will be within, and in which very pale blue will pass into clear white. This circle is produced, merely because a great number of spectra are placed side by side around the sun, and form a continuity like the Milky Way and the nebulæ, which are also composed of isolated points. The following experiment, very simple as it is, explains the mode of the formation of this circle, the centre of which is a luminous point. Take a glass plate from two to four centimetres square, and coat in on one side with a solution of alum: if the plate is placed horizontally, and the solution is uniformly spread, crystals of alum will be found after evaporation, the lateral faces of which will have the same inclination on the surface of the plate. If we look at a distant luminous point through this plate, as the homologous faces of the crystals reflect the light in the same direction, we see a series of points presenting prismatic colours, that are arranged in concentric circles, or unite into circles and continuous arcs, if the crystals are very numerous. When the evaporation takes place rapidly, the crystals are smaller, and the circle is not so clearly defined; we may also fix the plate of glass at the extremity of a tube of pasteboard blackened on the interior, and terminated at the other extremity by a circle, the centre of which is pierced by a circular hole.

Small crystals of ice floating in the atmosphere reflect light in this way. We have seen that flakes of snow are reducible into prisms, the surfaces of which form angles of 60°.* If a prism of this kind is turned upon itself in the atmosphere, rays continually leave it and reach the eye, but dis-

---

* The prisms formed by water in congealing are not triangular, but hexagonal; their two contiguous faces are inclined to each other, not at 60°, but at 120°. A diedral angle thus opened cannot allow any ray of light to pass: the ray, after having traversed the first face, if it reaches the second, experiences there a total reflection, which sends it back into the interior of the crystal.

It is not the same, if we consider two faces separated by an intermediate face; these two faces, ideally prolonged, cut each other exterior to the prism, at an angle of 60°; it is the binary combinations of the two faces, thus placed, which become rays of the sun, and produce the halo.

This arrangement is easily explained, by considering the prism as the result of the junction of two triangular prisms, alternate as far as concerns the position of their summits, and placed as is shewn in the central part of pl. iv. fig. 15.—B.

appear immediately afterwards; but it is evident that the ray will strike the eye for the longest possible time, when its elevation shall attain its *minimum*. If the number of these prisms is very great, it will then happen that we shall receive at the same time the rays refracted by one prism at the moment when those from the other are disappearing, so that the impression on our eye will be permanent, although the rays are not sent to it by the same crystals. In the position of the *minimum* of deviation, we shall see around the sun and the moon a brilliant circle, red within, of a pale blue or a brilliant white, which is confounded with the azure of the sky, without. As a great number of the prisms surrounding the sun send their spectra toward the coloured ray, or even further, we receive from this space only the light reflected by the aërial particles on the face of the prisms; and the consequence is, that this space is darker than that which is without the circle.

Experience confirms all these data of theory. If we consider a halo attentively, we shall see that the external edge is distinguished by an ill-defined dark colour, which is frequently greyish, and the more marked as the halo is more brilliant; if we examine the distance separating the middle of the red from the centre of the sun, we shall find it to be between 21° 50′ and 22°. On calculating this distance from the well-known refracting power of ice, we find exactly the same distance; and the calculation also shews that the light must be very vivid in the position of the *minimum* of deviation. On turning an equilateral prism around its axis, so that the angle of incidence each time increases by one degree, we find only 120 possible positions, and among these only 20, or one-sixth of the whole, which are such that the light undergoes a *minimum* of deviation, or only deviates 40′.

The explanation of the second circle (halo extraordinary), the red border of which is also turned toward the sun, and is 45° from it, presents greater difficulties. **Brandes** thinks that there is perhaps a refraction in two prisms situated one behind the other; **Fraunhofer** and **Schmidt**, that the prisms of ice with six surfaces are terminated by pyramids with hexagonal bases, the faces of which are inclined at angles of 90°, and that the second circle is an effect of the refraction of light in these pyramids. But the luminous intensity of this circle will be always less than that of the first, and consequently it would not be seen so frequently.*

* Every one agrees in the explanation of the halo of 22° radius; but it is not so in respect to the extraordinary halo of 46° or 47° radius.

However, of the two rival hypotheses, it now appears that the former

The third circle is still more rare; and we possess no complete observation, with the exception of **Hevel's**. It is 90° distant from the sun; and the violet is nearer the sun than the red: which distinguishes it from the two others at first sight. Here the ray falls on the prism, so that the posterior surface reflects it completely, and refracts it after this total reflection, as we shall see presently for the rainbow.

**CIRCLES PASSING THROUGH THE SUN.**—When the sun is near the horizon, a portion of the vertical circle may rise above it in the form of a column. On June 8th, 1824, appearances of this kind were seen in several parts of Germany. At Dohna, near Dresden, at 8 P.M., at the moment when the sun was disappearing behind the mountains, **Lohrmann** saw a luminous band, perpendicular to the crepuscular arc, and like the tail of a comet; this column was 30° degrees high, and 1° wide. As darkness arrived, the brilliancy of this column diminished; at the same time, the column became rounder at the upper extremity, and shortened very rapidly; light vaporous clouds floated before the column, until it disappeared: these probably were *cirrus*. The same phenomenon occurred next day at sunrise; and it was frequently seen afterwards. It is not so common to see a band beneath the sun or moon, and still less so to see a horizontal one pass through the sun, so that this body shall appear in the middle of a cross. **Roth** saw this phenomenon very distinctly, Jan. 2, 1586, at Cassel. Before the sun appeared, a luminous vertical column, of equal diameter with the sun, shone at the spot where it was about to rise; it resembled a brilliant flame, only its brilliancy was uniform throughout its height. An image of the sun soon appeared, so brilliant that it was taken for the sun itself; scarcely had this parhelion quitted the horizon, when the sun rose immediately beneath, followed by a repetition of the upper column. This column, with its three suns, continued to retain

---

(BRANDES') must be rejected; for, according to this hypothesis, the radius of the extraordinary halo would be exactly double the radius of the ordinary halo. and its value would be 43° or 44°; this value is decidedly too low to represent the observation.

The hypothesis, therefore, remains, which explains the extraordinary halo by a refraction through a diedral angle, whose faces are inclined to each other 90°. M. GALLE has justly observed, that it was not necessary to have recourse to the six additional faces, by which FRAUNHOFER terminates his hexagonal prisms, so that they finish in hexagonal pyramids; it is sufficient to close the prism by two faces perpendicular to its axis, so that there becomes a right hexagonal prism: this mode of viewing it is entirely conformable to what is known respecting the crystallisation of hoar-frost, or of snow (as pl. iv. figs. 3, 28, 29, 30, &c.) prove. Each base of the prism, in according with each of the six lateral faces, forms six diedral angles of 90°; and it is through these diedral angles, in the proper positions of the prism, that the breaking of the light, which causes the extraordinary halo, is effected.—B.

a vertical position; the three suns were perfectly similar, only the true one was brighter. The phenomenon lasted about an hour.

In my *Treatise on Meteorology*, I have said that small flakes of snow may unite by their extremities and form parallel filaments. These filaments disperse light in the same manner as a plate of glass covered with a fatty body, when continually rubbed in the same direction with the palm of the hand, is covered with parallel striæ, which disperse light, and produce a pencil of light perpendicular to the plane of the striæ. This analogical idea is confirmed by the fact, that I have seen these columns whenever filaments of *cirrus* existed in the atmosphere in the neighbourhood of the sun. However, one observation, bearing the date of Jan. 23, 1838, shews that this idea is incorrect, and leads us to explain the entire phenomenon, with **Brandes**, to the reflection of crystals of snow. For several hours I perceived above the sun a vertical luminous column, about 10° in height. The sun being 6° above the horizon, and 1° above some buildings that had hidden it from my view, I saw beneath the sun an analogous column; but what is most remarkable is, that this column was continued to the ground from the sun to me; the air was clear, and the temperature varied throughout the duration of the phenomenon between —19°,6 (eight o'clock) and — 10°,2 (noon). Many frozen particles were floating in the air; and, between the sun and myself, I perceived a great many luminous points on a space, the diameter of which was a little greater than that of the sun: these brilliant points appeared, and then suddenly disappeared, and the smallest number appeared in luminous lines, which, being driven onward by a feeble west wind, traversed the band throughout its length. Had the flakes been more numerous, or my station more elevated, so that I could have seen a greater number of points beneath me, I should undoubtedly have seen a continuous luminous mass, and I should not have perceived the motion of the isolated points. All these brilliant lines were white; I rarely observed coloured points. The shortest distance of the scintillating points was at most three decimetres; for, in front of the window at which I was making my observations, there was a balcony, the iron bars of which, being about a metre distant from each other, served as a term of comparison, whilst the luminous points passed between them. The phenomenon remained till mid-day; but, several hours afterwards, I saw isolated brilliant points situated vertically below the sun. There are no phenomena of refraction here, but merely effects of reflection. All the isolated flakes of snow that I examined were composed of little hexahedral films, the largest of which, of about the size of a pin's head, were very brilliant. Many crystals passed near me without reflecting light, because they were not in a favourable position. A short time after sunrise, I perceived a portion of the circle with 22° radius in the east; as I saw luminous points between my eye and the terrestrial objects situated in the direction indicated by theory.

Besides this vertical circle, another is frequently observed, called *parhelic circle* (*vide* pl. v. fig. 3, *a y g h f x*, and the figure on the frontispiece), which makes the circuit of the horizon, to which it is parallel, or nearly so; this circle is an effect of the reflection of crystals of snow, the reflecting surfaces of which are almost vertical, as **Huygens** supposed; whilst **Fraunhofer** and **Schmidt** deduced the phenomenon from the diffraction of light.

**Brandes** explains, in the same manner, the circles *h l a* and *h m a* (pl. v. fig. 3); he thinks they are engendered by the reflection of prisms, making an angle of 60° with the vertical.

**PARHELIA.** (*Nebensonnen*).—They always exist in the point where two circles cut each other; and consequently, when there are two producing causes of light: it is generally at the point where the vertical and horizontal circle cut each other; and they are even observed where there is no trace of either of these (pl. v. fig. 3, *x y*, and the plate on the frontispiece). They possess the colours of the interior circle, and frequently a prolongation in the form of a tail, the direction of which coincides with that of the horizontal circle. Exact measurements prove that the parhelia do not occur exactly at the point of intersection of the two circles, but that they are at a little distance from the sun. **Venturi** explains this circumstance, by saying, that refraction in vertical prisms does not occur exactly in a plane perpendicular to the faces; and, if this idea is developed by analysis, we see that the parhelion should be more distant from the sun, as the latter is more elevated above the horizon: not only does experience shew this in a general way, but the differences between the values observed and those given by calculation are so small, that this opinion may be considered as perfectly exact.*

---

* Conceive a great number of prisms of ice, the axis of which is vertical and the diedral angle, 60°. The diedral angle may present itself, in respect to the sun, in an infinity of different manners. One of them is remarkable, it is that in which a ray, on traversing the interior of the crystal, is perpendicular to the horizontal line, that divides this diedral angle into two equal

**TANGENT CIRCLES** (*vide* pl. v. *p z q*, and the plate in the frontispiece).—**Brandes** explains them by prisms floating horizontally; but it is impossible to account for the

parts. The total deviation, being the sum of the entering and exit deviations, is the least possible; and, on account of the *minimum*, the emergent ray scarcely changes place, if the diedral angle is turned around its vertical side, as on a hinge, a considerable number of degrees, whether in one direction or in another. There are then found, as in the theory of the rainbow and that of halos, a great number of rays all coming out in the same direction, and, according to established phraseology, these rays come out *efficacious:* hence the production of a parhelion. The medial branch of the broken route of the luminous ray at its *minimum* deviation is placed symmetrically, in respect to the vertical faces of entry and exit; thus, whatever be the angular height of the immergent ray, in respect to the horizon, that of the emergent ray must always be the same; the parhelion will, therefore, be as much above the horizon as the true sun itself is. With regard to the amplitude of the deviation, it is easy to see that it is greater as the sun is higher; for the incidence of its rays on the vertical faces of the prism becomes, by this single fact, more and more oblique, which determines a continually increasing augmentation in the angles of deviation. If the sun is in the horizon, and its ray traversed the prism perpendicular to the vertical plane that *bisects* its diedral angle, the deviation obtains its absolute *minimum* of about 22°, and the parhelion then occurs at the intersection of the *ordinary halo*, and of the horizontal circle passing through the sun. In every other case, the parhelion is situate without the ordinary halo; and this lateral deviation increases with the altitude of the sun, as the following numbers shew:—

| Height of the sun above the horizon | Lateral deviation of the parhelion | |
|---|---|---|
| 0° | 0° | 0′ |
| 10 | 0 | 18 |
| 20 | 1 | 13 |
| 30 | 3 | 2 |
| 40 | 5 | 46 |

The same way will lead us, without recourse to calculation, to the explanation of the circumzenithal arc, tangent to the ordinary halo,—that of 22°. In order to fix the mind, we will suppose the sun to be on the meridian.

Let us lay all our prisms in such a manner that all their axes, preserving their parallelism, now become horizontal; and let us first direct them in such a manner, that these axes shall be parallel to the line running east and west, and, consequently, perpendicular to the meridian. Every system of crystals with parallel axes must give rise to two parhelia, as we shall soon see. In order to discover how they will be situated, it is sufficient to make the sun and the prisms turn in one system round the meridian of the observer, at an angle of 90°; the crystals become vertical, the plane of the meridian becomes the horizon; the position of the two parhelia is immediately known from the rules given at the commencement of this note. Let us now turn back the whole system, and bring it to its primitive position; it is evident that one of the parhelia will be situated 22° above the sun, and the other 22° below. We, therefore, see that the actual case only differs from the preceding in that the plane of the meridian plays the part which the plane of the horizon just now played.

Let us consider a second system of prisms, the axes of which, being naturally parallel, are directed from the E. 1° S. to the W. 1° N.; the vertical plane, passing through the observer, and perpendicular to these prisms, will have an azimuth of S. 1° W.; the sun, still in the meridian, will then be on the left of this plane. Let us make a motion analogous to that of the preceding case, and turn the whole around the horizontal line, the azimuth of which is S. 1° W.; the vertical plane S. 1° W., after this turning, is confounded with the horizon; the *parhelic circle* is, therefore, a small circle of the sphere passing through the sun, and parallel to this great vertical circle.

phenomena, without having recourse to calculation; and, on this account, I pass it over entirely in silence.

**STATE OF THE ATMOSPHERE DURING HALOS.** —Neither in the world, nor yet in scientific books, have sufficient distinctions been made between coronæ and halos; it is, therefore, difficult to know whether their appearance is connected with certain modifications in the state of the atmosphere. However, the great majority of observations relate to true halos; and both are said to foretell rain, especially when they are seen around the moon, where they more frequently occur than around the sun; but, as coronæ may be observed whenever there are clouds in the sky, they lose all signification. It is only when the diameter of the corona diminishes sensibly in a short time, that is to say, when the size of the vesicles of fog increases rapidly, that we may expect approaching rain.

It is otherwise with true halos; they prove the existence of *cirrus*; and, as they occur most frequently when the barometer falls, rain will not be long in coming. This is mostly the case during summer; and I have often observed very beautiful halos, when violent storms, accompanied with hail, were at a distance, or in the neighbourhood.*

---

The corresponding parhelion will be placed on a small circle, at an angular distance a little greater than 22°, the excess of distance being greater as the distance of the sun from the vertical S. 1° W. is itself greater.

The system of prisms perpendicular to the plane, the azimuth of which is S. 2° W., would also give two parhelia, the one above, the other below, both exterior to the halo; and, as the angular distance of the sun at these different vertical circles S., S. 1° W., S. 2° W., . . . . . continues increasing, the deviation of the corresponding parhelia outside the ordinary halo increases simultaneously. If, therefore, we now consider the series formed by all these parhelia, we shall easily see that they form two distinct curves, which touch the ordinary halo, the one at its culminating point, the other at its lowest point, and that these curves are exterior to the halos. These two curves are circumzenithal arcs, tangents to the ordinary halo; and in this way they are completely explained. With regard to the predominance of prisms, with horizontal axes, it very probably occurs, because these prisms not being very elongated in reference to the dimensions of their bases, and forming a sort of hexahedral film, must fall in the air, presenting the edge.

The arc tangent to the extraordinary halo cannot be explained in this way. This arc arises, according to M. GALLE, from the refraction of rays in crystals, the axis of which is vertical; the rays, after having penetrated through one of the six vertical faces, come out traversing the hexagon, that forms the lower base of the crystal. For the complete explanation of the phenomenon, we must, moreover, admit that these prisms undergo little oscillations around the vertical. The brilliancy of this arc varies with the height of the sun; and the most brilliant period of its appearance is, according to M. GALLE, that when the elevation of the sun is 21° 57′. The rays then traverse the prisms in conditions that realise its *minimum* deviation; and the emergent light is *efficacious*.

BRANDES has interpreted the origin of this circumzenithal arc in a different way; but his theory does not accord so well with observations.—B.

* The atmospheric circumstances favourable to the appearance of par-

We might also ask why halos are so seldom complete,—why at one time circles are seen concentric with the sun, and why at another time they pass through this body. If it were possible to study the crystals of snow, that reflect and refract the light, it would be easy to reply to that question. It appears to me probable that these differences are due to the different forms that the crystals may assume: if they are prisms floating in the air, a luminous circle is produced by refraction; if they are lamellated crystals, the reflection produces a parhelic circle passing through the sun. It is only when the two species of crystals exist at the same time that we observe the two phenomena simultaneously. This combination is rare; for generally we only see a single kind of crystal floating in the atmosphere.

**RAINBOW.**—When the rays of the sun fall on drops of rain, we see in the opposite region of the sky one or two arcs of a circle tinted with prismatic colours, and known under the name of *rainbow*. If the two arcs are complete, they are also concentric; and exact measurement proves that their centre is where the shadow of the spectator's head is. The interior bow, which is more frequently seen, and the colours of which are more vivid, is called the first or inner bow (*hauptregenbogen*); the other, exterior, the second or outer rainbow (*nebenregenbogen*). In the former, the violet is within, the red without; and, consequently, the ray of the red bow is greater than that of the violet bow; sometimes the inner edge presents a repetition of colours in fine fringes, in which green and red are especially remarkable. In the second rainbow, the colours are arranged according to an inverse order, so that the diameter of the red circle is less, that of the violet circle greater.

In order that there may be a formation of a rainbow, it is sufficient that the sun should strike drops of water with its rays; thus we may see the rainbow on clouds, and even on terrestrial objects. In gusty weather I have frequently seen rainbows on a blue sky, when drops were falling to the earth, because they evaporated during their fall; but the rainbow presents vivid colours only when the light that strikes against the drops possesses great intensity: thus lunar rainbows very rarely present prismatic colours; they are merely white or yellowish.

Let us follow the course of a luminous ray in a drop, of

---

helia, sometimes exist over a great extent of country; M. ARAGO, on this point, has noticed some parhelia that were seen May 13, 1838, at Laon, Saint-Quentin, Cambray, Lille and La Fère. (*Comptes rendus de l'Acad. des Sciences*, t. vi. pp. 373–501.)—M.

which we will suppose the form to be spherical, and of which the refracting power for each coloured ray is well known. Let MNO (pl. v. fig. 5) be the section of a drop, by a plane passing through its centre, C: and LM a ray coming from the sun: if it falls on M, it will be refracted in the direction MN; in N, it reaches the other surface of the sphere; one part of the ray passes through, the other is reflected in the direction NO, whence it is again reflected towards the interior, and partly refracted in the direction OP, as it leaves the drop, so that the eye, situated on OP produced, sees an image of a luminous point. Thus a ray undergoes several partial reflections and refractions in a drop, and, in each of its refracted rays produced, the sun is seen. Furthermore, the angle made by the incident ray with the surface of the drop varies from 0°, where the ray is a tangent, and 90°, where it passes through its centre: it follows that rays leave the drop in all directions, and that on all sides we may see the image of the sun reflected; but, if any one region is to be distinguished by its brilliancy, it is that in which the emergent rays become parallel, because, under these circumstances, the images coming from several drops are placed one beside the others, so as to form an illuminated region.

If we look for the conditions necessary to the production of this effect by calculation, we generally find a very great number of directions in which a luminous image may be seen; but there are chiefly two in which the brilliancy is very intense, and which give rise to the phenomenon.

If the sun S (pl. v. fig. 6), the drop and the eye O, are in the same plane, then the eye only receives the rays situated in this plane, and passing through the centre of the drop; the ray SA is refracted at the interior in the direction AB, and reflected in the direction BC, and then refracted toward the eye in the direction CO. But, in order that a pencil of parallel rays may come from all the drops situated in the direction CO, calculation shews that the two lines SA and CO should make together a certain angle, which varies for the different coloured rays, on account of their unequal refrangibility. If CO is a red ray, the angle is 42° 23′; if a violet ray, it is only 40° 29′; so that the extent of the arc is 1° 54′, and red occupies its exterior edges.

When rays undergo a double refraction at the interior of the drop, the image of the sun is still visible. Let SA (pl. v. fig. 7) be a solar ray falling on the drop ABCD; it is refracted in the direction AB, then reflected in BC, again reflected in CD, and at D it is refracted, as it comes out in the direction DO. Calculation also gives in this case the angle formed by the lines going from the sun to the eye, and from the eye to the rainbow: it is 50° 21′ for the red rays, 53° 46′ for the violet, and the width of the arc is 3° 25′.

There is, therefore, a double image; the one produced by simple reflection, the other by the double refraction of the rays in the interior of the drop: the first corresponds to the inner rainbow, the other to the outer. Finally, there may be a third image produced by a triple reflection,—an image still nearer to the sun, in that it is distant only from 42° 30′ to 37° 41′. A fourth image, produced by a quadruple reflection, may occur at a trifling distance; its distance from the sun will be from 42° 44′ to 48° 53′; but the intensity of these two latter arcs is so feeble that they are rarely seen.*

Hitherto we have only considered a single drop; as this moves rapidly, the image can last but for a single instant: but, if a great number of drops fall in the same direction, each of them will produce an image in the same places, and the sensation will remain permanent; if rain falls in a sheet, then there is a deformed bow.

Suppose for a moment that the observer is above the cloud, turning his back to the sun and distinctly seeing the shadow of his head upon the cloud: if he imagines a plane passing through the sun and his head, he will distinctly see a red image of the sun in each drop so placed that the line coming from each drop to his eye makes an angle of 42° 23′, with the right line joining his head, and the shadow projected on the cloud. But this plane may occupy every possible position, and the image of the sun always appears forming the angle mentioned; a red circle is therefore seen, the centre of which is situated on a right line, joining the eye and the sun, and the apparent diameter of which is 42° 23′. These red rays, therefore, form a cone, the axis of which passes through the eye and the sun, and the planes of which, tangent to the surface of the cone, make with this axis an angle of 42 23′; the violet rays make an angle of 40° 29′. The second rainbows form an analogous cone.

This cone also exists when the observer is on the surface of the earth; if he is placed on the summit of a mountain,

---

* M. Babinet, when in the most favourable circumstances, on Mont d'Or, and on the Canigou, vainly endeavoured to perceive them. (*Comptes Rendus de l'Acad. des Sciences*, t. iv. p. 645.)

while the rain falls below, then he perceives a complete circle, corresponding to the great circle that was described when speaking of the parhelia: this is also the circle that is perceived, under favourable circumstances, on drops of dew. On the plains, on the contrary, we scarcely see a semi-circumference, although the sun is high; for, if the drops fall from a cloud, and the latter forms a dark ground, only a portion of the rainbow is seen on the cloud. With attention, traces of the rainbow may be seen even nearer to the observer, if the latter is illuminated by the sun; but frequently they are mere points.

If, therefore, we admit that the rainbow is formed only when there are clouds in the back plain, we may not only deduce the size of this bow, but also the conditions under which it cannot occur. If the sun were in the horizon, the shadow of the head of the spectator would fall there also; and, as the axis of the cone would be horizontal, it would follow that we should see a complete semi-circumference of an apparent semi-diameter of 41°. As soon as the sun rises, the axis of the zone falls, and the arc becomes smaller; finally, if the sun attains a height of 41°, the axis of the cone forms the same angle with the plane of the horizon, and the bow becomes tangent to this plane. If the sun were still higher, the bow would be projected on the earth; and, as we rarely see the phenomenon when thus presented, or when the image is very pale, it is commonly believed that it cannot be produced. The second bow disappears when the sun attains a height of 52°; on this account we cannot see a rainbow at noon in summer.

If the image of the sun is reflected by a surface of quiet water toward a cloud, this image may in like manner produce a rainbow. As, in this case, two suns, one of which is as much below the horizon as the other is above, project their rays towards the cloud, the two bows will always meet, so that the angle between the refracted and the incident ray is 41°; the two bows will, therefore, cut each other, but the point of intersection depends on the height of the sun; four bows are thus frequently seen, because the sun, and also its reflected image, each produces a second bow.

I will mention a few other appearances, that are very frequently, though not always seen. When a vividly coloured rainbow is projected on a dark cloud, the sky is much darker above than below the bow; this difference is the more striking when the sun is low: it is, therefore, a phenomenon opposed to that, which we have observed in respect to halos, in which the interior space is darker than the exterior. If we follow the course of a ray in the rain-drop, we shall see that the drops situated above that in which the bow is formed do not send us the rays reflected by their posterior surface, whilst the drops placed below do send them; and these, notwithstanding their divergence, vaguely illuminate the space situated beneath the bow.

**SUPERNUMERARY RAINBOWS.**—They present a remarkable anomaly: in the first bow, the violet occurs within, and the red without; but we frequently observe anomalous repetitions of these colours within the violet bow: these are the bows that are designated *supernumerary*, *supplementary*, or secondary (*secundaere Bogen*). A second green bow, and a second violet, then a third green and a third violet, are attached to the violet bow. In general these are the only two colours that are bright; however, I have several times perceived bright red; observers have described more or less perfect repetitions of all the colours. Thus **Langwith** saw an ordinary rainbow, in which the violet had a strong reddish tint: beneath it was a green bow, the convex part of which passed to light yellow, whilst the concave was of a deep green; above was a bow of a deep purple colour, which disappeared and returned several times so rapidly that it could scarcely be observed. Beyond the ordinary rainbow was the following succession of colours: light green, deep green, purple, green, faint purple. There were here four series of colours, and perhaps the commencement of a fifth, since the bright purple is probably produced by a mixture of red with violet rays. **Langwith** adds a remark already made by many observers,—it is that he never observed this succession of colours in the parts of the bow that seemed to rest on the earth, although the colours there are much more vivid than the upper parts, beneath which this repetition of colours is manifested; the repetition of colours has been rarely noticed in the second rainbows. However, **Brewster** saw, at their outer part, a red bow, and above this a green bow faintly marked.

It is not easy to explain these supernumerary bows in a satisfactory manner. **Pemberton** thought they were due to the same phenomenon of interference as the coronæ that surround the sun or moon. Indeed, when a great number of small drops fall with the larger, and the rays from the ordinary rainbow pass near them, they are diffracted in the same manner as the rays that come directly from the sun. But, in order that this idea be just, it is necessary that the small drops should all have the same diameter,—an hypothesis scarcely probable; moreover, according to this explanation, there would be as many supplementary arcs behind the parts of the arc that touch the horizon as behind the others. The opinion of **Venturi** is more probable, who thinks that some drops are flattened in their lower part during their fall. The spherical drops produce the principal rainbow; the flattened drops, the supernumerary rainbows. If the drops have not the same dimensions, this is because the flattening is not the same; and in this case there may be recurrences of colours.*

---

* According to MM. YOUNG, ARAGO, and BABINET, these *secondary*, *supernumerary*, or *supplementary* arcs, are a phenomenon of interference that is explained as follows:—

Let SA (pl. v. fig. 6.) be the incident ray, ABC its route in the interior of the drop, OC the emergent ray. We know, by the theory of the rainbow, that if the angle of incidence of the ray SA is 59°, the inclination of OC to SA will acquire its *maximum* value, namely 41°; the ray will make part of the *efficacious* fasciculus, that gives us the sensation of the rainbow. Suppose the incidence of SA is equal to 70°; calculation proves that the inclination of OC to SA will be 38° 12′, necessarily less than the *maximum* inclination 41°. Imagine now a ray parallel to SA, but the incidence of which on the drop is 46° 45′. This new ray will be reflected at the same point, B, as the preceding, but it will leave the drop parallel to CO; so that the pencil of rays that reach our eye from all points of the sky, of which the distance from the sun is equal to 180°—38° 12′, is composed of rays of two sorts, some incident under the angle 70°, others under the angle 46° 45′. And, in general, for all these distances, 39°, 38°, 37°, &c. (unto 16° inclusive), between the point of the rainbow under consideration and the point of the sky directly opposite to the sun, it is correct to say that the luminous pencil, perceived by the eye, contains at the same time rays of incidence greater than 59°, and rays of incidence less. The two rays of different incidence, composing the same fasciculus, are in the proper conditions for interference, since they come from the same source, and after a slight difference as to the length of the course they traverse. Thus, each of the drops comprised between the portion of the sky situated in the concavity of the arc will give rise to a series of fringes, situated in the plane of the sun and the drop; of this series a single element may be perceived by the observer; but, if we consider a multitude of drops more and more remote from the internal edges of the bow, the regular series of fringes will appear, providing the drops are of the same diameter, and it will be developed in concentric bows interior in the principal bow.

The larger the drops are, the more should the width of these fringes or coloured rings diminish; for we cannot, in this case, find the same difference, of course, in considering two rays, of which the difference of incidence is less than before. As the drops continue to become larger, the fringes are more and more compressed, and finally they become indistinct. This is, doubtless, the reason why the supplementary bows are never prolonged to the horizon, but always occupy the culminating point of the phenomenon.

Mr. AIRY has recently attached the existence of supernumerary bows to the theory of undulations, by an analytical solution of the problem: and Mr. MILLER has verified the results and the formulæ of Mr. AIRY on the supernumerary bows, produced by a ray of the sun falling horizontally upon vertical cylindrical threads of water, ½ and ⅓ of a millimetre in diameter.—B.

# VIII.

# AURORÆ BOREALES.

THE phenomena that we have hitherto studied really belong to the domain of Meteorology; they are, in fact, modifications of the atmosphere or of phenomena depending on them. In these two final chapters, we shall briefly treat of certain phenomena that we see through the atmosphere, bùt of which it is difficult to affirm with certainty whether they belong to the class of atmospheric phenomena. That to which we shall first direct our attention is the manifestation of the magnetic state of the terrestrial globe. It is probable that its distribution is intimately connected with that of heat on the surface of the earth. This, however, is not a sufficient reason for including this phenomenon in the domain of Meteorology, properly so called; it is merely a proof that heat may modify the distribution of magnetism. I shall consider here only one of the phenomena connected with it, viz. *auroræ boreales;* but, in order more clearly to shew their connexion with magnetism, I shall here relate certain fundamental facts connected with this magnetism itself.

**DIRECTION OF THE MAGNETIC NEEDLE.**—If we suspend a magnetised bar to a filament of silk, so that it can move freely in a horizontal direction, it makes a series of oscillations, that become smaller and smaller, until it takes a determinate position, to which it always returns, whenever removed from it; the same phenomenon occurs, if the bar is pierced and fitted with a cap, by means of which it is placed *in equilibrio* on a sharp point. A bar thus arranged is called a magnetic needle; in France, the vertical plane in which the needle rests, nearly coincides with the meridian.[22]

---

[22] *Vide* Note *v*, Appendix, No. II.

This coincidence was perfect a few centuries ago; and it was at that time thought that the magnetic needle always took such a position that one of its extremities was turned toward the polar star, and the other toward the sun at noon: the plane in which the needle remained at rest was, therefore, called the *magnetic meridian.* At Paris, this meridian makes with the astronomical meridian an angle of 22° toward the west: this is named magnetic *declination* or *variation* (*magnetische abweichung*); it is west or east, according as the end of the needle, that is turned toward the north, is east or west of the astronomic meridian. The amplitude of deviation is measured by the arc divided into nonagesimal degrees, comprised between the two planes, passing through the astronomic and the magnetic meridians.

The needle, by means of which the magnetic meridian is found, was so adjusted as to move only in a horizontal plane; but, if we suspend a needle by its centre of gravity, so as to take from it the action of gravity, and permit it to move in all directions, it will remain in the vertical plane, and its direction will not be parallel to the horizon; for, in our countries, the extremity directed toward the north will dip. To convince himself of this, **Normann** pierced an unmagnetised needle through the middle, and suspended it on an axis coinciding with its centre of gravity; this axis rested on points, so that the needle could move in a vertical plane. Having convinced himself that the needle remained *in equilibrio* indifferently in all positions, he concluded that the axis of rotation coincided with the centre of gravity: the needle was then magnetised, and placed in the plane of the magnetic meridian; its extremity directed toward the north immediately dipped, forming an angle which, in the middle of Europe, is about 70°. This angle is called magnetic *inclination* or *dip* (*magnetische neigung*). A very simple experiment shews that this dip really depends on the action of terrestrial magnetism. When the needle is at rest in the position alluded to, we have merely to touch its north pole with the north pole of an energetic magnet, and its poles are immediately changed; the end that was formerly south, and directed toward the sky, will dip, and, in like manner, make an angle of 70° with the horizon. We conclude from this that the earth is a magnet, which, in our countries, acts on a magnetic needle freely suspended, so as to place it in the magnetic meridian, and make the north end dip. In like manner, as a pendulum is motionless in its vertical position, so also we must admit that the dip indicates the direction in which the resultant of all the former acts, at the point where the observation is made.

**TERRESTRIAL MAGNETISM.**—Every where, on the surface and in the interior of the globe, the magnetic needle takes a determinate position; this position varies in each country of the earth: as we advance, proceeding directly to the west, we see that it increases, and attains its *maximum* in the Atlantic Ocean. From this point, the western declination diminishes; and, at the east of the United States, the needle points exactly to the north pole, and consequently the declination is nothing; more westward, the declination becomes east. If we had gone toward the east, the west declination would have diminished; it would be nothing in the east of the Russian empire; and then east, if we had continued our course toward the east.

In general, if, under any parallel, we take the circuit of the globe, we shall find a point where the needle is directed toward the north; afterwards the deviation becomes westerly, attains its *maximum*, and then diminishes, until it is nothing: thus the declination varies greatly. If we make our experiments under the equator, and repeat them every five degrees, we shall find that the difference between the *maximum* eastern and the *maximum* western declination increases as we approach the poles of the earth. Thus, in Greenland, the west declination is so great that the needle points to the west; and **Parry** found a point, in the west of Greenland, where the north pole of the needle was turned to the south.

The dip presents similar differences; in our countries it is northern, that is to say, the north pole is directed downward, and forms an angle of 70° with the plane of the horizon. In proportion as we advance toward the south, the needle approaches the horizontal direction, and, in the neighbourhood of the equator, it is altogether parallel to the horizon: the dip is, therefore, nothing. On passing into the southern hemisphere, we see the south pole of the needle dip, and the more so as we approach the south pole; going toward the north, the contrary would have been observed: thus, in one of the hemispheres, the dip is northern, and, in the other, southern. These two hemispheres are separated by a line of no dip, upon all points of which the needle is horizontal: this line, which cuts the equator in different points, and rises alternately into each hemisphere, is called the *magnetic equator*.

**MAGNETIC POLES OF THE EARTH.**—In a magnet, each molecule attracts iron; but we may suppose that the effects of all these isolated elements concur in a single point, in like manner as, when considering the weight of a body, we always, in imagination, transfer it to the centre of gravity of the heavy body. These two points, in which are concentrated the resultant of all the forces distributed in the half of each magnetic bar, are called its poles. In like manner, the resultants of all the magnetic forces of the earth may be supposed applied to several points, that are called the *magnetic poles* of the earth.

In our countries, as the magnetic needle is sensibly directed from south to north, it follows that the magnetic action of the earth is such, that the magnetic poles may be considered as situated in the neighbourhood of the poles of the earth: thus, formerly the action of the magnetic forces was placed at the poles themselves of the earth. More accurate observations have shewn that this is not the case. All the phenomena occur exactly as if there were two magnetic poles in each hemisphere. Thus, in the north of America, there exists a point, toward which the needle constantly turns. In proportion as we approach this point, the dipping needle increases in its tendency to become vertical: this point, which is situated to the west of Baffin's Bay, is, therefore, a magnetic pole. There exists another in the north of Siberia. Two similar points occur in the south of America and in New Holland. Although their position is not accurately determined, yet we cannot fail to remark their coincidence with the poles of cold.*

---

* Philosophers of the present day apply the term terrestrial magnetic poles to the points on the surface of our globe, where the magnetic needle, when suspended by its centre of gravity, remains vertical. In such points, the dip is equal to 90°, and the horizontal intensity is necessarily nothing. There exist only two such places on the terrestrial globe. The theory, recently published by M. GAUSS on terrestrial magnetism, assigns them, in the year 1825, the following positions:—

North pole, latitude 73° 30′, longitude 97° 30′ W. (of Paris).
South pole, latitude 72° longitude 151° E. „

M. DUPERREY, from the results obtained in his late scientific expeditions to the two poles, has, on his part, found:—

North pole, latitude 70° 5′, longitude 99° 12′ W.
South pole, latitude 75° 20′, longitude 130° 10′ E.

The term magnetic poles has sometimes been applied to the points, where the total intensity attains its *maximum* value, superior to the total intensity of all the neighbouring points. It was long thought that these points of *maximum* intensity coincided with the magnetic poles; but we now know that they may be very distant apart. There exist two such points in the northern hemisphere, one situated in Siberia, the other in North America. According to M. GAUSS's theory, this last point would be situated in 54°

**INTENSITY OF TERRESTRIAL MAGNETISM.**—Confining ourselves in the study of terrestrial magnetism, in considering the direction of the needle, is only looking upon one part of the question, since we ought also to appreciate the intensity of the force by which it is directed. As, in any force, this intensity diminishes as we recede from its origin, it is therefore probable that it will attain its *minimum* at the magnetic equator, and increase as we approach the pole. Exact measurements have established this truth in the most positive manner. The intensity of the magnetic force is measured in the same manner as that of gravity. If we deviate a magnetic needle from its position of equilibrium in the magnetic meridian, it will return, making, like the pendulum, a series of oscillations, which are the more rapid as the terrestrial magnetism is more intense at the place of observation. To be convinced of this, we have merely to count the number of oscillations that a magnetic needle makes in a given time. Suppose that this number is ten: now place on the plane of the magnetic meridian at the north of the needle the south pole of another magnet; the latter acts in the same direction as terrestrial magnetism; it tends to bring the needle back to its natural position, and it will execute its ten oscillations in a much shorter time than before. Thus, then, in order to know the intensity of the magnetic force on different points of the globe, we have only to make the same needle oscillate at these different points, and see in how long a time it makes a determinate number of oscillations.

**REGULAR VARIATIONS OF TERRESTRIAL MAGNETISM.**—The elements of terrestrial magnetism that we have to study are not so constant as might be imagined from what we have just said. Let us choose a magnetic needle of sufficient length to enable us to read minutes on the arc it describes, and suspend it to a filament of silk: this needle will never be at rest. Its movements do not depend on accidental shakings of the ground; this is proved by the certain regularity with which it moves. If we note its position hourly for a month, and take the mean of the hourly observations, we shall find that in Germany and France it is in its most easterly position at 8 A.M.; it then goes toward the west, and between 1 and 2 P.M. it has devi-

---

latitude N., and 101° 20′ longitude W.; and the Siberian point is 71° 30′ latitude N., and 117° 40′ longitude W. With regard to the *maxima* of intensity of the southern hemisphere, the observations are still too few in the Antarctic seas to enable us to say whether there are one or two, and to determine their situation, even approximately.—B.

ated several degrees (minutes?) toward the west; it then returns to the east, and about midnight it affects nearly the same direction as in the morning; it then remains stationary for several hours, and moves slowly toward the east. The amplitude of these regular oscillations is greater in summer than in winter, and during a fine than during a cloudy day. In our countries they embrace about 15′; they increase as we approach the pole, and diminish in amplitude toward the equator. But it has been proved that the north pole, in all places, is directed more toward the east in the morning than in the afternoon.

The dip and the intensity shew analogous variations; but hitherto they have not been so much studied; they are always connected with the unequal temperatures of the countries situated east and west of the place of observation. Before noon, the countries situated on the east being hotter than those on the west, the north pole of the needle recedes; in the afternoon it is the reverse: the north pole recedes from the hotter countries situated on the west, and it again turns toward the east. The greater the difference of temperature is during the day, the more marked are these oscillations: and thus their amplitude is greater in summer than in winter.

The dip appears to vary with equal regularity throughout the year; however, this element has not yet been determined by a sufficient number of observations.

**IRREGULAR VARIATIONS OF TERRESTRIAL MAGNETISM.**—If we choose very mobile needles, and are able to determine the position to a few seconds nearly, as can easily be done with M. **Gauss's** apparatus, we then see that, in our countries, the needle does not execute its movements in a regular manner; it marches, for a certain time, in a very uniform manner, it then stops and returns back, following its accustomed course. Even with less perfect apparatus, we may convince ourselves that the needle moves for several days toward the east or toward the west, and then returns to its mean direction in the plane of the magnetic meridian. These disturbances, on one of which we are about specially to fix our attention, exist in the dip and in the intensity, and are probably due to an anormal distribution of temperature at the surface of the globe. This supposition is the more probable, as the dip depends, like the height of the barometer, on the direction of the wind and on temperature. But these disturbances are manifested over a more extensive surface than those of the barometer; for powerful deviations have been observed, at one and the same time, in western Europe and in the interior of Asia.

These are the principal facts presented by terrestrial magnetism. In my *Treatise on Meteorology*, I have pointed out the laws and the methods of observation; here I have simply offered the facts that are essential towards enabling us to comprehend the principal phenomena of auroræ boreales, that appertain to Meteorology, because they probably occur at the limits of our atmosphere.

**AURORÆ BOREALES** (*nordlichter*, *nordscheine*, *polarlichter*).—Under these names are comprised the luminous phenomena that are seen in the north by the inhabitants of Europe; however, travellers have seen auroræ in the neighbourhood of the south pole: they are called *auroræ australes* (*südlichter*).

DARK SEGMENT. — According to the unanimous testimony of observers in the north of Europe, who have seen many auroræ boreales, their course is as follows,[*] if we may believe M. **Argelander**: a dirty appearance of the sky, in the neighbourhood of the horizon, in the direction of the north, precedes the aurora borealis; the colours soon become deeper, and a circular segment, of a greater or less size, is seen surrounded by a luminous arc: this segment has the appearance of a thick cloud. **Bergmann** and M. **Hansteen** say that at Upsal and Christiania this segment is sometimes black, or of a deep grey passing to violet. The more we advance towards the north the blacker is this segment; and, in high latitudes, it can hardly be distinguished. The segment is also perceived in lower latitudes; all the observers in Germany noticed it in the aurora borealis of January 7, 1831.

With the existence of this segment is connected **Gissler's** observation, who said that, in Sweden, on the high mountains, the traveller is sometimes suddenly enveloped in a very transparent fog of a whitish grey colour, passing slightly to green, which rises from the ground, and is transformed into the aurora borealis. Ancient observers have spoken of this analogy between the aurora borealis and light clouds; some travellers in the polar regions have again mentioned these appearances. **Wrangel** says positively that, as soon

---

[*] *Vide* also an excellent description of the aurora borealis by M. LOTTIN, in M. POUILLET's *Eléments de Physique*, t. ii. p. 663,[23] and the succinct resumé of all the observations made on this phenomenon during the wintering at Bosekop, in a letter to M. ARAGO. (*Comptes rendus de l'Acad. des Sciences*. t. x. p. 289.)

[23] *Vide* Note *w*, Appendix II; and plates vii. and viii.

as a light went from the aurora to the moon, the latter was immediately surrounded with a corona; frequently also the light dissipated into slight clouds, which remain white, and appear next day in the vault of heaven under the form of small *cirro-cumulus*.

The stars are very readily distinguished through this black segment in the north of Europe and in Germany: a number of observers have made this remark. It is very difficult to say what the nature of this segment is; on this point there are contradictions between philosophers, who have made observations in high latitudes. M. **Struve** expresses himself on this subject in the following manner: "The *stratus* that rests on the northern horizon, and appears to be the base of all the auroræ boreales that I have seen for a long time at Dorpat (lat. 58° 21′ N.), is not a cloud, but merely the sky somewhat darkened; very frequently, when it was quite black, and very high above the horizon, we have seen the stars without any diminution in their brilliancy. Its dark appearance is the effect of contrast with the luminous arc. When the segment is divided and lighted up by luminous rays, they must be attributed to the light that is shewn on points where it did not exist formerly." On the other hand, M. **Argelander** thinks he may conclude, from the numerous observations that he made at Abo (lat. 60° 27′ N.), in Finland, that this dark segment is something real; he rests upon the fact that the sky has a darker appearance before the phenomenon occurs, and that the twilight appears of a reddish brown, and is gradually confounded with the obscure base.

The culminating point of this segment is generally found in the magnetic meridian. Although several exceptional cases, observed in high latitudes, are quoted, yet the number of positive facts is sufficient to remove all doubts from this subject.*

---

* The summit of the arc does not always exactly coincide with the magnetic meridian. *Accidental* perturbations may alter the curvature of the luminous bands, and throw the point of culmination to the right or left of this great circle. There even exist, in certain regions, *constant* causes which tend to deviate the said point to a certain amount, and constantly in the same direction. Thus, at Abo (Finland), M. ARGELANDER found that this summit was 11° west of the magnetic meridian. At Bosekop (Lapland) the hybernating members of the French commission obtained a similar result. The deviation, in like manner, takes place towards the west; but it is very probable that it is less for arcs slightly elevated above the north horizon, than for the same arcs at the moment of their passage to the zenith of the observer. The mean of 120 observations gives 7° deviation for the first of these two cases, and 14° for the second. Should we eventually prove that by ascending vertically in the atmosphere (in Lapland and Finland) the

LUMINOUS ARC.—The dark segment is bounded by a luminous arc; from M. **Argelander's** observations, it is of a brilliant white colour passing slightly to blue. When the twilight is not entirely over, it becomes a little yellowish, or even greenish: its width is equal to one, two, or even three apparent diameters of the full moon. The lower edge is clearly defined, but the upper is only so when the width is very limited; it is effaced as its width increases, and a period arrives when there is no certain limit, but at which its luminosity is confounded with the brightness of the sky: its brightness is then very vivid; and, whilst only a narrow arc illuminates the northern horizon, a wider arc illuminates the whole sky, like the full moon half-an-hour after it has risen.

This luminous arc is a portion of a circle of which each spectator sees a different part; we may, with M. **Hansteen**, represent all the phenomena by means of the brass circles placed near the north pole on our terrestrial globes, and on which the hours are traced. Suppose that a small insect is crawling on the globe, following the 60th parallel of north latitude, it will only see a part of the circle, because the greater portion is concealed from him by the globe, and is consequently below the horizon. The most elevated part of the arc visible to him is just at the north: if he approaches nearer the small circle, he sees a larger portion; if he is below it, then the circle is at his zenith; if he approaches the pole, and goes within the circle, then the culminating point is towards the south. The middle of the aurora probably corresponds with the magnetic pole; if we are at the east of the latter, the arc will be directed from north to south, and the culminating point will be in the west: this is actually the case in Greenland. In the north of this country the arc is in the south; as **Parry** noticed it in Melville Isle. The arc must also rise in proportion as we approach the north; it must even sometimes appear elliptical, as several observers in Scandinavia mention.

When the aurora is very brilliant, we sometimes see one or more arcs more elevated toward the zenith, and concentric with the first; during severe frosts, white arcs have been observed at a considerable height; philosophers regard

magnetic meridian goes more and more to the west, the divergences that we have pointed out may be easily explained: by the angular deviation beyond the magnetic meridian a valuable datum would be obtained, whence we might deduce the vertical elevation of the arcs of the aurora borealis.—B.

them as reflections of the aurora borealis, the light of which is reflected to the observers by frozen particles, and forms a brilliant arc on the sky.

RADIATION.—When the luminous arc is formed, it frequently remains visible for several hours; however, it is not motionless, but in perpetual movement. The arc rises and falls; extends toward the west and the east, and breaks in various places. These motions become very remarkable, when the aurora borealis extends and shoots forth rays: the luminous arc then becomes more brilliant at one point, it encroaches upon the dark segment, and a brilliant light, like that of the arc, ascends toward the zenith. Its width is nearly that of the apparent semi-diameter of the moon, rarely more; it is more brilliant in the middle, and less toward the edges, which are perfectly detached on the azure of the sky. This ray darts with the rapidity of lightning to the middle of the vault of the skies, it is divided above into several secondary rays, and takes the appearance of an illuminated pencil; now it frequently ascends vertically, rarely making an angle with the horizon. Sometimes it is elongated, at other times shortened, and scarcely ever preserves the same form for several successive minutes; but it moves toward the east and the west, and bends like drapery shaken by the wind; it then gradually becomes paler, and finally disappears, to give place for other rays. If these rays are very brilliant, they sometimes present tints of a green or of a deep red colour; if they do not rise to a great height, then the arc resembles a comb furnished with its teeth.

NORTHERN CORONA.—When the rays darted forth by the luminous arc are very numerous, and their palpitating lights rise to the zenith, they form a northern corona, the centre of which is on the dipping needle produced: this corona forms the most beautiful and the most remarkable portion of the phenomenon. The whole sky seems to be a cupola on fire, supported by columns of divers colours. When the rays are darted less vividly, the corona soon disappears; here and there a pale light is visible, which momentarily increases, and is then extinguished, together with the luminous arc.

The intimate connexion of the aurora borealis with terrestrial magnetism, proved by the position of the arc and of the northern corona, is still more evident when the columns are considered. **Wilke**, who has directed his attention to this point, has endeavoured to prove that all the rays are parallel to the dipping needle: the same is the case, according to M. **Hansteen**, with the black rays of the aurora, corresponding to the black segment. We indeed very frequently see black rays, or columns of the same colour, rise like smoke below the luminous arc or the electric aurora; these black rays have the same mobility, and change as quickly as the luminous rays. M. **Hansteen** and others have distinctly seen them in Norway; however, authors rarely doubt this.

Admitting that the rays are columns of greater or less elevation, parallel to the dipping needle, we can understand, from the laws of perspective, that they must apparently unite in the direction of the dipping needle produced; it is the same illusion as that produced on a field by a great number of parallel furrows, which seem to unite in a point situated on the prolongation of the furrow that passes through our eye. The luminous arc above a black segment has the same origin; if it rises sufficiently high in the heavens, it sometimes seems broken in this point: whence we are justified in concluding that it is composed, like the rest of the aurora, of luminous pencils, parallel to the dipping needle, and which have not the appearance of a continuous luminosity, only because the intervals are filled by series of pencils placed behind each other.

**EXTENT OF AURORÆ BOREALES.**—We may perceive isolated auroræ boreales over a very extended space; the same aurora has frequently been seen in the whole of the north of Europe and in Italy. January 5, 1769, a beautiful aurora was seen in Pennsylvania and in France; the beautiful aurora of January 7, 1831, was admired in all central and northern Europe, and Lake Erie, in North America. Other analogous examples may be quoted. We may hence conclude that a great portion of the globe is concerned in the production of the phenomenon; its grandeur becomes still more striking, when we reflect that auroræ boreales have been seen at the same time at both poles of the globe. If, indeed, we analyse **Cook's** observations, we find that every time he observed an aurora australis, mention is made by observers of auroræ boreales seen in Europe, or at least the agitation of the magnetic needle proves, that they did exist in the neighbourhood of the north pole.*

---

* The following are a few facts, of more recent date, to which the names of the observers give great authority.

The aurora borealis of October 18, 1836, was seen at Dorpat, by M. STRUVE; at Caen, by M. MASSON; at Cherbourg, by MM. GACHOT and VERUSMOR; at Corbigny (Nièvre), by M. CHARE, civil engineer; at Geneva, by M. WARTMANN; and at Forli (Roman States), by M. MATTEUCCI. At Geneva, the height of the luminous arc was 25°; at Dorpat, 90°; M. WART-

**PERIODICITY OF AURORÆ BOREALES.** — The fact, that auroræ boreales are frequently visible at places differing greatly in longitude from each other, sufficiently proves that they are not manifested at any determinate hour of the night; they are seen both in the evening and in the morning. According as their light is more or less intense, they may be seen at a greater or a less period after sunset. **Richardson** saw, near Bear Lake, the palpitations of the aurora before the total disappearance of the light of day; during the day he had seen clouds arranged in arches and columns, like the light of the aurora.*

Their appearance is subject to an annual period; this period would be still more evident, if it were not disguised by the unequal length of the days in the different seasons. Suppose, indeed, that at every hour of the day and night, there was an equal possibility for the production of the aurora borealis, then the number of those that would be seen in winter must be greater than that of the summer aurora, because the prolonged darkness permits us to see them more frequently. If, then, they were more frequent

---

MANN, therefore, concluded that the aurora has an elevation of 200 leagues above the surface of the earth. At Paris the weather was cloudy, but the aurora was announced and indicated by the agitation of the magnetic needle.

Another aurora, that of September 3, 1839, was observed in the Isle of Sky, lat. 57° 22′ N., by M. NECKER DE SAUSSURE; at Paris by the astronomers of the Observatory; at New Haven, in Connecticut, by Mr. HERRICK; and at New Orleans, by observers worthy of credit.

As far as what latitude are auroræ visible? Auroræ are related as having been seen at Macao, at Caraccas, &c.; but the following is the most remarkable of all the observations that have come to my knowledge. January 14, 1831, M. LAFOND, commanding the brig Candid, being in 45° south latitude, and in the longitude of the centre of New Holland, saw in the N.E., between 9 and 11 P. M., an aurora borealis which he describes and characterises perfectly. (Vide *Comptes rendus de l'Acad. des Sciences*, t. iv. p. 589; t. iii. pp. 518, 536, and 585; t. ii. p. 329; t. ix. pp. 354, 374, and 603; t. xii. p. 347.)
M.

* It follows, from the observations made by the French commission in the north, that this succession of phases, through which the aurora borealis passes, is subject to an incontestable diurnal periodicity, which is manifested when the number of observations is considerable. Thus the arches, the rays, the coronæ, do not appear indifferently, or at least with equal facility, at all hours of the night. The rays, coloured red and green, the most brilliant part of this beautiful meteor, which act so powerfully on the magnetic needle, are for the most part manifested about ten o'clock in the evening; and their appearance is rare after four o'clock in the morning: the nebulous plates, of a grey and continually varying light, prevail, on the contrary, during the second half of the night.

The same periodicity is found in the displacements of the magnetic needle, which are subordinate to, or at least simultaneous with, the auroræ; it is found in the state of those needles, which are more calm or disturbed according to the different hours of the day: it is understood that the habitual diurnal solar variation must be previously calculated, and subtracted from the effects of the aurora borealis, before drawing any conclusions from the observations.—B.

in winter, it would be very readily explained by this circumstance; but **Mairan** and others have already observed, that their number was very considerable about the period of the equinoxes. The following table represents the number of auroræ that have been seen in each month:

NUMBER OF AURORÆ BOREALES IN EACH MONTH.

| | | | |
|---|---|---|---|
| January | 229 | July | 87 |
| February | 307 | August | 217 |
| March | 440 | September | 405 |
| April | 312 | October | 497 |
| May | 184 | November | 285 |
| June | 65 | December | 225 |

If, therefore, the number of auroræ is greater in winter than in summer, it is on account of the greater length of the nights: we, however, find two *maxima*, one in March, the other in September and October; in each of these months they are much more frequent than in the winter months.

Besides this annual period, there is another, a secular period, on which we know nothing positive. We find that, for a certain number of years, there is abundance of auroræ; then their number diminishes, they become rare, and, at the end of a certain time, they become more frequent. A period of this kind is comprised between 1707 and 1790; it attained its *maximum* about 1752; there was then a series of twenty years, during which they were more rare, but from the year 1820, they have again become more common.[*]

**HEIGHT OF AURORÆ BOREALES.**—Many philosophers and astronomers have endeavoured to determine the height of auroræ boreales above the surface of the earth, by comparing the apparent height of the arc, as seen at different places; but, as it is probable that each observer sees his own particular arc, the results thus obtained are not certain: experience supports this opinion. Thus MM. **Christie** and **Hansteen** calculated the height of the aurora of January 7, 1831; but, on combining their observations, we find heights varying between 37 and 192 kilometres. Ancient philosophers attributed to auroræ a height of at least 750 kilometres; modern observers have reduced this height to 150.

---

[*] From September 12, 1838, to April 18, 1839, the French observers, who were wintering at Bosekop, under the 70th degree of north latitude, counted 153 auroræ boreales, perfectly characterised, and six or seven doubtful ones.

From January 1 to September 3, 1839, Mr. Herrick registered twenty-two auroræ boreales at New Haven, lat. 41° 18′ N., long. 75° 18′ W.—M.

Whilst ancient philosophers gave the aurora borealis a height above that of our atmosphere, some modern observers think that it does not exceed the region of the clouds; lately MM. **Thienemann**, **Wrangel**, and **Struve**, assign it a very inconsiderable height. It is chiefly to the shepherd **Farquharson**, at Alford, in Aberdeenshire, that we are indebted for a long series of observations on auroræ; and he endeavoured to prove that their height is inconsiderable. Thus he once saw a very extensive mass of clouds on the horizon in the N. and N.E., whilst the rest of the sky was clear; this mass was illuminated by the rays of the aurora that sprung out of it, as if by the moon at its full, whilst other clouds in the sky were not illuminated. It was impossible, he said, to assign to this aurora a greater distance than that of the clouds, or to doubt their both forming part of a single phenomenon. December 20, 1829, a very brilliant aurora was visible from half-past 8 to 11 P.M., above a bank of very thick clouds, that covered the tops of the mountains situated at the north of the place at which he dwelt: although the rest of the sky was clear, yet the aurora did not go beyond a height of 20 degrees. At the same time, another Protestant minister, Mr. **James Paull**, at Tullynessle, 4 kilometres from Alford, saw that the aurora possessed an unusual clearness in the zenith, so that its height did not perhaps exceed 1300 metres.

The observations made by English sailors in the north seem to lead to the same results; **Parry** says that he has even seen a ray of the aurora borealis dart towards the earth, at a little distance before him. When auroræ boreales are visible over a great part of the earth, it would follow that their rays extend over a great surface.

**NOISE ACCOMPANYING THE AURORA BOREALIS.**—In high latitudes, some observers have heard a particular noise during the aurora borealis; some compare it to the rustling of silk stuff, when rolled upon itself; others to the crack of the electric spark; some to the noise of a fire agitated by the wind. This noise, it is said, is the more intense when the rays are darted with vigour. Other observers, worthy of all confidence, have never heard the least noise in Scandinavia; the English do not speak of it in their voyages to the north; **Thienemann**, in Iceland, and **Wrangel**, on the coasts of Siberia, have never heard any thing: be it as it may, it would follow that this noise does not accompany all auroræ boreales. Whatever the case may be, this noise is easily explained, without reckoning that it may be confounded with the whistling of the wind, to which no attention is paid when the mind is distracted by other noises, but which is noticed when we contemplate tranquilly an extraordinary phenomenon. If a single observer had been able to measure the interval that had elapsed between the darting of the rays and this noise, not only would its reality have been proved, but we might even deduce from it the height of auroræ boreales. No one has ever spoken of this interval. If we suppose for the rays a distance of two myriametres, I cannot say whether the noise would reach us; during storms, I have never found that more than forty seconds elapsed between the lightning and the thunder. It would not be correct to cite in this place the distances to which the noise of cannon has reached: for, on the one hand, the ground transmits sound more quickly than air, and, on the other hand, this sound is propagated in a stratum of air of the same temperature, whilst that which is produced in the higher strata of the atmosphere is transmitted into strata of different density.[*]

**STATE OF THE ATMOSPHERE DURING AURORÆ BOREALES.**—The connexion between the aurora borealis and certain states of the atmosphere is not less problematical than the noises that accompany it. In all countries, where they frequently appear, all the changes that occur in the weather are attributed to the aurora; but the results are so discordant, that it is impossible to draw from them any reasonable conclusion, and the more so as the observations are never applicable except to a determinate locality. Now, as the auroræ are not only visible in Europe, but also in America, we ought to know the mean state of the atmosphere over great spaces after auroræ: this is not possible in the present state of practical Meteorology. We may draw one solitary conclusion from all existing observations; it is that brilliant auroræ, which dart much into rays, are fre-

---

[*] During their wintering at Bosekop, MM. LOTTIN, BRAVAIS, LILLIEHOOK, and SILJESTRŒM, never heard any particular noise during auroræ boreales. On returning to France, through Lapland and Sweden, M. BRAVAIS and myself inquired of all the intelligent persons that we met. To our question, Have you heard the noise of the auroræ boreales? their answer was almost always affirmative; but, when we inquired what the nature of this noise was, we obtained the most contradictory replies. When we insisted on the possibility of confounding it with the noise of the wind, that of agitated trees, the rustling of snow swept before the wind, or the murmur of the waves of the sea, we arrived at the conviction that these observers were not on their guard against all such causes of errors: these noises struck them in the silence of the night, and because they were concomitant with a brilliant phenomenon, which attracted their attention. Thus these persons themselves were finally led to share in our incredulity, and to confess that they had adopted the received opinion, but that their conviction was not the result of an attentive and faithful observation.—M.

quently the precursors of gusts of wind, and of an anormal distribution of heat over the surface of the globe. But, as this subject is at present little known, I will not dwell upon it longer.

It is also equally impossible to say whether the atmospheric electricity is generally more powerful than usual; if certain observers have registered this fact, no one has well studied the nature of this electricity when, with a serene sky, the aurora borealis has not been seen in the heavens.

**TERRESTRIAL MAGNETISM DURING AURORÆ BOREALES.**—The connexion between auroræ boreales and terrestrial magnetism cannot be denied;[24] the culminating point of the arch is found sensibly in the magnetic meridian, and the centre of the northern corona in the line of the dipping needle produced; moreover, the magnetic needle is very much agitated during auroræ, as **Celsius** and **Hiorter** saw, for the first time, at Upsal, March 1, 1741. Sometimes it is deviated several minutes or degrees to the east, it is agitated, and returns slowly or rapidly into the plane of the meridian, which it occasionally passes to go toward the west. The oscillations of the needle are as variable as the auroræ boreales themselves. Sometimes the needle is very quiet; but this happens when the arc is motionless on the horizon; as soon as it commences to dart forth rays, its declination changes every moment: this happens in our latitudes, even when the auroræ are not visible except near the pole. The connexion existing between the rays of the aurora and the movements of the needle has not yet been sufficiently studied; we are ignorant whether the north pole is attracted or repelled: and this cannot be known, without making a great number of corresponding observations.

According to **Wilke**, the dip is as variable as the declination during great auroræ boreales; the needle rises and falls with the northern corona: the same remarks are made upon the intensity. According to M. **Hansteen**, it frequently increases greatly, a short time before the appearance of the aurora; but, as soon as the aurora begins, it diminishes in proportion to the brilliancy of the meteor, and it then returns slowly (frequently not until the end of twenty-four hours) to its primitive value: other observers have established this fact.*

---

[24] *Vide* Note *z*, Appendix, No. II.

* M. BRAVAIS concluded, from his observations at Bosekop (lat. 69° 58′ N.) on the variations of vertical intensity (vertical complement of the magnetic force), that this element, on the appearance of auroræ boreales, undergoes

**CAUSE OF AURORÆ BOREALES.** — Although they are evidently intimately connected with magnetism, it is yet impossible to say what this connexion is. Undoubtedly we are tolerably well acquainted with the laws of the distribution of magnetism on the surface of the earth, but we are yet ignorant whether the earth is composed of magnetic particles, or whether interior magnetic currents determine the direction of the needle: one thing is certain, that the distribution of magnetism is connected with that of heat, since the poles of cold and the magnetic poles probably coincide.

Imagine any cause whatever, such as the anormal distribution of temperature, to disturb the equilibrium of the magnetic fluid, and increase its force: then there is a magnetic spark, like that produced by an artificial magnet. Take a copper wire covered with silk, and having at one of its extremities a small copper plate, made very clean; wind the whole on a helix round a magnet, and bend the other extremity of the wire, so that it may not be far distant from

---

changes analogous to those of horizontal intensity. In general, its value increases when the aurora borealis appears or is about to appear, it then diminishes during the most active period of this phenomenon.

M. Siljestrœm, on his part, has discussed the observations that he made in the same place, and has compared together the simultaneous variations of magnetic declination, dip and horizontal intensity. He has also arrived at this remarkable law: " When the north pole tends towards the west, the dip generally diminishes, and the horizontal intensity increases."

At the same time, and likewise according to the same observations, when the north pole moves toward the west, the vertical intensity increases, but in a less ratio than the horizontal intensity. If, for example, the latter increases one-tenth of its value, the vertical complement will increase one-twentieth or one-twenty-fifth of its value: the diminution observed in the dip is the result of these two unequal increments.

Every time that a magnetic bar is deviated from its position, we may imagine a horizontal, a vertical, or an oblique force applied to its northern extremity, and the inverse force to its southern; and that the change observed is the resultant of this double disturbing force, superadded to the ordinary forces. If we now refer this to the law of simultaneous variation, discovered by Siljestrœm, and interpret it according to the preceding remark, we shall easily conclude that the disturbing forces are not indifferently susceptible of all the different directions that it is possible to imagine, and that they affect a preference for a certain direction, of which future observations may permit us to catch a glance, without granting rigorous determination. This identity of direction enables us to detect a community of origin, a sort of focus situated probably in the interior of the globe, and whence these forces emanate: the latter, moreover, might be attractive or repulsive of the north pole of needles. On placing a magnetic needle at Bosekop, in such a manner that it declined 33° to the west of the astronomical meridian, with a dip of 60°, its direction produced into the earth would meet this focus of disturbing magnetic forces. Observation further proves that the forces usually act by attraction on the north pole, at the period when the aurora appears, and by repulsion toward the middle and the end of the phenomenon. It remains now to know whether these indications will be confirmed by simultaneous observations made in different points of the globe.—M.

the copper plate, and may be at liberty to touch it: you will see a spark between the two extremities of the wire every time you break or make the circuit, that is every time you change the magnetic state of the magnet.

The aurora borealis appears to be an analogous phenomenon, due to a rupture in the magnetic equilibrium of the globe; but, to explain all the circumstances presented by the aurora, is impossible in the present state of our knowledge. In my *Treatise on Meteorology*, I have discussed the different hypotheses put forth on this subject; perhaps the magnetic effluvia are spread in the rarified air like the electric fluid *in vacuo*, and we can imagine that their direction would be that of the needle when freely suspended.

# IX.

# PROBLEMATIC PHENOMENA.

WHEN we study the history of the attempts that have been made to explain natural phenomena, we see that men are always attached to all those that present any thing marvellous. From the time when **Galileo** proved that the laws of the fall of bodies are of the highest importance in physics, this tendency has been a little modified; however, meteorology still feels its baneful influence. Where are the observers who are occupying themselves in the regular succession of the modifications of the atmosphere, and the philosophers who are seeking to recognise their laws? It is a trouble to them to look at their instruments. But, when the barometer or the thermometer presents an extraordinary rise or fall, then all the world are astonished, and begin to flatter themselves that meteorologists will draw some beautiful results from it. I have many times had occasion, in the course of this work, to shew that these extraordinary facts teach us nothing, precisely because they are observed isolatedly, without any trouble being taken as to what precedes them, and without examination made of what follows. These reflections are especially applicable to the facts that we are about to study in this section. Showers of sulphur, of blood, of ignited meteors, &c., have, from the most distant times, produced a great sensation; men of the world regard them as being the principal objects toward which meteorologists should direct their attentions. But the latter award to them no higher importance than zoologists award to monstrosities, the interest of which cannot be equal to that of the entire animal series. These subjects verge on romance, but they are not fertile in conclusions and in instruction.

**SHOWERS OF SULPHUR.**—Formerly, and even at the present time, flowers of sulphur have been said frequently to fall with the rain; after heavy showers, quiet waters were found covered with a yellowish dust; and, as it was easily inflamed, it was concluded to be sulphur: every year the newspapers contained notices of it. More acccurate researches have proved that this dust is nothing else than the pollen of certain flowers, and of pines in particular, which was swept off by the wind, and precipitated with the rain; **Elsholtz** had said this as long ago as 1676. The nature of the pollen depends on that of the vegetables that grow within a certain distance. **Schmieder** believes that, in March and April, it is the pollen of alders and filberts; in May and June, that of pines, elders, brich; in July, August, and September, that of lycopodium, *typha*, and several species of *equisetum*. When ponds are covered with this dust, these vegetable productions are generally found in the neighbourhood, and in the woods they are found in spots exposed to the winds.

**SHOWERS OF BLOOD.** — In the chronicles of the middle ages, showers of blood were often alluded to; for red spots were found on the ground and in the waters; and superstition traced in this the effects of divine anger. This phenomenon occurred from time to time. But microscopic researches have proved that these colourings arose from innumerable vegetables or animals that sometimes filled the waters. Frequently, however, a red powder fell with the rain, containing inorganic principles, and coloured with iron or hydrochlorate of cobalt.

Much attention has been directed of late to red snow; **de Saussure, Raymond,** and others, had long ago seen it on the Alps and the Pyrenees. In Baffin's Bay, **Ross** found that the snow was sometimes penetrated several decimetres by the colouring substance; in the Alps, it is observed on declivities that are slightly inclined. By the microscope, they are seen to be red granules, the nature of which is not perfectly known.*

---

* These granules may be considered as vegetables reduced to their most simple expression namely, to a cell filled with liquid. A great number of infusoria circulate in the middle of these utricles, which serve them for nourishment: the red colour is the most common; however, these utricles may become green like other vegetables. The following observation is a proof of this:—

When we landed at Spitzbergen, July 25, 1838, I perceived, while traversing a field of snow with my friend M. Bravais, that the impression of the last steps that we had made before passing from the snow to the earth were of a green colour. The surface itself of the snow was white; but, at a few centimetres beneath, it had the appearance of having been watered by the

**SHOWER OF CORN.**—After heavy rains, bodies have frequently been found on the ground, that possessed a distant analogy to grains of corn, and appeared, like the latter, to be composed mostly of farina; but it has long ago been demonstrated, that these were not grains of cereals, and that they had not fallen from the sky. MM. **Goeppert** and **Treviranus** have lately studied this subject.

In June 1830, there were found, near Greisau, a village of Silesia, after a rain-storm, a certain number of bodies of a vegetable nature on places covered with turf. These corpuscules were exteriorly of a yellowish brown, of a transparent white within, spherical, occasionally cylindrical, being from 4 to $18^{mm}$ long, and from 2 to 4 in diameter. They had the taste of farina, but left in the mouth a sharp and burning after-taste. By rapid desiccation, the sharp taste disappeared, and the grain had then the flavour of an

---

water resulting from a decoction of spinach. We collected this snow; and on being melted, it gave a slightly coloured water. In another excursion, I found this green matter, spread like dust on the surface of a field of snow, the greater portion of which was covered with an enormous quantity of *hæmatococcus nivalis*. Beneath the surface, and at the sides of the field, the snow was also coloured green. I collected the green matter from the surface, and, after a certain time, it was deposited at the bottom of the vessel; I then decanted the greater portion of the liquid that remained colourless.

A drop of this liquid was placed on the object plate of a microscope, illuminated according to M. DUJARDIN's method. This skilful observer was present, as well as M. BIOT, and we established the following facts. The water was filled with a green amorphous matter, in the midst of which we distinguished perfectly spherical green grains of *protococcus*. We also noticed some of a red tint, and much larger, and also others scarcely of a rose tint, and which in some were intermediate between the two former. I afterwards examined these red and rosy grains by the microscope, and found that this green snow was composed of granules varying in size and colour.

Some appeared *simple*; they were green or of a pale rose colour, and from 0,01 to 0,05 millimetres in diameter; a few rare specimens, of a blood red colour, were 0,02 millimetres. Other globules appeared *compound*, namely formed of an envelope containing globules in the interior. Their diameter was from 0,05 to 0,055 millimetres. M. MONTAGUE was very anxious to examine them with me, and to take sketches of some of them, under a magnifying power of 3000 times. It had thick sides, and contained five red granules. I could never distinctly see a globule containing green granules.

Having made a comparative examination of the red snow (*hæmatococcus nivalis*) collected in the neighbourhood of this green matter, we were able to verify the identity of the *red* globules of green snow with those of red snow. This latter presented, moreover, red chapelets of greater or less lengths, formed of simple globules attached end to end, and recalling to one's mind the moliniform appearance of species of the genus *torula*. It is evident, from what we have just said, that the green snow (*protococcus viridis*), and the red snow (*hæmatococcus nivalis*), are one and the same plant in different states; but it is difficult to decide which is the primitive state. However, on reflecting that we see colourless utricles containing red granules, which become free when the mother utricle disappears, we may reasonably suppose that the red colour is peculiar to the young globules, which afterwards become green under the influence of light and air. Now, we can imagine that, if the snow is not very old, or if it is swept by winds, as is more frequently the case, especially in mountains, the red *hæmatococcus* has not time to become green.—M.

almond. Accurate researches have shewn, that these grains were tubercles of the ficaire (*ranunculus ficaria L.*), a plant very common in Silesia. In the middle of June, the leaves and stalks of this spring-plant dry up, and nothing but roots remain, which consist of from six to twenty small tubercles fixed to feeble radicles. A heavy rain draws up these tubercles, separates them from the root, and carries them to inclined places; thus, they are frequently found after rain, but no one has yet seen them fall with it.

These tubercles have long been observed in various countries, but their true character was not recognised. Seeds of several plants, drifted and accumulated in certain points by heavy rains, have been also taken for products of the atmosphere: such as the seeds of *melampyrum nemorosum*, *veronica hederæfolia*, &c. No one will be astonished that gusts of wind should thus transport seeds and fruit.

**SHOWERS OF ANIMALS.**—Small animals, such as frogs, fish, snails, &c. sometimes appear to fall with rain: at least they are found in great numbers in fields after rain; but they are animals carried by the wind, drifted by the rains, or invited out of their retreats by the moisture. It has lately been maintained that these animals actually fall from the sky, even in calm weather. To all these assertions I know no other answer than that which one of the most distinguished naturalists of the age made to some one who assured him that he had seen one of these phenomena with his own eyes: "It is fortunate," he said, "that you have seen it, for now I believe it; had I seen it myself, I should not have believed it."

**DRY FOG** (*trockener nebel*, *hoeherauch*, *haaryauch*, *landrauch*, *sonnenrauch*, *moorrauch*, *heiderauch*).—This phenomenon occurs in south Germany in the following manner: When, during the day, the sky is perfectly clear and free of clouds, the blue of the sky has not its ordinary azure tone; it is dull, without presenting the tint that is observed when fine *cirri* disturb its transparency: in this latter case, the white colour is predominant; with the dry fog, the light blue is tarnished by a mixture of a dirty colour. At some degrees above the horizon, the blue of the sky is suddenly interrupted, and we perceive that it is terminated above by a ring of dull brown-red colour, that is more or less clearly defined. The *cumulo-stratus*, the upper edge of which is generally of a brilliant white, appears more or less of a red colour about mid-day, even when the clouds have a height of 30° or 40° above the horizon. Distant terrestrial objects of a deep colour appear effaced and covered with a blue veil.

The sun has a dull appearance even when it is high; its light presents a reddish tint. When the sun approaches the horizon, it is of a blood-red colour; it may be looked at without the eyes being dazzled, and its brilliancy is so reduced, that it ceases to be visible, even before it has descended below the horizon. It even happens that the lower edge of the sun is scarcely visible, whilst the upper presents a well-defined red edge.

Sometimes the dry fog has a remarkable intensity; several examples are found in our records. That of 1783 caused a general sensation throughout Europe; it presented the following phenomena: its thickness was such, that in some places objects at the distance of five kilometres could not be distinguished; they sometimes appeared blue or else surrounded with vapour. The sun appeared red, and without brilliancy, and could be gazed at in the middle of the day; at its rising and setting, it disappeared in the haze. At Copenhagen, it was first seen May 29th; it came after a succession of fine days. In other places, it was preceded by a gale. In England, it came after continuous rains; at La Rochelle, it was seen on June 6th and 7th; at Dijon, on the 14th; the atmosphere then became clear at La Rochelle till the 18th. It was noticed almost every where in Germany, France, and Italy, from the 16th to the 18th; on the 19th, it was observed at Franecker and in the Pays-Bas; on the 22d, at Spydberg, in Norway; on the 23d, at St. Gothard and at Buda; the 24th, at Stockholm; the 25th, at Moscow; toward the end of June, in Syria; the 1st of July, in the Altai. Some observers maintain, that they found traces of acid in it, but these observations have no more value than the experiments made on atmospheric electricity. It is accused of having caused the disease of smut in the corn, and diseases in vegetables generally; but we know that these diseases are manifested without being determined by dry fog.

Subsequently, and especially in 1834, a thick dry fog was also observed. I saw it on May 23d on the mountain of Victor, among the Harz. The same day, a violent north wind drove it to Basle, where it remained three or four days; on the 25th, it was seen with a violent N.E. wind at Orleans; and at the same period, chiefly on the 21st, 22d, and 24th, at Munster. Several times, in the course of this summer, I noticed dry fogs of various thicknesses. July 28th and 29th, they were remarked at Halle, Freiberg, and Altenberg, in Saxony, and they lasted several days; they finally disappeared, August 2d, during a rain-storm, and shewed themselves only for a few isolated days in the month of August.

Dry fog is very common in north and west Germany, as well as in Holland. **Finki** attributes it to the combustion of peat. Indeed, in order to prepare peat-lands for cultivation, they are dug up and the clods are turned over in autumn, that they may dry in winter; if the month of May is dry, they are set fire to, care being taken that they shall give off plenty of smoke and very little flame. The drier the air and the ground are, the better does the operation succeed; rain, on the contrary, interferes with it; in summer, large surfaces ignite spontaneously. The quantity of the products of combustion may therefore amount to 9,000,000 of kilogrammes.

In these countries the dry fog is coincident with the burning of the peat; when the air is dry, the smoke remains suspended in the atmosphere, and may be carried away by the winds. The wind always blows from the direction of the peat-bogs, when dry fog is manifested; and fogs have frequently been seen coming distinctly from the peat-bogs. The very thick dry fog of 1834 came partly from the combustion of peat, and partly from the fires for which this year was noted. Whilst it was observed in the end of May among the Harz, and in the neighbourhood of Orleans and Basle, there were fires amongst the peat-bogs. Thus, in particular, the peat-bog of Dachau, in Bavaria, was burned to the depth of $2^{m},5$; and the fire was even propagated beneath ditches filled with water; in the neighbourhood of Munster and in Hanover, several peat-bogs were consumed. Subsequently, in July, there were terrible conflagrations of forests and peat-bogs, near Berlin, in Prussia, in Silesia, in Sweden, and in Russia; the drought favoured the propagation of these fires, and the transport of the smoke.

To the same cause, probably, may be attributed the particular aspect of the air in autumn. In the fine days, when the atmosphere is very dry, the air is less transparent; distant objects are not seen distinctly, they appear surrounded by a slight fog. As in many countries, heaps of bad grass and potato-culms are burned at this period, I think that the smoke they produce is diffused throughout the atmosphere.

Can the dry fog of 1783, which was diffused over a great portion of Europe, be attributed to the came cause? At the period when it was manifested many hypotheses were devised in order to explain its origin: **Lalande** attributed it to the quantity of electricity developed during a very hot summer, that succeeded a moist winter; **Cotte** regarded it as formed of metallic emanations united with electricity, in consequence of the great heat and numerous earthquakes; other philosphers have connected this fog with electricity, without our being able to understand how the latter is able thus to disturb the atmosphere. However, **Veltmann** has shewn that these phenomena are concomitants with the great peat-burnings that took place in Westphalia.

In the same year there was a violent earthquake in Calabria, and a volcanic eruption in Iceland; several philosophers attribute the existence of this fog to these. It is true that volcanic phenomena rarely manifest themselves with so much violence; and we may add, in favour of this opinion, that, in the years when a very intense dry fog filled the atmosphere, the volcanoes were in activity: for example, the years 526, 1721, 1822, and 1834. However, the fog has several times preceded the irruptions. Are we, therefore, to regard volcanic irruptions as an immediate cause of dry fog? Although the column that rises above a volcano has a very great analogy to a column of smoke, yet more accurate researches have shewn that it is for the most part composed of the vapour of water and volcanic ashes, with which are mixed transparent gases in various quantities: no one has observed true smoke. But, when the lava runs over the side of the mountain, it carbonises every thing that it meets, and an immense cloud of smoke rises in the air. If we think of the immense quantity of vegetables that were consumed in Iceland, as well as seventeen villages, we can comprehend that the lava, when running over a soil covered with vegetables, might have been able to produce this smoke, which the north winds immediately spread over a great portion of Europe. Add to this, that the combustions of turf and the conflagrations of forests were as frequent this year as during those that are distinguished by excessive droughts. It is to the latter cause that we must attribute this odour, which is especially perceived in Holland.

The inhabitants of western and southern Europe attribute to the dry fog a great influence over the state of the atmosphere: they connect with its existence the predominance of the north winds which then prevail, and say that it drives away rain and storms, and is a cause of cold. It is true that things are in this condition at the season of peat-burning; but I doubt whether we should attribute them to this cause: this opinion, which is so generally prevalent in these countries, arises from considering a general phenomenon under a point of view of narrow locality. Thus it is that, on the coasts of Scandinavia, the cold that suddenly arises with north winds is thought to be due to the vicinity of the sea; and it is accused of many misdeeds of which it is innocent, because the same thing is experienced in the centre of Germany. These winds blow throughout Germany, accompanied with cold nights and dryness of the air; and young plants suffer greatly. With regard to the dispersion of storms by dry fog, or their transformation into fog, I should be tempted to believe that thick masses of dry fog accumulated in the horizon have been taken for storm-clouds, the true nature of which the spectator recognised when they approached him.

**SHOOTING STARS AND METEORIC STONES** (*Sternschnuppen und meteorsteine*).—Shooting stars are observed during serene nights. In a part of the sky, a luminous point appears in the form of a star of greater or less brilliancy, it moves through space, and is then suddenly extinguished; but its brilliancy diminishes at the moment when it is about to disappear. Sometimes the star leaves in its passage a luminous train; however, this is not constant: sometimes, also, the star gives forth sparks. The ancients regarded these meteors as stars actually falling; when they are of considerable size, they are called *igneous meteors*, *bolides*, *balls of fire* (*feuerkugeln*, *feuermeteore*). A luminous point is first seen, like a shooting star, or a small clear cloud, which is not long before it bursts into flames, or even one or several parallel striæ, which soon form a large flaming globe. This globe moves with a velocity equal to that of the stars, sometimes in bounds, which are a proof of an original impulse, or are an effect of terrestrial attraction; it increases and becomes a burning globe, sending forth flames, smoke, and sparks. This luminous globe generally draws after it a luminous train, which is drawn out to a point, and terminates in smoke. This tail appears to be formed of the substance drawn out from the ball itself; or else it is accompanied by little satellites, which themselves become small luminous globes; finally the ball bursts with a great explosion. These meteors frequently break again, and then the constituent parts that have not been volatilised fall in the form of masses of iron or stone. These meteoric stones or aërolites are of a different composition from that of stones found on the surface of the earth, and occupy a much smaller space than the large ball.

**HEIGHT OF IGNEOUS METEORS.**—As shooting stars and fire-balls only occur occasionally, it is difficult to go through the operations necessary for determining their height with certain precision; however, it has sometimes happened that several observers have been able to measure simultaneously the angle of the height of a ball seen from different places, and hence to deduce its absolute height in the atmosphere. **Benzenberg** and **Brandes** made the first observations on this point: being at two places distant from each other, they marked on a celestial planisphere every shooting star, in order to have its position and apparent course; knowing the moment of the observation, they were able to deduce the angle of the height, and to calculate the height of the meteor.

The elevation of shooting stars above the earth is very different, in that it oscillates between 16 and 230 kilometres; the greater portion move in a region comprised between 45 and 155 kilometres. The mean height, deduced from all these heights of **Brandes**, is 116 kilometres.

The greater portion of shooting stars move in a descending direction: however, some are directed horizontally, or even ascending; some have even been observed to describe a semi-circle, first rising and then descending: **Chladni** quotes several examples. It follows that these bodies are subject to the action of gravity; but that, in addition to this, they receive a very energetic impulse in order to take a direction, which must be always contrary to that of gravity: their velocity is from thirty to sixty-six kilometres per second.

The indications of the height of fire-balls are very discordant; I have given a great number in my *Treatise on Meteorology*. It follows that their mean height is about the same as that of shooting stars.

**FREQUENCY OF SHOOTING STARS.**—If shooting stars rapidly succeed each other, they are frequently observed in the same region of the sky. According to **Benzenberg**, there are often eight in the hour. During the night of the 6th and 7th December, 1798, **Brandes** counted 480 shooting stars. In these latter times, much attention has been paid to their periodicity; they are observed in a special manner in the nights from the 10th to the 15th of November, and on that of the 10th and 11th of August.

M. **de Humboldt** was the first who saw a large number on the night of the 11th and 12th November, 1799; they were observed at the same time in Guyana, Labrador, Greenland, and the environs of Weimar. **Hemmer** had before this been struck with their number at Mannheim, on the night of the 9th and 10th November, 1787. In 1813, many were seen in England on the night of the 8th November; in 1818, on that of the 13th November; and in 1832, on the 12th of the same month. From nine in the evening until sunrise many were counted; some had the appearance of small globes of fire. In England, France, Switzerland, Germany, Russia, Mauritius, observers were every where struck with the number and the brilliancy of these meteors. In the United States of America, the shooting stars were still more numerous. November 13, 1833, at 7 P.M. **Palmer**, at New Haven, in Connecticut, perceived a reddish vapour, which first appeared near the southern horizon, then rose gradually to the zenith; it was very transparent, but yet it concealed the smallest stars. The igneous meteors appeared from nine o'clock, but at four in the morning they appeared in greatest numbers. An uninterrupted succession of fire-balls, like fusees, seemed to originate from a point not many degrees from the zenith; they darted in all directions, but yet always in such a manner, that all their directions produced converged toward the point mentioned. Around this point, which, according to M. **Encke**, precisely coincides with that toward which the earth is directed in its annual revolution round the sun, a circular space of several degrees is found, in which no meteors are seen. Generally, they leave a luminous train in their passage, and, on disappearing, they burst, and are reduced into smoke; notwithstanding the most persevering attention, the noise of an explosion has never been heard. Besides these isolated masses, the atmosphere was illuminated by phosphorescent lines formed of the succession of a great number of luminous points, and similar to the lines produced in darkness by writing with a pencil of phosphorus.

In the following years, the nights of November were again remarkable for a great number of shooting stars, all of which seemed to come from the constellation Leo, toward which the earth is directed at this period of the year: the same observations are true of the nights of August 10 and 11, during which, also, many shooting stars are seen.

The balls do not appear to be equally common at all seasons. If we calculate their number for each month, we arrive at the following results:—

NUMBER OF FIRE-BALLS IN EACH MONTH.

| | | | |
|---|---|---|---|
| January | 69 | July | 47 |
| February | 50 | August | 69 |
| March | 50 | September | 51 |
| April | 45 | October | 61 |
| May | 46 | November | 89 |
| June | 29 | December | 71 |

The greatest number occur in November, the least, in June; doubtless the length of the days in summer allows a great number of these meteors to pass unperceived: however, we should observe that their frequency is greater in autumn than in spring. In August, when shooting stars are common, there are also many fire-balls.

**APPEARANCES OF FIRE-BALLS.**—Their brilliancy surpasses that of the moon; some have been so brilliant, even by day, that they have cast a shadow. Their light is of a dazzling white, or else reddish; other colours are also noticed, having a greater or less degree of distinctness.

Whilst they are traversing the atmosphere, flames, sparks, and smoke, come out from them in all directions; sometimes they seem to be extinguished by falling; they then light up again, after having emitted a quantity of vapour and smoke: when they traverse the atmosphere, they swell up and burst with noise. **Chladni** explains this rupture by the developement and the dilation of the interior fluids bursting their envelope. When they are not seen to burst, it is because they are too elevated or too far distant from the atmosphere, and have followed their route in space. Sometimes a fire-ball is divided into a certain number of fragments, and each of these fragments forms a small luminous globe, which then bursts in its turn; in some, the mass, after having given issue to the interior gases, sinks on to itself, and then swells out anew, to burst a second time. The balls, that make bounds, generally burst at the point separating the two successive bounds; these explosions are accompanied with vapours and smoke; and the ball is seen to pursue its course, casting forth a new lustre. The crash is sometimes such, that the houses tremble, the doors and windows open, and the assistants fancy that there is an earthquake. Sometimes, says **Chladni**, the explosion is not noticed, because the mass, after having given forth the gases, is enveloped with a thick smoke that conceals its brilliancy.

**AEROLITES OR METEORIC STONES** (*meteor-*

*steine*).—When the globe has burst, the fragments fall to the earth: these are sometimes in large quantities; witness those collected near L'Aigle, April 26th, 1803, and near Stannern, May 22d, 1808. However, they may also fall without breaking: these fragments are known by the name of *aërolites*.

The greater number of aerolites have a general form always the same; according to **Schreibers**, it is a prism, with four or five unequal surfaces, or an oblique pyramid. Outside they are covered by a black or blackish crust, which appears to have the same chemical composition as the nucleus, although it has passed into the state of scoriæ. This crust, the thickness of which rarely exceeds $0^{mm},55$, presents inequalities; it is black, and not very brilliant, or else of a brilliant blackish brown, as if the stone had been covered with varnish. Sometimes it has a metallic brilliancy like iron melted and slightly oxydised, or rather the aspect of bitumen. The crust may be so hard, that it strikes fire with the flint; on certain stones we find layers, veins, and spots of the same nature as the crust. The aërolite seems already to have been formed when a new swelling has brought a portion of the crust to the interior. This crust does not bear the least analogy to a volcanic product; and we cannot obtain an analogous crust except by melting these stones out of the action of the air; but it is difficult to say which of the constituent principles contributes most to the formation of this envelope. The composition of these stones is different from that of all stones that have been found at the surface of the globe. From the analysis made by M. **Gustave Rose**, some are found of a greyish mass, in which no other substance beside metallic iron is found; others are composed of different substances, of which some, that are white, are probably labrador (opal feldspar): others, that are brown, resemble a pyroxene.

If they are reduced to powder, we may extract about twenty per cent of iron and nickel; chemical analysis then gives the following principles: oxygen, hydrogen, sulphur, phosphorus, carbon, silica, chromium, potassium, sodium, calcium, magnesium, aluminum, iron, manganese, nickel, cobalt, copper, and tin. According to M. **Berzelius**, these eighteen elementary substances form the following compounds:—

1st. *Metallic iron*, containing a little nickel, cobalt, magnesium, manganese, tin, copper, sulphur, and carbon.

2d. *Sulphuret of iron*, with an equal proportion of sulphur and iron.

3d. *Magnetic iron.*

4th. *Meteoric olivine;* it constitutes one half of the residue that remains after the metals susceptible of magnetism are removed; its composition is the same as that of terrestrial olivine.

5th. *Silicates*, combinations of *lime*, *magnesia*, *oxides* of *iron*, *manganese*, *clay*, *soda*, and *potash*, insoluble in acids, among which the silicic acid is in double proportion to all the other bodies, and which probably form two minerals, the one *pyroxenic*, the other analogous to *leucite*.

6th. *Chromate of iron* in a small but constant quantity.

7th. *Oxide of tin.*

**METEORIC MASSES OF IRON.**—Sometimes the entire aërolite is composed only of metallic iron; however, this case is more rare than that in which it contains only a certain quantity. May 26th, 1751, two masses fell near Hradschina, in the comitat of Agra: one weighed thirty-five, the other eight kilogrammes. They have been found in other countries, though not seen to fall from the sky; but their form and composition must make us regard them as aërolites. One of the best known is that discovered by **Pallas**, in Siberia, in the year 1771, and which the Tartars regarded as a sacred object fallen from heaven; its weight was 700 kilogrammes. Analogous masses have been found in Bohemia, Hungary, the Cape of Good Hope, Mexico, Peru, Senegal, Baffin's Bay, &c. &c. The iron is full of cavities, filled with more or less perfect crystals of olivine; when these crystals are removed, the residue still contains ninety per cent of iron, a certain percentage of nickel, and the rest needs scarcely being taken into the account.

**ORIGIN OF IGNEOUS METEORS.**—As they are found in regions inaccessible to man, the imagination has a wide field for framing hypotheses which reason cannot gainsay. Formerly, these shooting stars were affirmed to be composed of gelatinous matter; and it has been frequently said, that the different species of *nostoch*, found on the banks of rivers, were shooting stars. **Chladni** was the first to shew, that fire-balls and shooting stars are one and the same thing, and only differ in their size. Since he has also proved that stones do fall from the sky, four principal hypotheses have been put forth, which we will now examine.

VULCANIAN HYPOTHESIS.—It was originally maintained, that these stones were vomited forth by the volcanoes of our globe; but this system is untenable, for our volcanoes cannot hurl them to any great height, and their composition is totally different from volcanic productions.

MOON-STONES.—Some mathematicians, **Laplace**, among others, have endeavoured to prove that these stones may be projected from volcanoes in the moon sufficiently far to enter into the sphere of our earth's attraction, and so to fall on it. Calculation shews that, in order for this effect to take place, the stone must have an initial velocity of 3250 metres per second, and that it would pass from the moon to the earth in two days and a half.

Notwithstanding the possibility of the fact, it still presents, according to **Olbers**, grave difficulties; for the body, darted forth by the volcano, is subject to this force of projection, and also to that resulting from the moon's motion, and which acts tangentially to the lunar orbit. Thus, then, the heavy bodies that are darted forth by the lunar volcanoes, and that approach the earth, are attracted by it, and describe a curve. In order that the body may fall to the surface of the earth, there must exist a determinate relation between the direction and the velocity of the projectile; and consequently few of them will fall to the earth. According to **Olbers**, the initial velocity of from 7000 to 11,000 metres per second, as determined by **Brandes**, is also contrary to this hypothesis; indeed, let us suppose that the stone is darted forth by the volcano with a velocity of only 2600 metres, it will arrive with an acquired velocity of 11,400 metres. Now, as fire-balls travel with a velocity of about 37,000 metres per second, they must be darted forth by the moon with a velocity of about 23,500 metres, a velocity that may be regarded as altogether impossible.

ATMOSPHERIC HYPOTHESIS.—Other philosophers have admitted that these igneous meteors were a product of our atmosphere; and although **Chladni** has rejected this explanation, it has yet been sustained by **Egen**, **G. Fischer**, and **Ideler**; the former especially has put forth several important considerations in favour of this opinion. A great number of metals rise into the atmosphere in a gaseous state; and, if chemical analysis does not find them, it is merely because their proportional quantity is very small. These arise annually from the metallurgical forges of Clausthal more than ten millions of kilogrammes of vapours, composed of water, lead, iron, zinc, sulphur, antimony, and arsenic; many of these metals have been recovered by **R. Brandes** and **Zimmerman** in rain-water. Then **Egen** especially rests his hypothesis upon the phenomena that have been observed during the formation of igneous meteors: either the sky has been disturbed by a dark or by a bright cloud, or else white bands have been united into a single mass. We must, in this case, admit, that a force, the action of which is attended by the production of light, determines the condensation of the vapours in the high regions of the atmosphere—vapours that become visible, like those of water when passing into the state of cloud, and that other forces at the same time urge them in a direction which is not that of gravity: this force, in his opinion, is electricity. **Egen** then examines in detail the different circumstances that accompany their translation, and deduces them from his hypothesis with much sagacity; he says, that the igneous meteors are especially common when the atmosphere is not in its normal state. We may object to him, that this arises from the celestial phenomena being at that time examined with more attention. It is, moreover, a difficult matter to comprehend how these vapours, diffused throughout an immense space, can be collected into enormous masses, and acquire considerable velocity. Other objections, and particularly that urged by **Chladni**, from the bounds of these meteors, fall of themselves, when we include the resistance of the air and the force of the inhalation of the gases that escape from the ball, since all flying fusees make bounds of this kind.

COSMICAL HYPOTHESIS.—Before it was known that fireballs were not incandescent masses of stone and iron, **Halley**, **Wallis**, **Bergmann**, and others, regarded them as bodies moving in space, and which the earth met and attracted to itself. **Chladni** admits this explanation from the beginning of his researches, and in the sequel he has always defended it; in his opinion, two causes are equally possible: either they are masses that have never belonged to any celestial body, or they are the fragments of an ancient planet. Although these two hypotheses have each their degree of probability, **Chladni** regards the former as the most probable opinion.

A great number of observations prove that, besides the large celestial bodies, there are small ones that move in space, such as points and luminous trains, which astronomers have often seen traversing the field of their telescopes; such are also the opaque masses that have been observed by day before the disc of the sun, and which often present a considerable surface. According to M. **Chladni**, these scattered masses are primitive matter disseminated in space, and destined to form new worlds; he also thinks that those nebulosities which the telescope cannot analyse into stars are themselves nothing but very diffused luminous matter spread over extensive spaces. Comets are distinguished from these masses by their small size, their isolation, and a greater degree of density; they are nothing but masses analogous to clouds, or formed of dust or vapour, the particles of which are mutually attractive. This feeble density of comets is not only proved by the attraction that the nearer planets exercise over them, but also by our being able to see the fixed stars through them.

It is also possible that these masses may be derived from the destruction of heavenly bodies. Several observations prove that stars have actually disappeared from the vault of heaven, and reason conceives the possibility of this destruction. When stars appear endowed with a great brilliancy, and shine for some time to disappear afterwards, this proves, according to **Chladni**, a violent combustion in a body which must be ranged among the fixed stars. Of this kind is the star that, in the eleventh century, burned for three months in the constellation Aries with variable brilliancy, and then disappeared for ever. The great red star that appeared in the spring of 1245, near Capricornus, diminished in intensity about the end of July; the star observed by **Kepler**, in the constellation Ophiucus, was visible from October 10, 1604, till the month of October, 1605; the brilliant star that burned during the years 945, 1264, 1572, in Cassiopœia, belongs to the same category. If planets or comets gravitate around such a star, this sudden developement of heat and light must have a great influence over them. When the force acting from within outwards, which tends to destroy a star, prevails over the mutual attraction of its parts, it may burst: thus the four telescope planets, Ceres, Pallas, Juno, and Vesta, are perhaps only the fragments of a large planet. If such explosions as these have taken place, we can understand that a large number of small fragments may be projected afar.

Whatever be the hypothesis we embrace, the periodical return of a great number of shooting stars, which all seem to come from the same point, without sharing in the earth's motion, is always a powerful argument in favour of the cosmical hypothesis. We may admit that, besides the planets and comets, millions of asteroids are moving round the sun, and become visible when they are ignited by entering into the terrestrial atmosphere. The greater portion probably again abandon the earth's atmosphere, to continue their revolution round the sun. These masses are spread throughout space, but not in a uniform manner, and there are points where they are collected in large numbers: of this kind are the groups traversed by the earth on August

10 and November 13. But they are not equally numerous on each of these points. Further, if we admit, with **Olbers**, that they execute their revolution round the sun in five or six years, it follows that the earth would meet a great number in summer and autumn; but also certain years, such as 1799 and 1833, are remarkable for an extraordinary abundance of these meteors.

If the mind can conceive how the earth meets these asteroids, it does not at all explain their incandescence. **Chladni** believes that, on arriving within the terrestrial atmosphere, they experience a resistance that produces bounds, and which is the greater as these bodies have an original volume greater than that of the stones which fall to the earth: we must hence conclude, that the ignited ball has a very feeble density. This resistance also produces the incandescence and ignition of the body; it compresses the air, and this compression produces such a heat that the body is inflamed. If it is objected, that the air is very much rarefied at so great a height, we may reply that the extreme velocity must be taken into account. M. **Parrot** admits, in addition to the compression, the action of the vapour of water on combinations of metals with sulphur; it would even be possible that the elements of meteoric stones were silicum, magnesium, calcium, potassium, &c., which would be transformed into silica, magnesia, lime, potash, &c., under the influence of water, a combination during which heat is always developed, and which, joined to that produced by compression, might render these bodies incandescent. Perhaps they contain bodies that are still more inflammable, and which disappear in the atmosphere before they arrive on the earth. It is impossible to say any thing positive on this subject, since we cannot transport ourselves into the region where the combustion commences.

THE END.

# NOTES

BY

# M. CH. MARTINS.

---

## NOTE A. p. 14.

To interpolate, is to supply deficient terms in a series of numbers, bearing in mind the law, according to which these numbers must proceed. Suppose that for thirty days, and at every hour during the day, the barometer has been observed: hourly means may be formed, by taking the mean of the thirty observations at noon, that of the thirty observations at one o'clock, and so on. Suppose, now, that we have omitted one of the thirty observations at one o'clock, we may restore it, by giving it its most probable value,—we *interpolate*. In the case before us, it is sufficient, as the intervals are short, to take for one o'clock the mean between the readings of noon and two o'clock. If we were content to take the mean of the twenty-nine observations actually made, by dividing their sum by twenty-nine, the number obtained could not admit of comparison with the other means: this mode of operating must, therefore, be rejected.

The number obtained by interpolation is only an approximation, since, the true law, according to which barometric pressures vary, is not known *à priori*: it is, therefore, impossible to avoid a little of what is arbitrary in the process of interpolation. One calculator may estimate that the arithmetical mean between noon and two o'clock is too low to represent the omitted observation of the intermediate epoch; another may judge it to be too high: the former will increase, the latter will diminish it. We will endeavour to give some rules calculated to diminish the arbitrary practice that prevails in this matter; these rules may be useful to observers in the reduction of their observations.

The first thing to be done is to interpolate, by supposing the range of the instrument to be uniform from the last of the observations that have preceded, which observation I will call A, to the first of those that follow, or the observation B. It is manifest that if we represent the observations by a plane curve, taking the times for abscissæ and the readings for ordinates, this method consists in admitting that, in the interval between the observations A and B, their curve is sensibly rectilinear.

The intermediate numbers obtained in this way, by means of the simple rule of three, are only a first approximation. We may confine ourselves to this first approximation in different cases: 1st, if we are not looking for great precision; for example, if we desire to obtain the state of the barometer within one or two millimetres, which is generally sufficient for the calculation of atmospheric refractions; 2d, in hourly observations instituted for the purpose of obtaining the curves of diurnal variation, if the interval of time does not exceed two or three hours; and, in general, when the interval between A and B shall not exceed the eighth part of the period, at the end of which the variations, whose laws we are seeking, are renewed; 3d, if the terms, which, in consequence of omitted observations, are wanting in the series of numbers whose mean we are taking, are not very numerous in respect to the terms really observed; if they only form the tenth or the twentieth part, we may content ourselves, without great inconvenience, with a *rectilinear interpolation.*

In other cases, we must apply to the numbers obtained by this method a correction, that is sometimes positive, at other times negative; in order to be able to apply it, we must deduce it from the observations themselves. Let us continue to suppose that the observation omitted is that of one o'clock; we must take in the preceding or following days the value of the term $B_1 - \frac{B_0 + B_2}{2}$; $B_0$, $B_1$, and $B_2$, representing respectively the barometric readings at noon at one and two o'clock. We shall obtain a series of numbers, some of which will be positive, others negative; they must be arranged in the same vertical column; we obtain from them the mean value, after having summed them up, attention being paid to the respective signs they possess. The mean thus obtained will be the correction sought.

It often happens that the form of the curve is already known with sufficient exactness by anterior observations, made under circumstances nearly similar. Conceive that these observations have given a series of mean numbers of the form $b_0$, $b_1$, $b_2$, $b_3$, and corresponding to the different hours of the day; we may adopt, without any further calculation, the quantity $b_1 - \frac{b_0 + b_2}{2}$ as representing the value of the quantity sought after. The legitimacy of this supposition is then verified *à posteriori* by the inspection of the means of our series, when we have obtained the value of these latter; let us designate them by $\beta_0, \beta_1, \beta_2, \beta_3 \ldots$: if the quantity $\beta_1 - \frac{\beta_0 + \beta_2}{2}$ differs but little from $b_1 - \frac{b_0 + b_2}{2}$, it is useless to return a third time to the value of the interpolated terms. In the contrary case, we must substitute for the provisionary correction $b_1 - \frac{b_0 + b_2}{2}$, the definitive correction $\beta_1 - \frac{\beta_0 + \beta_2}{2}$.

I will consider further, the case when the consecutive observations of one and two o'clock shall have been omitted; let $B_0$, $B_3$, be the observations of noon and three o'clock. For one o'clock, the rectilinear interpolation gives

$$B_0 + \frac{B_3 - B_0}{3} = \frac{2\ B_0 + B_3}{3}$$

Let $b_0$, $b_1$, $b_2$, $b_3$, be still the auxiliary series employed for correcting the interpolated numbers; the correction that must be added to the term $\frac{2\ B_0 + B_3}{3}$ will be $b_1 - \frac{2\ b_0 + b_3}{3}$

Other analogous cases are resolved in the same manner.

Finally, suppose that throughout a series, the observations of the same hour have been omitted: the relative mean at this hour will be entirely wanting. It is then necessary to study the entire range of the curve during the whole period, in order to determine the most probable value of the missing time. There is an extended case, in which a direct calculation may lead to this result; it is when periodical phenomena, such as diurnal thermometric, barometric, magnetic, or tide variations, &c., are at issue. We may then suppose, without any great error, that the observed curve is due to the superposition of two undulatory or *sinusoidal* * curves, one of which produces another similar to itself, after an interval of time, equal to the entire period; in order that this method may be applicable, it is farther essential that the number of the terms of the curve really determined be at least equal to five. The general formulæ, according to which the restitution of the omitted terms is then brought about, cannot have a place here; but I will yet give those which are fitted for two cases that frequently occur: 1st, if the period is divided by the observations into twelve equal intervals, which happen for a day of twenty-four hours, when observations are made every two hours; and for a year, in the calculation of monthly means; and if, moreover, a single term of such a series has been omitted, calling the missing term b, and the eleven others, following the term b, $b_1$, $b_2$, $b_3$ . . . . $b_{11}$, we shall have

$$b = \tfrac{2}{7}(b_1 + b_5 + b_7 + b_{11}) + \tfrac{1}{7}(b_2 - b_3 - b_4 + b_6 - b_8 - b_9 + b_{10}) \\ + \tfrac{1}{7}\sqrt{3}\,(b_1 - b_5 - b_7 + b_{11}).$$

2d. If the period is divided into eight intervals, which happens in the course of observations made every three hours; continuing to call the omitted term b, and the seven known terms following in the order of the hours $b_1$, $b_2$, $b_3$, $b_0$, &c., we shall have

$$b = \tfrac{1}{3}(b_1 - b_2 + b_3 + b_4 + b_5 - b_6 + b_7) + \tfrac{1}{3}\sqrt{2}\,(b_1 - b_3 - b_5 + b_7).$$

If b and $b_1$ were both unknown, we should form a similar equation to the preceding by augmenting the *lower indices*, by unity, and by changing $b_8$ into b, we should have

$$b_1 = \tfrac{1}{3}(b_2 - b_3 + b_4 + b_5 + b_6 - b_7 + b) + \tfrac{1}{3}\sqrt{2}\,(b_2 - b_4 - b_6 + b).$$

These two equations united would give the value of b and $b_1$, according to the ordinary methods of the resolution of two equations with two unknown terms.—B.

---

* We give this name to a curve, the ordinates of which are proportional to the sines of the abscissæ, these latter being calculated from a fixed point, and considered as being the arcs of a circumference, developed on this axis of the abscissæ.

## NOTE B. p. 30.

The determination of meteorological laws depends above all things on observation; and, in order to recognise the mutual connexion that may exist between the different phenomena, they should all be observed simultaneously. But the task of the meteorologist would then become so wearisome, that no one would be equal to it. Hence the lamentable blanks in the series made even by the most laborious men,—those most devoted to the science. We may, therefore, conceive of what importance to meteorology would be the construction of apparatus so arranged as to preserve traces of the influences to which they may have been subject, in consequence of variation in the principal elements that are considered in the science; and which, when once adjusted, would themselves register for a certain period of time, without being guided by an intelligent hand, all the phases through which temperature, barometric pressure, the force and direction of the wind, absolute and relative humidity, &c., may have passed.

D'ONS-EN-BRAY, one of the most distinguished mechanicians of the last century, appears to be the first who constructed an instrument of this kind. He has inserted in the *Mémoires de l'Ancienne Académie des Sciences* (for the year 1734, p. 123), the description of an "anemometer, which marks of itself on paper, not only the winds that have blown during the twenty-four hours, but also their different velocities or relative forces."

We will give a succinct idea of the part of the apparatus, which concerns the direction of the wind. A vertical cylinder mounted on the same axis as the vane, carries twenty-five pencils of equal lengths, planted perpendicularly to its surface, in the direction of a helix, forming a complete spiral, which is thus divided into twenty-four equal parts. A band of paper, by means of clock-work, is drawn parallel to itself, so as to be grazed slightly by one of the pencils, for a certain direction of the vane; and the cylinder, which follows all the movements of the latter, always brings to the surface of the paper one of the twenty-four pencils, whatever be the direction of the wind. We, therefore, see that the paper, the whole of the surface of which passes successively before the cylinder, carries in the direction of its length a succession of pencil-marks, the height of which indicates the direction of the wind, and the length of which is proportionate to the time during which that wind has been blowing.

This ingenious instrument of D'ONS-EN-BRAY was not appreciated as it ought to have been. It was not then seen that the principle of continuous observations might be extended to a number of other instruments, and might facilitate experimental research after a great number of physical and mechanical laws. D'ALEMBERT himself, in the article "anemometer" of the Encyclopœdia, does not allude to D'ONS-EN-BRAY's instrument, without an expression of doubt.

It is scarcely thirty years since the celebrated German hydraulician EYTELWEIN, while making some experiments on the motion of water in the hydraulic ram, devised a mode of determining the velocity of the motion of certain valves, by fixing to them a pencil that should leave its trace on a paper, to which uniform velocity was given by means of clock-work. The success of this process, the perfect identity of which with that of the French mechanician is evident, ought to have drawn the attention of experimenters. However, it was not until long after, about 1830, that M. ARTHUR MORIN, at that time a captain of artillery, employed it in a regular manner, and as a fundamental means in his beautiful researches on the friction of sliding bodies. It is remarkable that M. MORIN does not claim for himself the first idea of this method, but attributes it to a talented engineer, well known by his works on geometry, and applied mechanics. But, what we have said of D'ONS-EN-BRAY will, doubtless, be sufficient for us to restore to its true author, the very remarkable conception of apparatus for continuous indications.

Moreover, when an idea corresponds to the wants of an age, in the sciences as in the arts, it presents itself to the mind of several persons at once, is manifested under various forms, and is applied to several different objects. This is very nearly what has taken place with the subject in question. A few years after M. MORIN had made so useful an application of it to the determination of the laws of the friction of sliding bodies, M. LALANNE, civil engineer, proposed to employ it for several purposes, and addressed to the Académie des Sciences a memoir with the detailed description of a levelling machine, a machine to raise planes, &c. (*Comptes rendus de l'Acad.*, 1836, p. 43.) Not to speak here of the instruments relating to meteorology, and to the physics of the globe, it will be sufficient to mention, that the continuity of indications was applied in his memoir to the anemometer, barometer, thermometer, hygrometer, udometer, to the compass, and to the hydrometer, which indicates the rise and fall of tides. His anemometer presented a notable advantage over that of D'ONS-EN-BRAY, in that its indications were perfectly continuous, whilst in the other, each pencil only began to act a short time after the preceding one had ceased to mark.

After this communication, the Academy has received several others on the same subject, and apparatus for continuous indications have been constructed in various localities. We have seen in operation at the Observatory at Paris a thermometer, the temperature of which was marked on paper at very near intervals of time by a hole pierced with the point of a needle. Captain HOSSARD, a staff-officer, has recently proposed to borrow from photography the means of registering the indications of any instrument at hours fixed upon beforehand. It is really desirable that this excellent idea should not experience too many difficulties in being carried out, and that meteorology may be enriched by a mode of observation that will centuple, in the space of a few years, the still incomplete data on which the science at present rests.

Whatever may be the result, there are now in England apparatus for continuous indications, both well conceived and well executed, which appear to act in a satisfactory manner. The first number of the journal entitled *The Illustrated Polytechnic Review* (January 7th, 1843), gives a brief description of one of these apparatus, including at once an anemometer and a pluviometer. M. NEWMAN is mentioned as having introduced several important ameliorations to this apparatus, which is attributed to Mr. OSLER. The direction and intensity of the wind, as well as the quantities of rain, are marked by three different pencils on the same sheet of paper, which is $1^m$ long by $0^m,30$ wide, to which a clock communicates a progressive movement, and which is sufficient for the observations of twenty-four hours. The index of the direction of the wind is so arranged that equal spaces on the paper are allotted to equal points of wind. The force of the wind is directly measured by the pressure it exercises on a plane surface of determinate extent.*

Another number of the same review (that of February 4th, 1843), has given the fac-simile of the traces left on the paper of the instrument possessed by the Polytechnic Institution of London, during the tempest of Friday, the 13th of the preceding January. This figure is very curious; it enables us to follow the slightest variations that occurred during the prevalence of the tempest in the three elements, the subjects of the observation.

M. CHAZALLON, hydrographic engineer of the navy, who, without having any knowledge of the labours previously undergone in this subject, was also engaged in it, has just erected at Algiers an apparatus of the same kind, which will give the law of the variations in the level of the sea, at the same time with the pressure of the barometer, and the intensity and direction of the wind. The intensity is given indirectly, as in WOLTMAN'S mill, by the number of turns made in a given time. With regard to the direction, it is indicated by three pencils arranged at equal intervals on the length of an endless chain, in such a manner that only one at a time makes a mark, and that one of them begins marking as soon as the other leaves the field of the paper. This last arrangement was also devised by the author of the memoir cited above.

## NOTE C, p. 224.

For a long time, meteorology and botany were cultivated separately, as sciences that had no connexion with each other. Plants were studied as inanimate things, and not as living beings related to every thing that surrounds them. The spirit of speciality raised an insurmountable barrier between two sciences apparently foreign to each other. It was reserved to M. DE HUMBOLDT, who united in himself the sum of human knowledge, to shew that meteorology and botany, so distant in the hierarchy of the sciences, are sisters in the harmonious co-unity of Nature. In his numerous travels, he had every where seen vegetation modified or changed when the climatologic conditions were not the same; he studied the relations existing between the physiognomy of American flowers and the climates to which they correspond, and thus created *Botanical Geography*.

In this complex science, geography, the physics of the globe, geology and botany, lend their hand to unveil to us the laws that prevail in the distribution of vegetation, and the causes of these laws, M. KAEMTZ was obliged to confine himself to shewing the influence over vegetation of sea and of continental climates (p. 175), and that of the decrease of temperature with the height.

If we travel from south to north, we pass through different vegetable regions; but we conceive that these zones are limited by isothermal curves, and not by lines parallel to the equator. To determine the northern limit of the different species of vegetables is a labour of no use either to the advancement of science or even to the perfec-

---

* *Vide* Note *y*, Appendix, No. II.

tion of agriculture, or the forest art. But here, the choice of plants is not a matter of indifference. There are, indeed, vegetables that can live and propagate in different climates, as the shepherd's purse (*Capsella bursa-pastoris*) the dandelion (*Taraxacum dens leonis*), wild thyme (*Thymus serpyllum*), &c.; they must be rejected in order to characterise vegetable zones. I should say the same of cultivated plants, that man, by dint of care and trouble, has made to grow beneath a sky that is not made for them. The study of their distribution is interesting in a more special manner to the farmer and the economist. The vegetables that may serve to characterise a climate should include certain conditions, the first of which is to be found in a wild state in the countries they inhabit: it is not necessary for them to be very common, but they ought not to be rare. We should choose visible plants, and such as are easily recognised and very well known, so that there may be no doubt as to their generic or specific name. In general, botanists have preferred trees, such as laurels, oaks, beech, chestnuts, pines, firs, &c. This selection is excellent, because these perennials cannot live except in a condition for resisting the rigour of winter; but they do not always fructify in summer: we should, therefore, carefully distinguish the limit at which they cease to exist, and that at which they cease to fructify. Sometimes these two limits are confounded, but they are frequently distinct and very distant from each other.

When we have made choice of the vegetation, by which a zone is characterised, it will be easy to group around it the most remarkable plants. This work has been accomplished for Europe by M. Schouw, in his work entitled *Europa, physisch-geographische Schilderung.* He distinguishes four principal regions in Europe: 1st. The region of trees with ever-green foliage. 2d. That of the chestnut and the oak. 3d. That of the oak and the beech. 4th. That of the pine and the birch. These regions correspond very well with the agricultural regions, that are respectively characterised by the cultivation of the olive, the vine, cereals, and the absence of all culture.*

Botanists have then endeavoured to learn what the absolute number is of *species* contained in a region. This determination presents great difficulties; for, Europe excepted, we may say, that we never know above a small portion of the species that enter into the flora of any country; and it follows, that the numbers given are only provisional, and may be completely changed when persevering researches have made known all the vegetable riches of a country.

When the list is as complete as possible, we take notice of the families and genera, the species of which are predominant, and we then obtain an idea of the vegetable forms that characterise a botanic region.

The study of climate must advance parallel with that of vegetation; and the climateric circumstances frequently explain, in the most satisfactory manner, the differences presented by the flora of countries very near to each other, and very similar in other points of view.

The vegetation of mountains presents to us, on a small scale, the image of that of the earth considered as a whole. At the foot of the mountain, we find the flora corresponding to the climate of this region; but, in proportion as we ascend, the vegetables of the plain

---

* On this subject, *vide* also the *Revue Indépendante* of January 10th, 1843.

disappear in order to give place to other plants which always belong to the colder regions. Thus, then, to rise in the atmosphere or to travel towards the pole is to traverse successively zones that are more and more boreal.

We may study the vegetation of mountains in two points of view: 1st. To determine the altitudinal limit of the different vegetables, and thus to divide the mountain into zones or regions analogous to those that are found when we go from south to north on the plains of the continents. 2d. To make the flora of one of these zones complete, and to compare it with that which corresponds in latitude. These two classes of research present difficulties that are equally numerous, although of a different nature. If we endeavour to determine the limit of a characteristic plant in a chain of mountains, we must first include in the account the direction of the side on which it is found. Thus, we generally see plants rise higher on the south than on the north side; but we shall soon recognise, that on the same side their altitudinal limits vary greatly, according to the configuration in the relief of the woods, the direction of the valleys, the changes they determine in that of the predominant winds, the nature, coherence, colour, and humidity of the soil, and a host of other causes, some of which escape the most attentive observation. The following is a proof:—All botanists and even travellers have been struck, in the Alps, at the appearance presented by the zone characterised by rhododendrons (*Rhododendron ferrugineum* and *R. hirsutum*). These elegant shrubs, covered with beautiful red flowers, form a region distinctly limited, which succeeds that of the pines, and precedes that of the Alpine plants. They are ever quoted as a very evident example of a vegetable zone, the height of which above the sea is very fixed. In a journey on the two sides of the Alps, comprised between Mont Blanc and Mont Rosa, I undertook to determine, by means of the barometer, the limits of this zone, and the following are the numbers I obtained:—

### LIMIT OF THE ZONE OF RHODODENDRONS, ON THE TWO SIDES OF THE PENNINE ALPS.*

| NORTH SIDE. | | SOUTH SIDE. | |
|---|---|---|---|
| Lower Limit. | Higher Limit. | Lower Limit. | Higher Limit. |
| 1220$^m$ | 1984$^m$ | 868$^m$ | 1898$^m$ |
| 1469 | 2079 | 1500 | 2081 |
| 1494 | 2112 | 1620 | 2120 |
| 1584 | 2208 | 1670 | 2152 |
| 1640 | ,, | 1677 | 2194 |
| 1691 | ,, | 1788 | 2388 |
| 1509 | 2101 | 1517 | 2139 |

---

* In this table, the numbers have been arranged simply according to their value; and the two limits placed opposite to each other do not necessarily refer to the same locality.

We see that these numbers present great differences on the same side; however, we may say in general terms, that the zone of rhododendrons has a height of 592 metres on the north side, and 622 on the south. Thus, the direction has little influence over the altitudinal limits of the rhododendrons, which, in the Pennine Alps, appear to be almost the same on both sides.

Isolated mountains, such as the Ventoux in Provence, Etna in Sicily, and the Peak of Teneriffe in the Canaries, are of singular service in the studies of botanic geography; for there a portion of the disturbing causes, that we have pointed out, tend to disappear. It is on these mountains that the influence of exposure becomes predominant; for it is not counterbalanced by the protection formed by the surrounding woods. Thus, on these mountains a few barometric measurements are sufficient to determine the limit of a plant, whilst, on long chains, the exactness of the results is in proportion to the number of observations from which the means have been deduced.

The nature of the soil has sometimes an equal influence with that of climate; thus, in Norway, the wood pine is next to the white birch, the tree that advances farthest to the north; in particular, it passes beyond the pitch-tree (*Abies excelsa*). In the Alps, every thing is the reverse: the wood pine stays at the foot of the mountains, whilst the mean limit of the *Abies excelsa* is 1800 metres. This is because the pine cannot flourish except in a sandy soil; now the alluvial soil ceases at the foot of the Alps, the pine stops at its limit. In the north, on the contrary, it is found even in the most distant fiords of Lapland.

If we wish to make the complete flora of a vegetable zone, in order to know what the plants are that are peculiar to it, and those which rise from the plain, or descend from the higher regions, the same difficulties are experienced as for the flora of a country on the plain; namely, that notwithstanding the most persevering researches, we always risk being incomplete. It is good in this case to prefer an isolated summit, because then the limits of the region are better circumscribed, the action of climate is more powerful, and the influence of neighbouring regions less marked. Ramond was the first to give an example of this kind of researches, in his memoir, entitled, *State of Vegetation at the summit of the Peak of Midi de Bagnères*. This summit is 2880 metres above the sea. Ramond ascended it thirty-five times in fifteen years; and each time he collected all the plants that he found in flower. The lower limit of these herborisations was sixteen metres below the summit. He established the existence of 133 species, of which seventy-one were phanerogams and sixty-two cryptogams.

I executed the same labour on the summit of the Faulhorn in Switzerland. The elevation of this summit is 2683 metres; it is terminated by a cone eighty metres high and four and a half hectares in superficies. I undertook the flora of this cone with my friend, M. Bravais. We stayed there forty-five days in 1841 and 1842. The climate of the summit is now very well known, thanks to these two sojournings, and to those of M. Kaemtz, which had preceded ours; for now, the knowledge of the temperature of the summer months rests on 131 days of observations, distributed through four different years.

The following are the temperatures of the summer months and of the year; those of winter and spring possess no importance, since the plants are then buried under a bed of snow, which almost always attains several metres in thickness.

Mean temperature of
June...... 2°,5
July...... 4 ,0
August.... 3 ,5
September 1 ,5

Mean of the year, —2°,33.

Very well! under the climate which is colder than that of the North Cape (lat. 71°), and the summer of which is scarcely warmer than that of Spitzbergen, on this isolated rock, beaten by winds in all directions, nearly 200 species grow, of which 126 are phanerogams, that flower in the summer. When we look through the list, we find plants of the plain that have ventured to this height. Such are: *Cerastium arvense*, *Alchemilla vulgaris*, *Capsella bursa-pastoris*, *Thymus serpillum*, &c.; others belong to the subalpine region; for example: *Aconitum napellus*, *Arabis alpina*, *Oxytropis campestris*, *Arnica scorpioides*, *Bartsia alpina*, *Cirsium spinosissimum*, *Gentiana campestris*, *Phalangium serotinum*, &c. A great number have been observed by RAMOND on the peak of the Midi, and must be considered as really mountain plants. Such are: *Cardamine bellidifolia*, *Draba fladnizensis*, *Silene acaulis*, *Dryas octopetala*, *Saxifraga stellaris*, *S. oppositifolia*, *Oxyria reniformis*, *Polygonum viviparum*, and *Trisetum subspicatum*.

I cannot here enter into fuller details on the interesting connexions to which these comparisons give rise; but I hope to develope the subject in the botanical part of the *Voyages of the Commission of the North*, and to shew what are the analogies and differences between the vegetation of the elevated summits of the Alps and that of the northern countries of Norway, and Spitzbergen in particular.

## Note D. p. 227.

The whole of organic nature is found to be in dependence upon meteorological phenomena. The influence of climate is very powerful over the existence and developement of vegetables and animals. However, among inorganic masses there are some that are also powerfully modified by temperature, moisture, winds, rains, snow, and barometric pressure: these are the *glaciers*. The author has already sufficiently shewn the mechanism by which a glacier is formed. Derived from the region of eternal snows, it descends like a solid river into the valleys that proceed from them; and lower, in proportion as the regions of eternal snow whence it originates are higher. Thus, from the height at which the lower part of a glacier is found, above the level of the sea, we may almost determine that of the region of eternal snows, whence it derives its origin. The farther this lower part of the glacier descends toward the plain, the more elevated in the atmosphere is its higher part. The following is the proof. Among the glaciers whose elevation above the sea is known, are those of Grindelwald, the Bossons, and Brenva, which descend lowest, the mean height of their lowest part being 1230 metres above the level of the sea; now, these four glaciers descend from Mont-Blanc and the Jungfrau, the two most elevated summits of the eastern and western Alps. Doubtless the direction, and the depth and width of the valley, are not without their influence; but the principal condition is the elevation of their source, or, in other words, the climate of the glacier at its origin. We, therefore, see that the length and power of the glacier are the direct result of atmospheric conditions, and of temperature in particular.

Let us now examine, under a purely meteorological point of view, the phenomena presented by glaciers; we shall see that it is not rash to maintain that the time will come, when we shall be able to conclude the modification of a glacier from those of the atmosphere, and *vice versâ*. But, in order to establish in a positive manner the point which connects meteorology with the physics of the globe, it is desirable that long series of observations be made in the neighbourhood of the glaciers, in order to connect the two orders of phenomena.

Of all atmospheric agents, temperature is that whose action is the most energetic. The glacier, doubtless, is also under the influence of that of the soil; but MM. BISCHOFF and ELIE DE BEAUMONT have shewn that this action is altogether insignificant, and may be neglected. Temperature acts in two ways: first, it directly melts the glacier, principally at its lower part, then the snow, converted into water under its influence, infiltrates into the mass, penetrates, hollows out, and undermines it, and forms galleries and caves, that admit the external air; and, under this triple influence, the mass of the glacier diminishes, and its lower extremity is partly melted. If this melting is of sufficient amount to prevail over the progression of the glacier, then the latter recedes; otherwise it continues to go onward, even during summer. Thus, in 1818, according to the measurement of M. de CHARPENTIER, the glacier of the Rhone advanced forty-eight metres. But, during the hot summers, the glacier generally receded very sensibly. It follows, from the alternations of hot and rainy summers, that we observe in Switzerland an oscillation of the lower extremity of the glaciers, which sometimes advance, carrying before them trees and barns, and sometimes recede, leaving, as a trace of their passage, a barren soil, strewed with flints, sand, and blocks of rock.

But temperature also effects a complete change on the surface of a glacier. During a hot day, innumerable streamlets of water flow over its surface and fall, like cascades, into the crevices; small transparent pools, perfectly blue, are formed in the hollow parts: but when a cold and clear night succeeds this day, all returns to silence; the brooks are stayed, the pools of water are covered with a pellicle of ice; and the next day this movement begins again, when the sun comes to reanimate this motionless plain.

The upper surface of the glacier melts as well as the lower; we convinced ourselves of this, by planting stakes and burying stones in the ice; at the end of a certain time the stakes were exposed, and the stones were on the surface of the glacier. By direct measurements, taken on the rocks by which the glacier is bounded, we proved that the level of these stones remained the same so long as they were buried in the glacier, and that it *fell* from the moment that they were on the surface; we also measured the fall of the surface. In the summer of 1841, viz., from July 26th to September 4th, with a mean temperature of 4°,61, and a relative humidity (*vide* p. 78) of 76 per cent, M. BRAVAIS and I recognised that the mean diurnal melting of the surface of the small glacier, situated below the summit of the Faulhorn, was $37^{mm}$. During the same period, this surface had fallen $1,54^{m}$. In 1842, M. AGASSIZ observed a fall of the surface or mean *ablation* of $77,3^{mm}$ per day, on the glacier of Unteraar, and in the same year, Mr. FORBES found that the sea of ice at Chamounix had fallen at its edges 80 centimetres from June 26 to September 10.

This fall of the surface gives rise to a curious phenomenon. When a large block of stone, by its mass, protects the ice that it covers against the action of the sun, the ice does not melt; but around it the ice exposed to the action of heat is continually melting: there the surface of the glacier falls, and the block is at last on the summit of a pedestal of ice, the height of which gives an appropriate idea of the melting of the glacier. Thus, at all places where its surface is covered by a mass of blocks, we observe that its level is higher.

The hygrometric state of the air exercises no less an influence. If the air is hot and dry, the evaporation of water and ice is more active; if it is cold and moist, vapours will condense on the glacier, and contribute to its increase.

All these effects will be still more marked, if the air is in motion: and here the action of the wind is added to that of the vapour of water. Is it necessary to insist on the part played by hydrometeors in the economy of glaciers? Who does not understand that warm rains hasten the melting much more than warm air, on account of the greater capacity of water for heat; that a thick bed of snow places it temporarily under shelter from atmospheric influences, and modifies these influences, as soon as it enters into fusion? But the exact appreciation of the part played by all the meteorologic agents would require long and persevering researches; it is by observing simultaneously the glacier and the meteorological instruments, that we may arrive at an appreciation of the phenomena that it presents, and probably to the discovery of their causes.

Does barometric pressure play an important part in the phenomena of glaciers? This part, doubtless, is not comparable to that of temperature, winds, and hydrometeors; nevertheless, I have been able to establish that pressure is not altogether foreign to their formation. A mass of snow, when not settled, is filled, as we know, with an immense number of bubbles of air; when this mass is penetrated with water, it is then changed into a glacier by successive congelations, the air is disengaged in the form of little bubbles, that rise and burst on the surface of the little pools of water, of which I have spoken, and with a very marked crepitation. Now on the glacier that I observed the mean barometric pressure is only $560^{mm}$, instead of 762, as at the sea-coast, in equal latitude. It is, therefore, evident that the bubbles must be liberated with greater facility than if the phenomena occurred at the level of the sea.

I do not here enter further into detail; my only object was to shew that glaciers form the transition between geology and meteorology; and that their dependence on the atmosphere is much greater than that of lakes, rivers, and the sea. The study of their phenomena presents great difficulties, because they are very complex, and result from the combination of forces, the knowledge of which enters into the domain of physics, chemistry, meteorology, the physics of the globe, and geology.

## NOTE E, p. 342.

As M. PELTIER deduces from his experiments and observations interpretations very different from those of other philosophers, we deem it useful to present here the summary of the researches that he has published up to the present time, and those which he has recently communicated to us.

An old experiment of DE SAUSSURE and ERMANN, which remained without any result, is the starting point of the series of facts which induce him to regard the aqueous and igneous phenomena on the atmosphere in an entirely new point of view. The following is this fundamental experiment, as it has been modified by M. PELTIER.*

A person stands on a perfectly open place, above all the surrounding objects: he takes an electrometer, armed with a rod of about four decimetres in length, surmounted by a ball of polished metal of from three to four centimetres of radius, in order to increase the effects of induction, and to avoid the escape of the electricity which may be repelled in the upper part. The instrument is held in one hand and adjusted with the other, by putting the rod in connexion with the platinum. All the reactions being equal on all sides, the gold leaves of the electrometer fall straight, and mark zero. In this state of equilibrium the instrument may be left in contact with the free air for a whole day, under a clear sky, without its manifesting the least signs of electricity: we may even move it and agitate the air; from the instant it is held at the same height, it will remain entirely still. But if, instead of leaving it in the same stratum of air, we raise it from four to five decimetres, we immediately see the gold leaves diverge and indicate a *vitreous* tension. (M. PELTIER prefers the words *vitreous* and *resinous* to *positive* and *negative*, as being less significant and not savouring of any theory.) If we restore the instrument to the original place, the leaves fall again exactly to zero; if we cause it to descend below this point of equilibrium, the leaves diverge again, but then they are charged with *resinous* electricity. On raising it again to the original point, the instrument recovers its zero, and preserves nothing of the free electricities which it shewed an instant before. Since no free electricity remains in the instrument, the air, therefore, has not communicated any thing to it, and the signs which it gave were only the result of a new distribution in the electricity, which the rod possessed at the point of equilibrium; we have merely to replace the instrument at the same point to make them disappear. They were, in short, only signs of induced electricity in a body which approaches or recedes from another charged with free electricity—a phenomenon

---

* *Vide* his Memoirs in the *Annales de Chimie et de Physique*, t. iv. 3d series; *Mémoires de l'Acad. de Bruxelles*, t. xv. 2d part; his *Traité des Trombes*; the article *Atmosphère* of the Supplement to the *Dictionnaire des Sciences Naturelles*; and the *Comptes rendus de l'Acad. des Sciences* of Paris, from 1838 to 1842.

which may be reproduced in a room by standing on a *resinous* or under a *vitreous* surface.

If, instead of a polished ball, we place one or several points, or a lighted match, as VOLTA did, the phenomenon ceases to be simple, and no longer permits us to distinguish whether the primitive effect was a new distribution of electricity, or whether it is electricity taken from the atmosphere. In fact, when we raise the instrument, the *resinous* electricity coerced by the *vitreous* induction of celestial space to the extremity of the rod, instead of maintaining itself there, escapes by the points or by the flame; when we lower the instrument it is deficient of all the dispersed electricity, and the former equilibrium cannot be re-established. Then there remains permanent *vitreous* electricity, which is wrongly attributed to the contact of the air; it is in reality only the portion separated from that of the contrary name which has vanished by the points, and which can no longer be neutralised when we replace the instrument at the original point.

This experiment, proving that neither the air, nor the vapour that it contains, possesses free *vitreous* electricity, invalidated the consequences that VOLTA, LAVOISIER, and LAPLACE had drawn from their experiments. On repeating and analysing these latter,* M. PELTIER has endeavoured to prove that vapour produced at a temperature below 110° centigrade never carries off free electricity; that there is no electricity but that formed at a temperature higher than 110°. This temperature not being that of the surface of the globe, the electric vapours which rise cannot, therefore, proceed from the simple evaporation of saline or pure waters.†

The electricity of clouds and fogs cannot be denied: he inquired whence it proceeded. As soon as he had established that the terrestrial globe is a body charged with *resinous* electricity, it was easy to demonstrate, by experiment, that the vapour which rises is *resinous* like itself, that this electric state of the globe is a powerful cause of evaporation, and that this latter may be quintupled and sextupled by a high tension. The vapour which rises from the earth being *resinous* like itself, its tension must react downwards against that of the globe, and successively reduce all its effects. This is what takes place; and it demonstrates the decrease of terrestrial induction on the electrometers in proportion as vapour is formed during the heat of the day. These instruments do not give the measure of the whole of the electricity, but only the difference of the quantities which act upon the coatings on the one hand, and upon the rod that sustains the gold leaves on the other. It follows, that they may be placed in the centre of a mass of vapours, charged with a great quantity of electricity, without giving the least sign of it. Thus, their decreasing manifestation with the formation of vapours is a proof that these latter are charged with *resinous* electricity like the globe, and that they react from above downwards against its action, which is from below upwards.

Vapour being in a trifling degree conducteous, does not long retain the equal distribution of its *resinous* tension; the incessant action of the globe repels the *resinous* electricity towards the upper strata, and thus renders the lower strata *vitreous*. The new distribution of

---

* Researches on the Cause of the Electric Phenomena of the Atmosphere, *Annales de Chimie et de Physique*, t. 4, 3d series.

† *Vide* note *l*, Appendix No. II.

electricity is made the more easily in proportion as the density increases. This is why the electrometer, which had almost ceased to give electric signs in the middle of the day, gradually recovers extent in its indications when the condensation of the evening is felt: the lower vapours become *vitreous* by induction, and the upper vapours become more *resinous*. During the night, the lower vapours being deposited in dew, the quantity of the *vitreous* vapours has diminished, the upper vapours then react more freely, and, towards the morning, the electrometer gives a less amount of indication than it did on the previous evening.

The first effect of the rising sun is to cause the vapours, that are condensed during the night, to return into the state of elastic vapour, whether they are or are not in the vesicular state.

These vapours being placed between the *resinous* earth and the *vitreous* celestial space, the first, that pass into the state of elastic fluid, carry off, on rising, a higher *resinous* tension, which they obtain by weakening such of the vapours as they leave behind, and which, having thus become less *resinous* than the globe, are *vitreous* in comparison to it and our instruments. During this first moment of the re-evaporation of the upper vapours, the strata left behind having become *vitreous*, are attracted by the earth, act more on our instruments by their proximity, and often produce a second dew, until at length the sun, by darting direct rays upon the earth itself, warms it and reproduces *resinous* vapours, which are diffused in the atmosphere, and react from above downwards on the instrument, as on the previous evening, and reduce anew the effect of the globe.

This play of electric induction is shewn on a very grand scale, and several times a-day, around the tops of high mountains. Since M. Peltier has established that all grey and slate-coloured clouds are charged with *resinous* electricity, and that all the white, rose, or orange-coloured clouds are charged with *vitreous* electricity, it was easy for him to follow at a distance this order of phenomena, without being obliged to go and measure their tension with the electrometer. This is the extract of his observations. When a white cloud hangs over the summit of a mountain, its powerful *vitreous* tension rouses and hastens the evaporation of its damp sides; the quantity of vapours produced get beyond the point of saturation of these cold regions, they immediately pass into the state of vesicular vapour, and appear under the form of ashy-grey flakes, of a tint which is deeper as the upper cloud is of a more dazzling white. The grey tint does long remain uniformly distributed; the *vitreous* attraction of the white cloud renders the bordering of the grey cloud more *resinous*, which then takes a deeper tint and forms a narrow riband at its upper part. This extreme stratum is divided into sinuous and trembling striæ, which shake, rise, and disappear, by passing again into the state of elastic vapour. These first vapours being dispersed, are replaced by others, which experience the same transformation, and so on. The greatest *resinous* tension of the upper riband, as manifested by its more slate-coloured tint, cannot take place but by taking from the former vapours the *resinous* electricity which they have carried off from the earth; by the decrease of their *resinous* tension, these latter lose by degrees their grey tint, and finally become almost as white as the upper cloud. This last itself has lost its original lustre, in proportion as its own vapours were neutralized by those which radiated from the grey band. The phenomenon then stops, and the mountain ceases to *smoke*, not to commence again until the winds shall have cleared it from those clouds which have become similar.

The presence of a grey cloud above the summit of the mountain produces an analogous effect, but with inverse electric signs. The cloud which issues from its sides is white; it is charged with *vitreous* electricity; its upper riband is more dazzling than the centre; it repasses into the state of electric fluid, and the rest loses by degrees its lustre and becomes grey. In fact, these same phenomena are again produced under a clear sky, but with less energy; the *vitreous* tension of celestial space is sufficient to carry the evaporation beyond the point of saturation of that stratum of air. The electrometer also frequently indicates that the invisible elastic vapour is powerfully charged with electricity, which is sometimes *vitreous*, at other times *resinous*. Under this new influence, the smoking of the mountains considerably increases; this abundance of vapours proceeding from the side of mountains is itself an indication of the presence of upper vapours, still in a transparent state. It also shews that their near condensation, in proportion as their electricity is neutralised, will give abundant rains.

On attentively following all these transformations on the mountains or in the middle of plains, we see that every day produces very nearly the same series of facts. There are vapours produced either by temperature alone, or by temperature seconded by electric attraction; then towards evening, or during the night, their condensation takes place, and, consequently, a new distribution of electricity under the influence of the globe. At sunrise, it is the re-evaporation of opaque vapours, or a fresh dilatation of those which are yet elastic; both are produced under this same influence, *resinous* below, *vitreous* above: the first vapours that rise are the most *resinous*, the last are less so, and are then *vitreous* in comparison to the first; they thus form opaque clouds of different tensions, when cooling condenses them. The daily vapours, by thus rising in the atmosphere, soon experience the effect of another electric induction, which powerfully reacts from above downwards: it is that of the upper current of the atmosphere, which carries away to the polar regions the *resinous* vapours of the tropical regions. The height of this current and the energy of its *resinous* tension varying with the seasons, produce reactions more or less distant from the surface of the earth. There is, again, between these two forces a resultant of the difference depending on the proximity of one or other of these forces, and the concomitant actions of temperature and winds. We cannot enter into further details,—it would be trespassing beyond the limits of a note; it is enough to have pointed out the new path that M. Peltier has followed in his works; each one will be able to obtain evidence for or against these results by new observations, and thus to decide, by the aid of time, which is the road that conducts most directly to the knowledge of the true cause of the meteors.

## Note F. p. 409.

The succession of tints by which the sky is coloured during twilight offers several peculiarities which are not very easy to explain, in the imperfect state in which the optics of gases are still found. As a complete explanation of the phenomenon may serve as a basis to every theory that would explain these facts, I will here communicate the results of the observations made by M. Bravais on the summit of the Faulhorn, 2683 metres above the level of the sea, and which embrace no less than thirty perfectly serene twilights. He had at his disposal the most exact means of appreciating both the position of the sun above or below the horizon, and the apparent distance of the coloured zones from the zenith of the beholder. We are about to follow the sun in each two degrees of its course, in proportion as it approaches the horizon, towards morning twilight. The following zenithal distances refer to the centre of the sun, not displaced by the effect of refraction; zenithal distances greater than 90° indicate that the sun has not yet risen.

1st. Zenithal distance of the sun 102°. In the east a reddish or orange-coloured band, whose height is nearly equal to 0°. We do not yet distinguish any other tint above this orange-coloured band; the height of the crepuscular curve is 7°. The spindle comprised between these two arcs is of a whitish blue, clearer than the rest of the sky.

2d. Zenithal distance of the sun 100°. The height of the orange zone is 1°. Above, yellow begins to appear, and its height attains 2° 30′ in the sun's vertical. No green is yet to be seen. The height of the crepuscular curve is 12°.

3d. Zenithal distance of the sun 98°. The part tinged with red extends from the horizon to 1° 15′. Above, yellow tint as far as 3° 10′. Green begins to appear upon the yellow; the greenish band scarcely gets beyond the height of 5°. Above, a weaker bluish shade, as far as 25°, where the limit of the twilight is formed.

4th. Zenithal distance of the sun 96°. The elevation of the orange-coloured and yellow zone has not changed; the greenish tint prevails to a height of 7°. The crepuscular curve rapidly reaches the zenith; its height is 70°. The western sky does not yet present any trace of light.

5th. Zenithal distance of the sun 94°. The yellow and orange-coloured bands preserve the same elevation above the horizon. The greenish zone attains to 12°. Above it a purplish tint begins to be manifested, at least if circumstances be favourable. M. Bravais has never seen it begin till the zenithal distance of the sun is equal to 95°, nor remain after that distance has become less than 93°. It forms a little after the passage of the crepuscular curve beyond the zenith, and its existence does not last many minutes. It is towards the height of 25° that this rose-coloured tint presents its *maximum* of intensity, and it does not get beyond the height of 45°. We do not observe the yellowish fringe which separates it from the greenish region situated below. The tint of the zenith is blue, sometimes perhaps slightly tinged with green.

In the western horizon the *anticrepuscular* arc is traced at towards the height of 10°; it does not offer as yet a very evident red tint, but a dark bluish, with a purplish shade more or less decided. Below, the sky seems clear.

6th. Zenithal distance of the sun 92°. The eastern red begins to turn yellow; its height remains the same: the upper limit of the yellowish zone is still equal to 3° or 3° 15′. From thence to the height of 18°, a more intense green colouring than in the preceding periods; the secondary purplish tint has entirely disappeared.

In the western horizon, the height of the anticrepuscular arc is 3°; the colouring in red extends from 3° to about the height of 15°. The red fringe often presents a tint of violet, or, at least, a purple. Below the anticrepuscular arc, we have never been able to discover the yellowish white fringe pointed out by M. KAEMTZ; but the blue of the sky appeared there to be sometimes slightly tinged with green, probably by an effect of optical contrast. Above this red zone, the usual blue prevails without any other perceptible intermediate tints.

7th. Zenithal distance of the sun 90°. The sun is risen; his disc and the neighbouring atmospheric portions frequently present a yellowish tint, and still more often an orange tint. The orange band which was stationary on the eastern horizon is effaced; this disappearance, which has been as slow as possible, occurs when the sun has attained the zenithal distance of 89°, or 88° 30′. The yellow remains to the height of 3°; from thence to 22°, being distinct green. The zenith blue.

On the opposite side, the anticrepuscular arc has gained the horizon, the red tint rises to the height of 4° or 5°. The yellow, which began to appear above when the zenithal solar distance attained 91°, now rises to the height of 6° or 7°. Above the yellow a little green begins to appear.

8th. Zenithal distance of the sun 88°. The red has entirely abandoned the eastern horizon; the yellow alone remains, and becomes weaker and weaker. The green tint surmounts the sun and extends to the height of about 25°; the zenith is blue. In the west, the red of the anticrepuscular arc has completely disappeared; the yellow still remains; its upper limit does not pass beyond 3°. The green which surmounts it presents its *maximum* of intensity about 5° or 6°; thence it extends towards the height of 10°, or even beyond; it is difficult to measure the height of the point of division of this zone with the blue of the zenithal part of the sky.

9th. Zenithal distance of the sun 86°. The yellow itself has disappeared; but the green still very frequently exists, especially in the part of the sky opposite to the sun: this last vestige of crepuscular colouring is gradually effaced.

The summary we have just made presents the succession of colours only in the vertical plane, which incloses the centre of the sun. The colouring of the sky in the lateral regions, although less important to know, nevertheless presents some peculiarities worthy of notice. Thus the lines which separate the different tints from each other decline in general, in proportion as they recede from the sun's vertical; but this rule is, however, subject to some exceptions. The points of the horizon situated at 90° from the intersection of the sun's vertical commence being coloured a little after the crepuscular curve has passed beyond the zenith. The appearance of the red tints in this place precedes that of the green, which surmount the latter. The lines of separation of these tints are less clear than in the sun's vertical; the rose colour is less intense there than in this same vertical; but it is not the same with the green tints, which often, on these two parts of the sky, have a more marked tint than the green of every other part, at least, for the few minutes which precede the rising of the sun.

We may explain the observed succession of all these tints by admitting that the passage of the solar rays through strata of air that are sufficiently thick, gives at first a yellow colour, and that a more prolonged course in these same strata, or in more dense strata, makes the orange tint finally predominate. This double mode of colouring is not contrary to the laws of optics, and colour transmitted by a coloured glass often changes with the increase of its thickness: we may see numerous examples of it in HERSCHELL's *Treatise on Light* (vol. i. part 2). These effects, which are well known to philosophers, result from the fact that the extinction of the rays of the different colours that compose white light, does not follow with the same rapidity for all these rays. The green tints of twilight cannot be attributed to the effect of an optical contrast produced by the complementary colour of green, which is red. The two following facts give the proof of this. The red tints disappear from the sky as soon as the sun rises; it is at this moment that the green tints often present the greatest intensity. On the circumference of the horizon, where a curtain of mountains rises sufficiently to hide from the sight of the observer the red zone, which is always very low, the other tints, yellow or green, remain as usual, and surmount the line of the ridge of the chasm, without the presence of this curtain altering their natural position.

To explain these greenish tints, it is not necessary to admit that the gradation of tints due to molecular aerial absorption begins with the green; it is sufficient to take account of the blue rays reflected and sent back to the eye by the upper strata of the atmosphere, and which, in their course, from the sun to the reflecting molecule, have only crossed very rarified strata. Under this point of view, the green zone, both eastern and western, is only the continuation of the yellow zone, whose normal tint is altered in the upper half by the mixture of blue rays arriving in a sufficient number from the high regions of the atmosphere, and which have experienced a much weaker extinction than that experienced by the rays proceeding from reflection in the lower strata (see the *Journal l'Institut*, 10th year, p. 310). We then easily conceive why the solar disc, at its rising, may appear orange, yellow, but never green. However, several circumstances are yet difficult to explain: the permanence of the blue tint towards the zenith, the white tint, which, from the summit of the coloured zones, extends even to the crepuscular curve; and, finally, the appearance of rose towards the height of 30°; when the sun is at 94° from the zenith; for it is very improbable that this rose, although very feeble, can be attributed to an optic contrast produced by the green band which it surmounts.

## Note G, p. 415.

If the crepuscular curve, which is seen to set in the evening in the western horizon, about an hour or an hour and a half after sunset, were really the result of the intersection of the cylinder of shades projected by the earth and the terminating surface of the atmosphere, the height of the atmosphere, which we might deduce from it, would be the same, whether the hour of observation were more or less advanced. Now, this result does not take place; the differences of results are not due to errors of observation; they go increasing in proportion as the sun sinks below the horizon; the numerous observations made by M. **Bravais** on the Faulhorn lead to the same consequences. It is a certain proof that we have not well interpreted the notion of the crepuscular curve: the hypothesis with which we set out was not correct. Thus the point where the visual ray drawn from the eye to the summit of the crepuscular curve meets the terminating surface of the atmosphere, does not of necessity coincide with the point where the solar ray tangent to our globe pierces that surface; it is either nearer to, or further from us, than this last point. **Lambert**, and after him M. **Biot**, have thought that the former of these two suppositions was the true one, and that the crepuscular curve corresponded, not with this outline of the terrestrial shadow, but with a region of the zone, which does not receive the direct rays of the sun; in a word, with M. **Biot**'s *second crepuscular space*.*

It however appears more natural to admit that this crepuscular curve corresponds on the contrary with the zone entirely enlightened by the sun, and that the more extreme part of the segment disappears on account of the strong absorption which the rays tangent to our globe experience. Whatever may be the position of this point, providing it is always placed in the same manner with regard to the crepuscular segment, we shall be able to determine it exactly by making one or two observations of the height of the curve made in known epochs. Instead of considering the observer as motionless, and the sun as descending in a vertical plane and drawing along with it the different crepuscular spaces in a common movement of rotation round the fixed centre of the earth, we may equally suppose that the whole crepuscular system remains immovable in the atmosphere, and that the spectator removes along the great circle obtained by cutting the terrestrial globe by a plane passing through its centre, the centre of the sun, and the eye of the observer; the phenomena of twilight are produced to the moving observer as well as for the fixed observer of nature, providing the arcs traversed in a given time on the great terrestrial circle represent the increases of the zenithal distance of the sun.

Every observation of the height of the crepuscular curve then gives a trajectory proceeding from a determined point of this great circle, and all these trajectories must cut each other on the top of the immovable crepuscular curve. Thus, in this manner of viewing the subject, we determine the height of the atmosphere by the phenomena of the apparent rotation of the crepuscular curve around the observer, or of this latter, around the summit of the curve, independently of the consideration of the rays tangent to the terrestrial globe.

In discussing under this point of view the observations of twilight made on the summit of the Faulhorn, M. **Bravais** found they were very accurately represented by admitting that the summit of the crepuscular curve was situated 115,000 metres above the level of the sea, and on the prolongation of a terrestrial ray, which would make,

---

* Mémoires de l'Académie des Sciences, t. xvii.

with the ray drawn to the centre of the sun, an angle of 95° 58′; so that the passage of the crepuscular curve to the zenith of the observer may take place at the time when the zenithal distance of the sun is equal to this latter angle. As to the setting of the same curve in the western horizon, the same calculations prove that it will take place when the zenithal distance of the sun shall equal 107°.

Finally, the following are the numbers whence these results are derived. For more precision, the twenty-one original observations have been grouped in threes, and we only give here the mean of each of these ternary groups. The first column represents the zenithal distance of the sun; the second column, the height of the curve above the horizon, corresponding with this zenithal distance:—

ZENITHAL DISTANCES OF THE SUN AND CORRESPONDING HEIGHT OF THE CREPUSCULAR CURVE.

| | |
|---|---|
| 95° 49′,9 | + 75° 23′ |
| 97 11 ,5 | + 44 8 |
| 99 54 ,9 | + 12 0 |
| 100 43 ,8 | + 10 45 |
| 101 43 ,9 | + 7 34 |
| 103 46 ,7 | + 4 53 |
| 106 14 ,1 | − 0 30 |

M. **Bravais** has calculated in the same manner the observations made by **Lambert**, at Augsbourg, 19th November, 1759; he has obtained a still more considerable height, one equal to 160,000 metres.

According to these numbers, the crepuscular curve, such as we see it, would correspond with the first crepuscular space; that is to say, with a region of the atmosphere directly illuminated by the sun, and even the rays which illuminate this space would still appear 80,000 metres above the earth; thus, every ray tangential in the strata of the atmosphere at a vertical elevation, less than 80,000 metres, would again experience a very considerable absorption, and one sufficient to prevent it from attaining the surface of egress from the atmospheric medium. This result appears too much opposed to what we know of the law of the diminution of densities in the atmosphere to be admitted. It therefore appears probable that the supposition we have just adopted is itself incorrect; and that the limit of shade and light does not correspond with a fixed and determined point of the crepuscular segment, but that it removes according to the relative position of the observer.

In this new point of view, the problem of the determination of the height of the atmosphere by the phenomena of twilight becomes very complicated. We must determine, indeed, by calculation, the intensity of the light of the different luminous arcs that compose the vertical circle, which, when produced, contains the sun; to compare these results of calculation with those of observation, so as to deduce the value of certain constants, such as the coefficient of the absorption of light by the air; those of reflection under different incidences; that which would determine the law of the decrease of the density of the air, &c. and, finally, the height of the atmosphere itself. This point, which we judge to be the summit of the crepuscular curve, will be that where the intensity of light will change with the greatest rapidity, and the condition of a *maximum* in the rapidity of the changing would, in like manner, serve to the solution of the problem.

Observations, followed out for a long period, on the phases of the rotation of the crepuscular curve from the zenith to the horizon, photometric atmospheric measurements, comparisons between the brilliancy of the different regions of the atmosphere, and that of the stars of various brilliancies as seen through, and more complete notions on the law of the decrease of the density of the aerial strata will, perhaps, one day, permit us completely to solve these delicate questions on meteorological optics.

Let us add that the observations on the eclipses of the moon, that the phenomena which are produced at the entrance of this luminary into the shadow of the earth, prove that the height of our atmosphere is, *at least*, equal to 80,000 metres; thus the height of 115,000 metres is not, perhaps, so exaggerated as we might have been tempted to believe, after the opinion of some learned physicians.

We have not spoken of the *anticrepuscular* curve; the laws of the evolution of this last are different from those which preside at the evolution of the preceding one. If we combine together in pairs the luminous trajectories which unite the curve to the moving observer, we find that they intersect each other at greater distances from the surface of the earth, in proportion as the anticrepuscular curve itself gains height, and the counion of all these tangent trajectories engenders a *closed* curve, which turns its convex side towards the ground, and which separates the luminous aerial region from the dark region. The rotation, also, of this curve from the eastern horizon to the zenith is much more speedy than that of the crepuscular curve descending from the zenith to the western horizon. Under the equator, at the time of the equinoxes, twenty-two minutes is sufficient for it to attain the zenith, whilst it employs double the time, forty-four minutes, to descend again from the zenith to the horizon. We will not speak here in further detail upon the anticrepuscular curve, seeing that it has not been, like the preceding, employed in the measurement of the height of the atmosphere.

# APPENDIX

## ON THE GRAPHICAL REPRESENTATION
## OF
## METEOROLOGICAL TABLES,
## AND
## OF NATURAL LAWS IN GENERAL,

BY LÉON LALANNE,

CIVIL ENGINEER.

# APPENDIX.

## I.

### ON THE PRINCIPLES EMPLOYED FOR THE CONSTRUCTION OF THE FIGURES OF THE APPENDIX.

**GRAPHICAL REPRESENTATION OF LAWS WITH TWO VARIABLES.**—The construction of plane curves has been for a long time successfully employed to represent the mutual dependence that may exist between two variable quantities. The determination of a curve of this kind is easily made. Starting from a fixed point, we set off on a straight line, lengths proportional to the arbitrary values given to one of the two quantities; from the extremity of each of these lengths, we draw, parallel to a constant direction, making a certain angle with the former, other lengths, proportional to the corresponding values of the other variable; we then draw a continuous line through the extremities of these straight lines, which must be sufficiently near together for this purpose.

The first distances, calculated from the fixed point, are called *abscissæ;* the lengths measured parallel to one fixed direction, and through the extremities of which the curve passes, are *ordinates.* The name of *co-ordinates* is applied equally to the abscissæ and the ordinates. The starting point on the straight line of the abscissæ is the *origin of the co-ordinates.* This straight line bears the name of the *axis of the abscissæ;* the *axis of the ordinates* is that drawn through the starting point, parallel to the constant direction of the ordinates. Generally, for more simplicity, axes of rectangular co-ordinates are taken.

Let us propose, as a first example, to construct the curve expressing the connexion between the different months of the year, setting out from the month of March, and the corresponding mean temperature for the 18th hour at Halle.

The law of the mutual dependence between the epoch of the year and the temperature of a given hour of the day at Halle, is contained in the numbers given by the different lines of the table, page 15.

Let us, therefore (*App. pl.* I. *fig.* 1, *bis*), take two rectangular axes of co-ordinates, $A\ x$ and $A\ y$. Let us set off on the axes of the abscissæ $A\ x$, twelve equal intervals, the extremities of each of which represent one of the months of the year, excluding, on account of the smallness of the scale, the inequality that really exists between the lengths of the months. Let us take parallel to $A\ y$, beginning from its extremities, lengths proportional to the temperatures given in the table for the 18th hour of the corresponding months. Finally, let us join, by a continuous line, the extremities of these co-ordinates, and we shall have a curve $m\ n\ p\ q$, which, if it is constructed on a proper scale, may supply the place of the numbers corresponding to the 18th hour in the table of page 15, and which, moreover, will have the advantage, that the isolated numerical results of this table have not, of bringing forth the law of increase or decrease of temperature according to the months, for the 18th hour at Halle, in a prominent manner. The rapidity of these changes evidently depends on the inclination of the tangent to the curve at different points.

We have, moreover, been careful to calculate *below* the axis of the abscissæ the ordinates corresponding to temperature below zero (indicated by the sign —). Hence it is that the arc $p$ of the curve is below $b\ x$.

**CONSEQUENCES OF THIS REPRESENTATION.**—The continuity of the line $m\ n\ p\ q$ gives the curve another particular advantage over isolated numerical results. Suppose, indeed, that the numbers of the table of page 15 are applied to a mean of observation made on the 1st of each month. We have but to divide properly the interval between the extremities of two consecutive abscissæ, and to measure the ordinate of the point of division, in order to obtain, with an approximation that is frequently quite sufficient, the temperature corresponding to a given date for the 18th hour of the day.

Thus, the length of the ordinates that fall at one, two, three, and four-fifths of the interval between two consecutive ordinates, will shew the temperatures of the 18th hour, for the 6th, 12th, 18th, and 24th of the month, the name of which corresponds with the ordinate at the left.

Let us now propose to know, by constructions effected on our figure, the period of the year at which the mean temperature between all the monthly temperatures takes place for the 18th hour. This mean, as we know (p. 13), is equal to the sum of the observed temperatures divided by their number. Now, if we admit that the observations are sufficiently close together for the intermediate ordinates to be the exact representation of the temperatures observed at the corresponding periods, the length of the ordinate, representing the mean temperature, will be what is called in geometry the *mean distance* of all the points of the curve $m\ n\ p\ q$ from the axis of the abscissæ; a distance which is the same as that of the centre of gravity of the outline of this curve.

If we, therefore, determine mechanically the position of this centre of gravity, its distance from the axis of the abscissæ will make known the mean temperature; and the position of the ordinates equal to this distance will determine the periods of the year at which this temperature takes place.

These conditions are sufficient to shew the principal advantages of the graphical representation of a law connecting one variable quantity with another. Among the natural laws, resulting from observation, we may quote those of mortality as offering matter for the most curious and useful appreciations deduced from the construction of curves. The direct determination of certain ordinates, points, and centres of gravity of certain segments, serves for the investigation of probable life, mean life, and the mean age of the population, &c.

**GRAPHICAL REPRESENTATION OF LAWS, WITH THREE VARIABLES.**—It is easy to foresee that the graphical representation of laws containing three variable elements, one of which may be considered as depending on the other two, would present no less interest than that which is applied simply to two elements. Now, two co-ordinates determine the position of a point on a plane: every point of a plane may, therefore, be considered as corresponding to the known values of the first two variable elements. If, then, we imagine that, at each of the points in this plane, a perpendicular is raised proportional to the value determined for the third element by those of the abscissa and ordinate at the foot of the perpendicular, the upper extremity of the latter will be a point of which this construction will determine the exact position in space.

Supposing a perfect continuity between the positions of all the points thus determined, we readily see that they are placed on a curved surface, the form of which is very fit to be depicted to the eye, and to bring out the principal properties of the natural law with three variable elements that we have desired to represent.

Although the establishment of a curved surface of this kind seems to require the three dimensions of space, we possess a notation as simple as it is expressive, by means of which it is easy to replace the constructions that we have just indicated in space by others effected on a plane surface.

Let us imagine that we have drawn divers planes equidistant from each other, parallel to the plane on which we calculate our first two co-ordinates. These planes will cut the curved surface in question according to certain curves, called *contour lines of elevation* (*lignes de niveau*, Fr.), the form of which will be eminently suited to give an idea of the surface. Now, in order to preserve these curves exactly of the natural size, and as much as possible in their relative positions, we have merely to *project* them parallel to each other on the plane of the first two co-ordinates; then, by attaching to each of them a number or *index* (*cote*, Fr.), indicating the height of the cutting-plane, by which it has been determined, we shall have, on a single plane, all the elements necessary if we desired it, to establish the curved surface on which they were traced.

Fig. 1 gives an interesting example of a representation of this kind. The object was to depict to the eye the curved surface, whose vertical ordinate expresses the mean temperature corresponding to a certain hour of the day and a certain month of the year. The months were first counted off on the axis of the abscissæ, and the hours on the axis of the ordinates. We drew, through the points of division of each of these axes, right lines parallel to each other; we then imagined, on each of the summits of the squares formed by the mutual intersection of these lines a perpendicular to the plane proportional to the number given in the table of p. 15, for the temperature of the month and the hour, that determines the position of this summit. Finally, we projected on the plane, parallel to each other, the *curves of equal temperature*, determined on the surface which should pass through all the extremities of these perpendiculars in planes parallel to the former, drawn at distances from the latter, respectively equal to those which, on the third coordinate of the surface, represent 1, 2, 3 . . . degrees above or below zero. The *indices* (or numbers assigned to the curves) are positive for sections made above the primitive plane, and negative (indicated by the sign —) for the sections made below.

This process is altogether the same as that which is employed for painting to the eye elevation of land on topographical plans, carefully raised and traced out. The minutes of the new map of France by the officers of the staff, and charts on a large scale to serve projects of fortification, sometimes even plans of roads and canals are covered with indices, and possess the traces of the contour curves of the elevation of the ground.

**GENERAL PROPERTIES OF PLANES EXPRESSING NATURAL LAWS, WITH THREE VARIABLES.**— It is evident that this graphical representation in relief, which expresses the law of the variations of one element dependent on two others, will be possessed of properties entirely analogous to those of isolated curve lines, such as *m n p q* (*App. pl.* I. *fig.* 1 *bis*).

Thus, if it is constructed on a suitable scale, it will give the same results as the table of p. 15.

If, for example, we desire to know the mean temperature of the month of August at 6 P.M.; we follow the ordinate of the month of August until it meets the abscissæ passing through six o'clock; the point of intersection falling sensibly on the curve whose index is 20, we hence conclude 20° for the temperature sought after. The numeric table gives 19°,95.

In the same manner we find that the point corresponding to 9 P.M. and to the month of July, falls between the curves indexed 17 and 18, at about $\frac{8}{10}$ of the interval separating them; we, therefore, take 17°,8 as the temperature sought. The table gives 17°,88.

Then the undulations of the surface are perfectly expressed by those of the contour curves, so that the mere inspection of the latter acquaints us with all the circumstances of the variation of temperature, at the different hours of the day, and at the different periods of the year. According as these curves approach or recede, they denote greater or less variations of temperature, in the order perpendicular to their direction. When they close around a certain region they indicate a culminating point or hollow (*encuvement*, Fr.) in this region; when, on the other hand, they open in a contrary direction, they indicate a depression and valleys, &c. a pass in an elevation-line (*col dans une ligne de fâite*, Fr.).

It is easy to see that the culminating point of the surface represented in figure 1 is about the month of July at 3 P.M.: it is an *absolute maximum.* The lowest point is in January, between the 18th and 19th hours (6 and 7 A.M.) This point is the bottom of a hollow: it is an *absolute minimum.* Between 1 and 2 P.M. in January, is a pass which indicates a *relative minimum* to the longitudinal elevation-line, comprised between 2 and 3 o'clock, and a *relative maximum* to the *thalweg*, or bottom of the valley, nearly corresponding to the month of January. Between July and August, about the 15th hour, is another pass, which is a *relative maximum* to the longitudinal elevation-line, prevailing about the 15th hour, and a *relative minimum* to the transverse elevation-line, which nearly follows the line of the month of July.

If we further suppose, as we have already done for the curve *m n p q*, that the numbers of the table at p. 15 are applicable to the mean of observations made on the first of each month, we may employ figure 1 to obtain a view without calculation, of the temperatures corresponding to any moment whatever of the day, and at any date of the year.

So, also, the position of the centre of gravity of the curved surface in figure 1 will serve to shew the contour line corresponding to all the moments of equal temperature in the year.

Finally, if we unite by continuous lines the succession of points of contact of the contour curves with tangents parallel to the ordinates and abscissæ, we shall have the projections of the *inclination-lines* (*lignes de pente*, Fr.) perpendicular to the axes of the co-ordinates. The first will make known the succession, according to the season, of the hours of the day at which the diurnal *maximum* and *minimum* take place; the second marks the periods of the year at which the *maximum* and *minimum* for each hour are produced.

These properties are very general, and have their analogies in all graphical representations of the same kind.

We must here make an essential observation. The monthly means, calculated by M. **Kaemtz**, apply, in reality, not to a given day of the month, but to the entire month. So that we cannot, on the graphic constructions deduced from the tables of this author, rigorously follow out the consequences resulting from the probable continuity of the results between observations made at periods sufficiently close together. We require, therefore, in order that the curves of our figure 1 should really give the temperatures of the day corresponding to a given date, two conditions, which the data and constructions on which we have operated do not satisfy, namely:—

1st. That we should know exactly the date of the day of the month on which the diurnal mean is equal to the monthly mean:

2d. That the intervals marked off between the monthly lines on the figure should be proportional to the lapse of time that had occurred between the dates of the days corresponding to the monthly means.

Admitting, as we have done, in order to explain the consequences deducible from the establishment of our indexed planes, that the monthly mean falls exactly on the same date each month, we, therefore, commit an error, to which we direct the attention of meteorologists, who may be tempted to apply our graphical constructions. It is true that, on a small scale, the error committed in the appreciation of the general range of the results will not be very considerable, when we suppose the monthly mean falling at the middle of each month; but, since our object is to obtain accurate results, this hypothesis can no longer be admitted, and we must necessarily come to the exact determination of the time of the month at which the mean occurs. Now, for this purpose, we must necessarily group together closely occuring observations; every three days at least, and, perhaps, even, to be accurate, every day.

Whatever be the plan, we are convinced that the graphic representation of natural or mathematical laws with three variables, that the substitution of indexed planes for numerical tables with a double entry is a fertile idea, that will not fail in bearing fruit.

When meteorologists, philosophers, and engineers, shall become familiar with the employment of this process, they will be in a better condition for discussing the results of their experiments, of directing their researches, of simplifying their calculations, than if they operate directly on numbers, whose mutual dependence is not always easily recognisable, or which is obtained by complicated operations.

The figures of the Appendix, that have been so constructed according to the notation of indexed planes with rectangular co-ordinates, are those numbered, 1, 4, 7, 8, 9, 12, 18, and 32; the numbers 4 *bis*, 17 and 31 *bis*, are planes of *curves of equal element*, but not indexed, and of polar co-ordinates (*Vide* the explanation that follows, p. 516, *et seq.*)

**GENERAL PROCESS FOR THE CONSTRUCTION OF INDEXED PLANES.**—It remains to explain the process by which we may deduce the construction of the contour curves of figure 1, from the numerical results of the table on p. 15.

Suppose we cut the curved surface of which we desire to trace the level curves by a succession of planes drawn perpendicular to the plane of projection, along the right lines corresponding to the different hours of the day. The intersections of these planes with the surface will be no other than the curves among which *m n p q* is found, and which express the annual variation of temperature at the different hours of the day. The points where the contour curves meet these first curves are, therefore, projected on the hour-lines, drawn parallel to the line on which the months are marked off. Thus, in order to have the points of projection of the different contour lines on the right line of the 18th hour, placed at the top in our figure 1, we must, in figure 1 *bis*, draw a succession of right lines parallel to *A x*, at intervals, representing a degree; and project on the right line 18, as is done on the figure by means of dotted lines, all the points at which the curve *m n p q* is met by one of the lines parallel to *A x*. The rank of the parallel above or below zero gives the index of the contour line to which each of these points belongs.

As we can, also, by means of the numbers on p. 15, construct twenty-three other curves analogous at *m n p q*, it is easy to obtain all the points of the different contour lines for the 24 hourly lines.

But there are a certain number of these lines which must close between two consecutive hourly lines; we must, therefore, in the case before us, by means of the column referring to the month of July in our table, also construct the curve of diurnal variation represented in figure 1 *ter*; and carry, on the monthly line of July, as we have done by dotted lines parallel to the hourly lines, fresh points of the contour curves. Thus, we have been able on figure 1 to close all those which ought to be closed.

This process of construction is very simple; it is founded on the ordinary methods of descriptive geometry, and is, also, very general. We have applied it to the construction of all those of our figures, except one, which represent surfaces, characterised by their contour lines.

For fig. 9, we have substituted, for the hourly curves polygons inscribed in these curves; and we have thus been able to determine by simple rules of three, the points at which the projection of each contour curve cuts the hourly right lines.

**DIFFERENT SYSTEMS OF CO-ORDINATES TO BE EMPLOYED FOR INDEXED PLANES.**—The graphical representation of curved surfaces, by means of the projections of their contour lines, is not confined to the system of rectangular co-ordinates that is generally used. This is only a particular case of a more general notation, in which, whatever system of co-ordinate may be adopted, we could trace on any surface whatever the orthogonal or polar projection of the curves that correspond to the same value of the third co-ordinate.

When we have to consider notative or periodical elements, such as the directions of the winds, on the 24 hours of the day, we may find advantage in certain cases in adopting polar co-ordinates. For example, suppose we wish to express graphically, for a certain place, the duration of each of the winds that blow during the twelve months of the year. We should trace, around a certain point (*vide* fig. 4 *ter*), four lines mutually inclined to each other at half a right angle; then, on their directions, which refer to the eight principal points of the compass, we shall calculate, starting from the central point, lengths proportional to the duration of these winds. On joining, by a continuous line, the extremities of the right lines thus measured for the same month, we have merely to place the name of the month beside each of the twelve curves thus constructed, in order to have the graphical representation in question. But this system, while inferior to that in which we take, as rectangular co-ordinates of the plane of projection, the monthly intervals and the duration of the winds (*vide* fig. 4 *bis*), which would give monthly curves less confused than the preceding, is still more so to that system, in which the rectangular co-ordinates are the months and the points of the winds, whence result the curves of equal duration of the wind.

Moreover, we might easily obtain a graphical delineation analogous to that of fig. 4, but simply with the polar co-ordinates. For this purpose, we have merely to calculate the points of the wind as longitudes, and the monthly intervals as latitudes, either on a sphere, or, better still, on a right cone, the axis of which would coincide with that of the equator, on which the points of the wind were measured. Then contour curves analogous to those of fig. 4, would be traced among the diverging lines and concentric circles, which would supply the place of the rectangular squares of this figure.

**ANTERIOR LABOURS ON THE SAME SUBJECT.**—The first idea of the graphical representation of the relief of the globe, by means of indexed contour of elevation curves, appears due to **Du Carla,** of Geneva, who proposed to the Academy of Sciences, in 1771, to apply it to geographical charts.

M. **de Humboldt** was then the first who thought of uniting on the surface of the globe, by continuous curves, other points than those that are found at the same level above the ocean. The analogy of his *isothermals* (*vide* p. 195), with the application that we make to meteorological laws, is manifest. The difference consists merely in that the isothermals are applied to points, the existence of which on the surface of the terrestrial globe is real; whilst the curves of the equal duration of the winds in the same place, during the different seasons of the year, are applied to points, whose position on a plane, or a sphere, or a cone, has been determined by pure convention, by a particular choice of co-ordinates to represent two variable elements.

We have, therefore, reason to be astonished that this ingenious idea of the illustrious scholar, who has attached his name to the perfection of almost all the sciences, has not taken a wider range, and has not been generally applied to the results of the physics of the globe, and of meteorology. For only one step was required to pass from the idea of isothermals to curves of *equal element,*—those of which we have just exposed the theory. It, moreover, appears, that M. **Piobert,** commander of a corps of artillery, has used the notation of indexed planes since 1825, to verify balistic tables; the *gunner's plank,* by M. **de Obenheim,** represented in the third volume of the *Memorial de l'Artillerie* (1830) is established with the same notation; and, in the same volume, M. **Bellencontre,** commander of a troop, proposes also to apply this notation for constructing the results of the Lombardy tables. It is said that, about the same period, M. **Didion** employed them in summing up the results of experiments on shooting at a mark. In 1840, M. **Allix,** nautical engineer, published a new system of tariffs containing graphic multiplication-tables, founded implicitly on the principle of representing a surface by means of its contour lines. Finally, M. **Chazallon,** hydrographic engineer of the navy, constructed *a card of barometric winds,* analogous to that of our figure 31, but without publishing any thing on this subject.

We may be permitted to add, that these various works did not come to our knowledge until after the period at which we thought of applying, in a general manner, to all natural laws, and to numerical tables containing three variable elements, the graphical representation devised by **Du Carla**. We have reason to hope that the numerous results we have deduced from the first idea of **Du Carla** and M. **de Humboldt**, and from some others, which are our own, will appear of a nature to confirm our assertion. To mention only two results of a special work that we anticipate soon publishing; it will be sufficient for us to quote among these consequences the establishment of our *abacus*, or universal *reckoner*, which will supply with advantage the rules of calculation, and serve for a multitude of operations that these rules cannot accomplish; and the construction of tables and instruments for the resolution of numerical equations of a degree higher than the second. Finally, we do not pretend to take to ourselves any thing belonging to those who have preceded us; and, whatever credit the opinion of competent and disinterested judges may accord us, in the application of the process to natural laws, and to numerical tables, we shall be happy if we can in any way contribute to give popularity to a notation, that appears destined to render real service in the sciences of observation and even calculation.*

---

* It is our duty specially to make mention here of the zeal and intelligence with which JEAN PREVOTEL, Jun., has assisted us in the construction of the figures of the Appendix. It was he, also, who made, or at least, most carefully revised, the long calculations that have been required for the conversion of all the numerical tables of the original into metrical measurements.

## II.

## EXPLANATION OF THE FIGURES OF THE APPENDIX.

### FIGURES 1 (*vide* p. 15.)

*Law of the variation of mean temperature per hour, in the different months of the year, at Halle.*

SCALES. 5$^{mm}$ for two months, set off on the axis of the abscissæ of *fig.* 1; 5$^{mm}$ for two hours, measured on the ordinates of *fig.* 1, and on the abscissæ of *fig.* 1 *ter*; 1$^{mm}$ per degree, set off on the ordinates of *fig.* 1 *bis* and *ter*.

The lines of the twelve months of the year are designated by their initial letters, and are set off parallel to the length of the plate; the lines of the twenty-four hours of the day are recognizable by figures placed at their left extremity, and are drawn perpendicular to the former. The curves of equal temperature are traced in the interior of the square, and indexed in centesimal degrees. Those whose indices are preceded by the sign — (*minus*), toward the right of the figure, indicate temperatures below zero. In order to obtain the temperature that prevails in a certain month, and at a certain given hour, we must follow the line that indicates the month, until it meets that which indicates the hour, and take the index of the nearest curve.

Thus, in ascending along the line of the month of June, we see that the point where it cuts the line of midnight falls at about 0,3 of the interval between the curves indexed 12 and 13; consequently, the corresponding mean temperature is 12°,3.

*Fig.* 1 gives rise to several interesting observations. We immediately see that, although it is obtained from a series of observations made for a few years only (M. **Kaemtz** does not say exactly how many), by a single observer, it presents a very satisfactory regularity in the form of the contour curves. Whence we should conclude, that the series need not extend to more than fifteen or twenty years, in order that the greater part of the accidental inflections should disappear.

Then, it is far more easy to recognise on the figure, than on the numerical table of p. 15, the range of the diurnal and annual temperature. Indeed, let us at once follow the lines of the month, from below upward, we shall see that they meet the curves of equal temperature, so that the figures of these curves go on increasing to a certain point situated between half-past one and three P.M.; and diminishing to another point situated between the 15th and 19th hours, namely, between two and seven in the morning. We thus recognise the *maximum* and *minimum* of diurnal temperature. The figure shews that the position of these points varies according to the seasons; that the *maximum* occurs in summer at about three in the afternoon, and at about half-past one in winter; and that the *minimum*, which occurs in the month of January about seven in the morning, occurs at three in the morning in the month of July. These results are conformable to those deduced by M. KAEMTZ, from the examination of the numerical results (p. 19).

If we pass from the lines of the months to those of the hours, we arrive at analogous results, namely, that we not only recognise the existence of the annual *maximum* and *minimum*, but also the different dates of the days on which they take place for each of the twenty-four hours, provided always, that we knew the exact dates of the monthly means, or else that we have taken these means constantly on the same day of the month.

The four curved lines, traced in dotted lines on *fig.* 1, establish the law of continuity between the various epochs of the diurnal and annual *maxima* and *minima*. Two of these lines, those of the diurnal *maxima* and *minima*, are nothing more than the projections of the inclination-lines traced on the curved surface, perpendicular to the direction of the monthly right lines; the other two, those of the annual *maxima* and *minima*, are projections of the inclination-lines, perpendicular to the direction of the hourly lines. It is easy to comprehend the reason of this property; it occurs because all the points that correspond to a diurnal *maximum* and *minimum*, on the curves of equal temperature, are determined by tangents parallel to the monthly right lines; and because the annual *maxima* and *minima* of the hours are those of the contact of the same curves with tangents parallel to the hourly lines.

The hourly curves represented in *fig.* 1 *bis*, and which are constructed directly by means of the hourly lines of the numerical table in p. 15, all present, without exception, a singular inflection about the month of November. There is another inflection of the same kind, but much more pronounced, about the month of May. What is the cause of this? M. **Kaemtz** is not explicit on this point, and does not even mention the fact. Is it because the relative results of the month of November have been interpolated inaccurately? Should we recognise in the anomaly of May the fall of temperature pointed out by M. **Erman**, professor of the University of Berlin, and attributed by him to the interposition between the sun and the earth of the asteroids, that we meet about the 13th of November? The November anomaly, of which M. **Erman** makes no mention, remains to be explained, whilst he announces one about Feb. 7, which is not appreciable here. (Vide *Les Comptes Rendus de l'Académie des Sciences*, 1st half-year, 1840, p. 21.)

### FIGURE 2 (*vide* p. 19).

*Law of the diurnal thermometric variation observed at Bosekop, during the forty days preceding, and the forty days following the winter solstice.*

Scales. $9^{mm}$ for four hours, set off on the abscissæ; and $9^{mm}$ for four-tenths of a degree, set off on the ordinates.

This curve was constructed by M. **Bravais.** It presents in its undulations a satisfactory regularity, which seems very well to indicate that they are not accidental.

### FIGURE 3 (*vide* p. 20).

*Law of the monthly variation of the coefficient by which we must multiply the excess of the maximum over the minimum of temperature; the sum of the product and of the minimum giving the mean of the day.*

Scales. $2^{mm}$ per month, set off on the abscissæ. The ordinates, which represent the coefficients of reduction, are taken on the scale of $\frac{1}{20}$ of the values of the coefficient, considered as a fraction of the metre, constantly deducting $15^{mm}$. The curve relating to the observations at a fixed hour is designated by H, that of the observations by the thermometrograph by T.

The irregularity of the two curves seems to indicate the necessity of observations prolonged over a much more extended space of time in order to the establishment of the exact values of the coefficient of reduction. It is probable that these values would vary, according to the places and even according to the days. It would, therefore, be desirable that they should be sought, by assiduous observations, in many points of the globe sufficiently distant from each other.

## FIGURES 4 (*vide* p. 43).

*Law of the frequency of winds* (monsoons) *in the different months of the year, at Dum-Dum, near Calcutta* (eight years of observation).

*The scale* of *fig.* 4 is $5^{mm}$ per month on the abscissæ, and $6^{mm}$ for each of the principal directions of the wind on the ordinates.

The curves constructed in the interior of the square are those of the equal duration of the winds. Their numbers have reference to the total duration of the winds that have blown in each month, a duration represented by 20. Thus, by following the line of the month of September, until it meets the line of the east wind, we fall on the curve indexed 4, whence we conclude, that during this month the east wind only blows $\frac{4}{20}$, or 0,2 of the time during which the wind blows in some other direction. The table on p. 43 gives 0,207.

*Fig.* 4 *bis*, properly speaking, is not at all a topographical plan. It contains the curves of the annual variations in the duration of the different winds. The same abscissæ are taken as for *fig.* 4, and the ordinates are on the SCALE of one decimetre for the total duration of the winds during each month. The curves referring to the different directions of the wind are designated by the letters by which they are recognised. They are constructed directly by means of the table on p. 43, in which the numbers of the same column express the lengths of the ordinates of any one curve.

Imagine that we have cut the curved surface, of which *fig.* 4 is the topographical plan, by vertical planes, drawn through the lines N. E., &c. of the directions of the wind. The intersections of the surface by these planes are precisely the curves of *fig.* 4 *bis*, and this figure itself is nothing more than the association of the eight curves projected on a vertical plane parallel to themselves.

The intersections of the same surface by vertical planes drawn in the direction of the monthly lines, would give rise to a series of curves analogous to those of *fig*. 4 *bis*, but which would represent the variation of the direction of the wind for each of the thirteen months of the year. These curves may, moreover, be constructed directly by means of the numbers contained in the horizontal lines of the table on p. 43.

*Fig*. 4 *ter* is supplementary to that which we have just mentioned, and gives the same results. Only, instead of setting off the directions of the wind on a right line taken as the axis of the abscissæ, we have indicated them in the true direction. But, on each of their directions we have set off on the SCALE of a decimetre for the total duration of the winds during a month, the partial duration of the wind that corresponds to this point. The curves thus obtained for each month are recognisable by the letters of these months; namely,

| | | | | | |
|---|---|---|---|---|---|
| J. | January. | M′. | May. | S. | September. |
| F. | February. | J′. | June. | O. | October. |
| M. | March. | J″. | July. | N. | November. |
| A. | April. | A′. | August. | D. | December. |

In addition, we may verify, on any one of the *figs*. 4, 4 *bis*, 4 *ter*, the result of the examination which M. **Kaemtz** undertook (p. 44), namely, the marked predominance of N. W. winds in winter, and that of S. E. winds in summer. But, of the three figures, the topographical plan is evidently the one which presents the greatest clearness, and which is best suited for the discussion under all its features.

The last may be called *monthly card of the duration of the winds*. It is analogous to the cards represented in *figs*. 17 and 31 *bis*, and to those that are happily indicated by *figs*. 11 and 12.

## FIGURE 5 (*vide* p. 48).

*Law of the relative frequency of the winds in different countries.*

SCALES. $2^{mm}$,5 for each point of the wind, set off on the abscissæ, and 5 centimetres for the total duration of the winds during a month, set off on the ordinates.

Initial letters indicate the curve of the variations in the duration of the winds, referring to each country of the table on p. 48; to wit,

E. England.
F. France, Netherlands.
G. Germany,
D. Denmark.
S. Sweden.
R. Russia and Hungary.
A. North America.]

The figure, like the table, shews the predominance of S.W. winds, and the tendency, a little to the north of the west, of the mean direction of the wind in Russia.

We must, moreover, only consider the differences of the ordinates in the same curve, and not in any degree their absolute values, because, in order to prevent confusion, we have, in several of these cases, moved back the axis of the abscissæ parallel to itself.

## FIGURE 6 (*vide* pp. 96 and 71).

*Law of the increase of the tension of the vapour of water, according to the temperature.*

Scales. $3^{mm}$ per four degrees for the abscissæ; three-fourths of the natural size for the tension expressed by the height of the mercurial column sustained, set off on the ordinates.

The lower curve is that resulting from the law found by M. **Kaemtz**; the other represents the law declared by M. **August** from **Dalton's** experiments.

The mere inspection of these curves shews, that the difference between the results given by the two laws goes on increasing with the temperature.

## FIGURE 7 (*vide* p. 83).

*Law of the variations of the tensions of the vapour of water contained in the air, per hour, in the different months of the year, at Halle* (four to five years of observations).

Scales. $3^{mm}$ per month for the abscissæ; $1^{mm}$ per hour for the ordinates.

The curves of equal tension of the vapour of water are traced in the interior of the figure: their numbers indicate the tensions expressed in millimetres of the height of the mercury. Thus, for example, by following the line of the month of June until it meets the line of midnight, we find, that the point of intersection falls almost exactly on the curve numbered 10; we hence conclude, that the mean tension of the month of June, at the hour indicated, is $10^{mm}$. The table on p. 83, gives $9{,}96^{mm}$.

In seeking, in the same manner as in *fig.* 1, for the position of the inclination-lines perpendicular to the right lines expressing the monthly ordinates, we find that four may be traced on certain portions of the figure. Two curves, the highest and the third, reckoned from below upward, correspond to *maxima;* the two others to *minima.* Their position on the topographical plan indicates the hourly range of the variation of the quantity of vapour contained in the air at Halle, according to the different seasons, in a manner that is partly conformable to the conclusions of M. **Kaemtz** (*vide* p. 85).

The summer curves present a regular range; but those of winter present anomalies that seem to result from the series not having as yet been sufficiently prolonged. Now, a considerable number of observations is the more necessary, as the curves of hourly variation in the winter months present less pronounced undulations. We shall easily establish these curves by means of our figure, since they result from the intersection of the surface represented by our topographical plan with the vertical planes drawn through the monthly right lines.

With regard to the monthly curves of variation for each of the hours of the day, they are derived from the intersection of the same curved surface by vertical planes drawn along the hourly lines. On constructing them, we shall recognise that all, without exception, present, in November, a singular inflection, altogether similar to that which we have pointed out for the monthly curves of temperature in *fig.* 1 *bis*, and in the same direction. We cannot discover the cause of this remarkable anomaly.

### FIGURE 8 (*vide* p. 84).

*Law of the variations of the relative humidity of the air per hour, in the different months of the year, at Halle* (four to five years of observation).

SCALES. $9^{mm}$ per two months for the abscissæ, and $3^{mm}$ per two hours for the ordinates.

The curves of relative equal humidity are traced in the interior of the figure 8. Their indices give the quantities from the table on p. 84.

The manner in which these quantities express the relative humidity is elsewhere explained on p. 78.

Thus, we find about 73 or 74 for the month of June at 9 o'clock; the table on p. 84 gives 74,2.

As the determination of these curves takes place according to the same series of observations as the preceding figure, we must not trust entirely to the results given by the winter months.

Furthermore, the inclination-lines, which may be traced on the curved surface perpendicularly, either to the monthly or the hourly right lines, follow a very regular range. The former, two in number, indicate the hours in each month of diurnal *maximum* and *minimum*, of which M. **Kaemtz** speaks (p. 85). The latter are four in number, and shew the hourly range of annual *maxima* and *minima*.

### FIGURE 9 (*vide* p. 87).

*Law of the variations in the tension of the vapour of water, contained in the air, per hour (from 7 A.M. to 11 P.M.) in the different months of the year, at Apenrade.*

SCALES. 5$^{mm}$ per month for the abscissæ, and 5$^{mm}$ per two hours for the ordinates.

The curves of the topographical plan indicate the moments of equal absolute humidity. Their indices express the hygrometric tension in millimetres of mercury.

Thus, for the month of May at 3 o'clock, we find a result comprised between 9 and 9,5. The table on p. 87 gives 9,23.

The comparison of this figure with *fig.* 7 shews the essential difference between the range of the absolute hygrometric state of the air at Halle and at Apenrade. M. **Kaemtz** points to these differences without being able to assign the cause (*vide* p. 88).

### FIGURE 10 (*vide* p. 89).

*Comparison of the tension of the vapour of water at the same hours at Zurich and on the Rigi, at Zurich and on the Faulhorn.*

Scales. $1^{\text{mm}}$ per hour for the abscissæ, and the fifth of the natural size for the pressure in millimetres, set off on the ordinates, deducting always $25^{\text{mm}}$ from the ordinates of the series Zurich-Rigi, and 15 from the ordinates of the series Zurich-Faulhorn.

Z Z and R R, corresponding curves of the first series, at Zurich and on the Rigi. (June 1832 and July 1833.)

Z′ Z′ and F F, corresponding curves of the second series, at Zurich and on the Faulhorn. (September and October 1833.)

The investigation given in the body of the book (p. 90) may be followed easily in these curves.

### FIGURE 11 (*vide* p. 101).

*Law of the variations of relative humidity during the different winds in the four seasons at Halle.*

Scales. $5^{\text{mm}}$ for each of the principal points of the wind, set off on the abscissæ, and half a millimetre per unity of relative humidity, for the ordinates, constantly deducting $30^{\text{mm}}$ from the latter.

| | |
|---|---|
| SS. | Spring curve. |
| Sm. Sm. | Summer „ |
| AA. | Autumn „ |
| WW. | Winter „ |

The contrast between winter and summer immediately appears on the mere inspection of these curves. The *maximum* of relative humidity at Halle corresponds to the east wind in winter, and to the west wind in summer; the *minimum*, to the west in winter, and the east in summer. These results are drawn by M. **Kaemtz** (p. 102), from the consideration of the figures in the table in p. 101. It might have been added that, between autumn and winter, there ought to exist a time when, *at a mean*, neither the east nor the west wind gives rise to *maxima* or *minima*; so that the relative humidity is, as it were, stationary, whatever the wind be at this period. The same thing takes place between winter and spring, but only for the east wind; then, between spring and summer, but only for the west wind.

These curves might be constructed so as to constitute an *hygrometric card of winds* analogous to the cards of figs. 17 and 31 *bis*.

## FIGURE 12 (*vide* p. 103).

*Law of the absolute diurnal variation in the quantity of the vapour of water contained in the air, above and below the mean, corresponding to each hour, according to the different winds at Halle.*

SCALE. 15$^{mm}$ per four hours, set off on the abscissæ; and, for each of the four principal points of the wind, set off on the ordinates.

The curves of equal difference of tension have indices indicating the differences, expressed in tenths of a millimetre of the height of the mercury. The indices preceded by the sign — indicate tensions below the mean; the indices of the tensions above are not preceded by any sign.

By following the hourly line of 0, or noon, until it meets the line of the south wind, we find that the point of intersection falls between the curves indexed 4 and 5, at about two-thirds of the interval between them. We hence conclude that, for this wind, and at this hour, the tension of the vapour, at a mean, is 0$^{mm}$,467. The table of p. 103 gives 0$^{mm}$,465.

The position of the inclination-lines perpendicular to the hourly lines shews the direction of the winds by which the relative *maximum* and *minimum* of each hour occurs. The determination of the hours of the day to which the relative *maximum* or *minimum* for each wind corresponds, depends, on the contrary, on the inclination lines, perpendicular to the right lines of the winds.

M. **Kaemtz** was the first to point out (p. 104) the anomalies of his table, which are set forth by the topographical plan that represents it. Moreover, in order to recognise them, he has employed the graphical construction of the curves, which, with us, result from the intersection of the curved surface, of which fig. 12 is the topographical plan, with eight vertical planes, drawn through the right lines of the winds.

The same remark as before may be made in respect to the establishment of a card of winds giving the absolute humidity.

### FIGURE 13 (*vide* p. 111).

*Law of the variations in the diameter of the vesicles of fogs, according to the different months of the year.*

SCALES. $5^{mm}$ for two months, set off on the axis of the abscissæ, and 500 times the natural size, for the diameters measured on the ordinates.

The progression from winter to summer is disturbed, as we see, by many anomalies, although there is a sensible diminution in character from one season to the other.

### FIGURE 14 (*vide* p. 112).

*Comparative range of the temperatures of the air of the Rhône and the Saône at Lyon* (four years of observations by M. **Fournet**).

SCALES. $5^{mm}$ per two months for the abscissæ, and $1^{mm}$ for 2° for the ordinates.

AA. Curve of the air.
RR. „ Rhône.
SS. „ Saône.

### FIGURE 15 (*vide* p. 140).

*Distribution of the quantity of rain in the four seasons in different countries of Europe.*

SCALES. $15^{mm}$ for the entire year, set off on the axis of the abscissæ, and $3^{mm}$ for eight units of rain fallen (the annual quantity being 100) set off on the ordinates.

To prevent the interlacing of the curves, they have been separated parallel to themselves: we must, therefore, refer to the figure only for the differences between the ordinates; and not for the absolute lengths of the latter.

W. Winter.—S. Spring.—Sm. Summer.—A. Autumn.

*a a.* Curve of Western England.
*a′ a′.* „ the interior of England.
*f f.* „ Western France.
*f′ f′.* „ Eastern France.
*a″ a″.* „ Germany.
*p p.* „ Petersburg.

### FIGURE 16 (*vide* p. 157).

*Comparative range of the quantities of rain that fall, and of the corresponding monthly temperatures in India, at Anjarakandy* (fig. 16), *at Madras* (fig. 16 *bis*), *and at Calcutta* (fig. 16 *ter*).

SCALES. $2^{mm}$ per month for the abscissæ; $\frac{1}{40}$ of the natural size for the heights of rain set off on the ordinates; $\frac{1}{4}$ of a millimetre per tenth of a degree set off on the ordinates, always deducting 25° for Anjarakandy, 24° for Madras, and 18° for Calcutta.

*t.* Curve of temperature.
*r.* „

To the summits of the rain curves on the three figures, depressions in the curves of temperature nearly correspond, conformably to the conclusions of the author (pp. 156, 158).

### FIGURE 17 (*vide* p. 159).

*Law of the variations of temperature during the four seasons, according to the different winds, at Paris.*

SCALES. $1^{mm}$ per degree, set off from the centre of the figure on the direction of the corresponding wind.

A. Curve of the mean of the year.
*a.* „ „ Autumn.
*s.* „ „ Spring.

This *thermometric card of winds* has been constructed according to the numbers given by M. **Mahlmann** in his translation of a work by M. **Forbes**, entitled "*Abriss einer geschichte der neueren Fortschritte der Meteorologie*" (Berlin, 1836).

Fig. 31 *ter*, is an exact copy taken from this work, of the manner in which the graphical representation of a card of winds of this kind was conceived before our time.

It is useless to point out the advantages of the mode of representation to which we have been led by the consideration of *curves of equal element.*

### FIGURE 18 (*vide* p. 162).

*Law of the hourly observations of temperature above and below the mean, due to the influence of the different winds at Halle.*

SCALES. $3^{mm}$ per hour, set off on the abscissæ, and $9^{mm}$ for each of the principal points of the wind, set off on the ordinates.

The indices of the curves of equal variation are centigrade degrees.

The inclination lines perpendicular to the hourly right lines determine the direction of the winds by which the relative *maximum* and *minimum* of each day takes place, and the inclination lines perpendicular to the former shew the hours of the day to which the relative *maximum* and *minimum* for each wind correspond.

The irregularities of the curves of this topographical plan indicate that they have been deduced from an insufficient number of observations.

### FIGURE 19 (*vide* p. 211).

*Law of the variation in the height to which we must ascend, in order to have a fall of* 1° *of the thermometer, at the different hours of the day.*

SCALES. $1^{mm}$ per hour, set off on the abscissæ, and $1^{mm}$ for four metres of height set off on the ordinates, from which 120 metres must be previously deducted.

C. Curve of the Col du Géant.
R. „ Rigi.

With regard to the irregularities of the curves, the same observation as in the preceding figure.

### FIGURE 20 (*vide* p. 212).

*Law of the hourly variation of temperature on the same day, at different heights* (44 days, end of July and August).

SCALES. $3^{mm}$ per hour, set off on the abscissæ, and $9^{mm}$ for eight centigrade degrees on the ordinates.

F. Curve of the Faulhorn.
P. „ of Paris.
G. „ of Geneva.
Z. „ of Zurich.
B. „ of Berne.
L. „ of Lucerne.
M. „ of Milan.

The ordinates of these curves being set off, starting from the different right lines, parallel to the abscissæ, passing through their extremities, their undulations must be regarded as expressing only differences, and not absolute temperatures.

### FIGURE 21 (*vide* p. 213).

*Law of the variation of the difference of level, corresponding to a fall of* 1°, *according to the different months of the year.*

Scales. $1^{mm}$ per hour, set off on the abscissæ, and $1^{mm}$ per four metres of height, set off on the ordinates, from which 140 metres is always deducted.

G. Curve of Geneva and St. Bernard.
Gr. „ Southern Germany and Northern Italy.

The irregularities of the second curve, although less marked than those of the former, indicate that the observations are not yet sufficiently numerous.

### FIGURE 22 (*vide* p. 248).

*Law of the diurnal barometric variation in different places.*

Scales. $5^{mm}$ per four hours, set off on the abscissæ, and one centimetre for $4^{mm}$ of barometric height, set off on the ordinates.

O. Curve of the great Ocean.
C*m*. „ Cumana.
G. „ Guyana.
C*l*. „ Calcutta.
P*d*. „ Padua.
H. „ Halle.
A. „ Abo.
P*t*. „ Petersburg.

In order to prevent the interlacing of these curves, the axis of the abscissæ has been moved parallel to itself for those which might have been confounded with each other.

### FIGURE 23 (*vide* p. 250).

*Law of the variation of the tropical hours of the barometric height at Halle* (ten years of observation).

SCALES. $5^{mm}$ per two months, set off on the abscissæ, and for four hours, measured on the ordinates.

*m*, *m*. Curves of the two diurnal *minima*.
M, M. „ „ *maxima*.

### FIGURE 24 (*vide* p. 252).

*Variation of the amplitude of the mean diurnal oscillation of the barometer, according to the different months of the year* (ten years of observation).

SCALES. $5^{mm}$ per two months, set off on the abscissæ, and ten times the natural size for the diurnal oscillation, measured on the ordinates.

M. Curve of Milan.
H. „ of Halle.

### FIGURE 25 (*vide* p. 253).

*Law of the diurnal variation in the barometric height observed simultaneously in divers places* (from July 19 to August 7, 1841).

SCALES. $3^{mm}$ per hour, set off on the axis of the abscissæ, and $3^{mm}$ per tenth of a millimetre of the variation of the barometric height, set off on the ordinates.

F. Curve of the Faulhorn.
P. „ „ Paris.
G. „ „ Geneva.
Z. „ „ Zurich.
B. „ „ Berne.
L. „ „ Lucerne.
M. „ „ Milan.

## FIGURE 26 (*vide* p. 254).

*Law of the diurnal barometric variation at different heights.*

SCALES. $5^{mm}$ per four hours, set off on the axis of the abscissæ, and five times the real size of the hourly variation, set off on the ordinates.

ZZ. First curve of Zurich.
RR. Corresponding curve of the Rigi.
Z′Z′. Second curve of Zurich.
FF. Corresponding curve of the Faulhorn.

In this figure, we must only consider the undulations of each curve, and not, in any degree, its absolute position in relation to the axis of the abscissæ.

## FIGURE 27 (*vide* p. 261).

*Law of the amplitude of the diurnal barometric oscillation according to the latitude.*

SCALES. $1^{mm}$ per 2° of latitude, set off on the axis of the abscissæ, and twenty times the real size of the oscillation, set off on the ordinates.

## FIGURE 28 (*vide* p. 264).

*Law of the corresponding inverse oscillations of the barometer and thermometer.*

SCALES. Half the natural size for the barometric oscillations, set off on the axis of the abscissæ (the positive on the right, the negative on the left, of zero), and $2^{mm}$ per degree, set off on the ordinates (the positive degrees above, the negative below, the axis of the abscissæ).

BBB. Line of Bagdad.
OOO. " Ofen or Buda.
CCC. " Cambridge.
EEE. " Eyafiord.

For each of the three latter curves, the axis of the abscissæ is drawn back parallel to itself, and passes by the letter at the middle of the curve.

## FIGURE 29 (*vide* p. 271).

*Variation of the diurnal pressure of dry air at Apenrade, according to the seasons.*

SCALES. $5^{mm}$ per four hours, set off on the axis of the abscissæ, twice and a half of the excess of the real barometric height over $740^{mm}$.

S. Curve of Spring.
Sm. „ Summer.
A. „ Autumn.
W. „ Winter.
A. „ The entire year.

## FIGURE 30 (*vide* p. 281).

*Mean monthly barometric height at different latitudes.*

SCALES. $5^{mm}$ per two months, set off on the axis of the abscissæ, and ten times the natural size for the differences of the ordinates.

1 Curve of the Havannah.
2 „ Calcutta.
3 „ Benares.
4 „ Macao.
5 „ Cairo.
6 „ Paris.
7 „ Strasburg.
8 „ Halle.
9 „ Berlin.
10 „ Petersburg.

We must only consider the oscillations of these curves, and not, in any degree, their absolute position in respect to the axis of the abscissæ, which has been moved back several times parallel to itself.

## FIGURES 31 (*vide* p. 286).

*Law of the variation of the barometric pressure, according to the different winds, in divers places, in the mean latitudes.*

### FIGURE 31.

SCALES. $5^{mm}$ for each of the eight points of the wind, set off on the axis of the abscissæ, and five times the excess over $0^{m},75$ of the barometric height, set off on the ordinates.

| | | |
|---|---|---|
| *l.* | Curve of | London. |
| *m.* | ,, | Middleburg. |
| *h.* | ,, | Hamburg. |
| *c.* | ,, | Copenhagen. |
| *a.* | ,, | Apenrade. |
| *p.* | ,, | Paris. |
| M. | ,, | Minden. |
| C. | ,, | Carlsruhe. |

### FIGURE 31 *bis.*

SCALE of double the natural size, for the excess of the barometric height over the constant number, $0^{m},75$, an excess set off on the direction of each of the eight principal points of the wind. This figure is the *barometric card of winds, for Paris.*

| | | |
|---|---|---|
| *s.* | Curve of | Spring. |
| *sm.* | ,, | Summer. |
| *a.* | ,, | Autumn. |
| *w.* | ,, | Winter. |
| *y.* | ,, | The year. |

### FIGURE 31 *ter.*

The same card of winds, under a different, but less expressive form, adopted by M. **Mahlmann**, in the work already quoted (*vide* p. 527).

| | | |
|---|---|---|
| *w.* | Circle of | Winter. |
| *s.* | ,, | Spring. |
| *sm.* | ,, | Summer. |
| *a.* | ,, | Autumn. |
| *y.* | ,, | The year. |

It is easy to see that the law of the variation in barometric pressure in any given place, according to the winds, may be placed under a fourth form, which would be that of a topographical plan. For this purpose we have only to take as co-ordinates on the plane of projection, the intervals of the points of the wind, and those of the seasons, and to refer to them the projections of the lines of equal barometric pressure.

An indexed plane of this kind would be still more satisfactory, if the seasons were divided into months.

## FIGURE 32 (*vide* p. 290).

*Law of the variation in the hourly height of the barometer, with the different winds above and below the general mean at the same hour* (series of four years of observation).

SCALES. $5^{mm}$ per two hours, set off on the axis of the abscissæ, and for each of the eight principal points of the wind, measured on the ordinates.

The curves of equal variation of height are traced in the interior of the square. Their indices express millimetres above and below the mean; these latter with the sign —.

There are but two inclination-lines for the portion of the day comprised in the topographical plan. One, perpendicular to the line of the winds, makes known the direction of the winds that correspond to the greatest falls in the day, in regard to the hours; this direction, in the figure, varies from the south-west to the south. The other makes known the hour of the day to which the lowest height determined by each wind corresponds.

## FIGURE 33 (*vide* p. 292).

*Law of the variation of the differences of level calculated for the barometer between Halle and three other towns, during different winds* (three years of observation).

SCALES. $5^{mm}$ for each of the four principal points of the wind, set off on the abscissæ; and $1^{mm}$ for four metres of difference of level, set off on the ordinates.

B. Curve for Berlin.
P. „ Paris.
Z. „ Zurich.

## FIGURE 34 (*vide* p. 308).

*Variation in the height of the barometer at Berlin, during rain, according to the winds.*

SCALES. $5^{mm}$ for each of the four principal points of the wind, set off in the abscissæ, and natural sine for the heights measured on the ordinates, constantly deducting $0{,}740^{m}$.

### FIGURE 35 (*vide* p. 311).

*Variation of the barometer at Stockholm, above and below the mean, at the approach of rain, during different winds.*

Scales. $5^{mm}$ for each of the four principal points of the wind, set off on the abscissæ, and five times the natural size for the variation of barometric pressure, measured on the ordinates.

*b.* Curve of the day before rain.
*r.* „ „ of rain.

### FIGURE 36 (*vide* p. 315).

*Variation of temperature between Halle and the Brocken, for different winds, at a mean, and the days of rain.*

Scales. $5^{mm}$ for each of the four principal points of the wind, set off on the abscissæ; $1^{mm}$ per degree for the differences of temperature, set off on the ordinates.

*m.* Curve of the general mean.
*r.* „ days of rain.

### FIGURE 37 (*vide* p. 317).

*Simultaneous variations in the height of the barometer and thermometer, during the tempest of January* 14 *and* 15, 1827, *at Halle.*

Scales. $3^{mm}$ per four hours, set off on the axis of the abscissæ; $3^{mm}$ per $2^{mm}$ of height above $0^{m},720$, set off on the ordinates of the curve B of the barometer; and $15^{mm}$ per four degrees of temperature, set off on the ordinates of the curve T of the thermometer.

### FIGURE 38 (*vide* p. 343).

*Variation in the number of negative rains, with the direction of the wind.*

Scales. $7\frac{1}{2}^{mm}$ for each of the four principal points of the wind, set off on the abscissæ; $4\frac{3}{4}^{mm}$ for 100 falls of rain, set off on the ordinates.

*s.* Curve, according to **Schubler.**
*h.* „ „ **Hemmer.**

The dotted line is drawn at the distance of 100 from the axis of the abscissæ. The position of the curves, in respect to this line, shews the relation of the number of negative to the number of positive rains.

## FIGURE 39 (*vide* p. 359).

*Relative number of storms, according to the seasons, in different countries.*

SCALES. $15^{mm}$ per year, set off on the axis of the abscissæ; $15^{mm}$ per 40 storms, set off on the ordinates; the number of storms that have occurred during the whole year being 100.

W. Winter; S. Spring; Sm. Summer; A. Autumn.

*eee.* Curve of West Europe.
*sss.* „ Switzerland.
*ggg.* „ Germany.
*e'e'e'* „ The interior of Europe.

The axis of the abscissæ has been successively raised parallel to itself, for each of these four curves.

## FIGURE 40 (*vide* p. 360).

*Distribution of storms, according to the seasons, in different points of Scandinavia.*

SCALES. $5^{mm}$ per month, set off on the axis of the abscissæ; $10^{mm}$ per unit of the relative number of storms; the total annual number being supposed at 100.

*bbb.* Curve of Bergen.
*sss.* „ Sœndmœr.
*s's's'* „ Spydberg.
*s''s''s''* „ Stockholm.
*s'''s'''s'''* „ Skara.

## FIGURE 41 (*vide* p. 378).

*Number of hail-showers per hour, according to the season.*

SCALES. $5^{mm}$ per two hours for the abscissæ, and $1^{mm}$ per fall of hail, set off on the ordinates.

The axis of the abscissæ has been drawn back parallel to itself for the construction of each of the curves.

| | | |
|---|---|---|
| SSS. | Curve of | Spring. |
| Sm. Sm. Sm. | „ | Summer. |
| AAA. | „ | Autumn. |
| WWW. | „ | Winter. |

## FIGURE 42 (*vide* p. 379).

*Distribution of hail-showers, in the four seasons, in different countries.*

Scales. $5^{mm}$ per season, set off on the axis of the abscissæ; $1^{mm}$ per fall of hail, set off on the ordinates; the total number of showers in the year being 100.

| | | |
|---|---|---|
| EEE. | Curve of | England. |
| FFF. | „ | France. |
| GGG. | „ | Germany. |
| RRR. | „ | Russia. |

# APPENDIX, No. II.

## NOTES BY CHARLES V. WALKER.

### *Preliminary Note on Decimal Notation.*

The complex and unphilosophical system of weights and measures which has been handed down to us from our fathers is a sore hinderance in all numerical operations. Not only must the memory be burdened with an heterogeneous mass of ratios, but much time must be consumed in the actual reduction of values by means of these inconstant co-efficients. It is to be hoped that the time will come when these hinderances to the advance of knowledge shall be banished from our land, and when we shall possess, as do our continental neighbours, a decimal system of notation. In the meantime, we can scarcely help continuing to think in terms familiar to us, and using such ratios as circumstances have presented to us. In the present volume, the metrical and decimal measurements are retained; but, in order that the English reader may be enabled to compare these dimensions with his own standard, I have given a table, p. 541, containing the values of such measurements as present themselves in these pages.

THE METRE.—The unity of linear measurements, and the base also of weight, is the *metre*. It is the ten-millionth part of the quarter of the meridian of the earth. The original standard, made of platinum, was deposited in the Archives of France on the 4th of Messidor, in the year Seven; and, when it is at the temperature of freezing, it gives the legal length of the metre. Its true value in English inches is 39,37079. Taking this name as unity, the notation is carried on by a certain set of prefixes to indicate tens, hundreds, &c. of this unit, and another certain set for tenths, hundredths, &c. as shewn in the following table:—

| | | metres. | | | |
|---|---|---|---|---|---|
| *Myria-metre* | = | 10000 | = | 6,2138 | miles. |
| *Kilo-metre* | = | 1000 | = | 0,6213 | ,, |
| Hecto-metre | = | 100 | = | 109,3638 | yards. |
| Deca-metre | = | 10 | = | 10,9363 | ,, |
| *Metre* | = | 1 | = | 1,0936 | ,, |
| *Deci-metre* | = | 0,1 | = | 3,9371 | inches. |
| Centi-metre | = | 0,01 | = | 0,3937 | ,, |
| *Milli-metre* | = | 0,001 | = | 0,0393 | ,, |

In the right-hand column I have given the values, not in one name, but in the terms of our standard, which would be employed in parallel cases. Of these measurements, two are of very constant occurrence throughout the volume, the *metre* and the *millimetre*. Three others, the *myriametre*, *kilometre*, and *decimetre*, occur occasionally; the others are rarely employed here. For greater convenience of reference these five terms are abstracted, and the values of their respective digits are given in the table, p. 541. This plan of presenting the value of each digit will be found very convenient for ready reference.

The *metre* is constantly applied to such dimensions as we should express in yards, or occasionally feet, as, for instance, the heights of mountains, short distances, &c. Its approximate value is one yard and one-twelfth; so that any height expressed in metres may be roughly converted into yards, by adding to it one-twelfth. For correct reductions the digital table is thus used:—

Any number of metres being given, to convert them into feet the value of the *units-digit* is taken from the table; beneath this is placed (one space more to the left) the value of the *tens-digit*; beneath this and one more to the left, the *hundreds-digit*, and so on; if there are decimals, the value of the *tenths-digit* is placed under that of the *units*, but one space to the right; for example:—

Height of the Faulhorn = 2672 metres.

metres. feet.
2 = 6,5617
70 = 229,662
600 = 1968,53
2000 = 6561,7

8766,4537 feet.

Column of water equalling the mercurial column = 10,2 metres.

metres. feet.
0, = 0,
0,2 = ,65617
10,0 = 32,808

33,46417 feet.

These results will not come out so accurate by ordinary calculation, unless the work is increased by the use of another decimal figure.

The *millimetre* is chiefly employed in reference to the height of the barometer; the general method of conversion, and general values, will be given in Note *h*; see also the second column of the table. Accurate results may be obtained from the accompanying table by the method which has just been given for metres.

The *kilometre* and *myriametre* are employed for long distances, on which account their value is given in English miles.

Several other terms of dimension occur in the course of the volume; these are collated at the top of the second column of the table, together with their values, in the most convenient terms.

*Gramme.*—The unity of weight is the *gramme*; it is the weight in vacuo of a cubic centimetre (,06102 cubic inches) of distilled water, at the temperature of 4° cent. (39,2 F). Prefixes are employed with the gramme, similar to those used for measures. I have given in the table digital tables of the terms chiefly employed in this volume; namely, *decigrammes*, *grammes*, and *kilogrammes*.

## DIGITAL TABLE OF FRENCH MEASURES, WITH ENGLISH VALUES ATTACHED.

| | | | |
|---|---|---|---|
| Millimetres. | 1 | = | ,0393 inches. |
| | 2 | = | ,0787 ,, |
| | 3 | = | ,1181 ,, |
| | 4 | = | ,1574 ,, |
| | 5 | = | ,1968 ,, |
| | 6 | = | ,2362 ,, |
| | 7 | = | ,2755 ,, |
| | 8 | = | ,3149 ,, |
| | 9 | = | ,3543 ,, |
| Decimetres. | 1 | = | 3,937 inches. |
| | 3 | = | 7,874 ,, |
| | 3 | = | 11,811 ,, |
| | 4 | = | 15,748 ,, |
| | 5 | = | 19,687 ,, |
| | 6 | = | 23,622 ,, |
| | 7 | = | 27,559 ,, |
| | 8 | = | 31,496 ,, |
| | 9 | = | 35,433 ,, |
| Metres. | 1 | = | 3,2808 feet. |
| | 2 | = | 6,5617 ,, |
| | 3 | = | 9,8426 ,, |
| | 4 | = | 13,1235 ,, |
| | 5 | = | 16,4044 ,, |
| | 6 | = | 19,6853 ,, |
| | 7 | = | 22,9662 ,, |
| | 8 | = | 26,2471 ,, |
| | 9 | = | 29,5280 ,, |
| Kilometres. | 1 | = | ,6213 miles. |
| | 2 | = | 1,2427 ,, |
| | 3 | = | 1,8641 ,, |
| | 4 | = | 2,4855 ,, |
| | 5 | = | 3,1069 ,, |
| | 6 | = | 3,7283 ,, |
| | 7 | = | 4,3497 ,, |
| | 8 | = | 4,9710 ,, |
| | 9 | = | 5,5924 ,, |
| Myriametres. | 1 | = | 6,2138 miles. |
| | 2 | = | 12,4277 ,, |
| | 3 | = | 18,6415 ,, |
| | 4 | = | 24,8554 ,, |
| | 5 | = | 31,0693 ,, |
| | 6 | = | 37,2831 ,, |
| | 7 | = | 43,4970 ,, |
| | 8 | = | 49,7108 ,, |
| | 9 | = | 55,9247 ,, |

Square metre = 1,196 sq. yds.
Square centimetre = ,155 sq. inches.
Hectare = 2,4711 acres.
Cubic metre or stere = 35,317 cub. feet.
Cubic decimetre = 61,028 cub. in.
Cubic centimetre = ,06102 ,,
Cubic millimetre = ,00006 ,,
30 in. = 762$^{mm}$
1 ,, = 25,4$^{mm}$
1$^{mm}$ = $\frac{1}{25}$ in. nearly.

---

| | | | |
|---|---|---|---|
| Decigrammes. | 1 | = | 1,5438 grs. troy. |
| | 2 | = | 3,0876 ,, |
| | 3 | = | 4,6314 ,, |
| | 4 | = | 6,1752 ,, |
| | 5 | = | 7,7190 ,, |
| | 6 | = | 9,2628 ,, |
| | 7 | = | 10,8066 ,, |
| | 8 | = | 12,3054 ,, |
| | 9 | = | 13,8942 ,, |
| Grammes. | 1 | = | 15,438 grs. troy. |
| | 2 | = | 30,876 ,, |
| | 3 | = | 46,314 ,, |
| | 4 | = | 61,752 ,, |
| | 5 | = | 77,190 ,, |
| | 6 | = | 92,628 ,, |
| | 7 | = | 108,066 ,, |
| | 8 | = | 123,504 ,, |
| | 9 | = | 138,942 ,, |
| Kilogrammes. | 1 | = | 2,2055 lbs. avoirdupois. |
| | 2 | = | 4,4110 ,, |
| | 3 | = | 6,6165 ,, |
| | 4 | = | 8,8220 ,, |
| | 5 | = | 11,0275 ,, |
| | 6 | = | 13,2330 ,, |
| | 7 | = | 15,4385 ,, |
| | 8 | = | 17,6440 ,, |
| | 9 | = | 19,8495 ,, |

### NOTE *a*. (*vide* p. 7.)

To have converted the centigrade degrees of this treatise into those of the scale to which the English reader is more accustomed, to wit, FAHRENHEIT'S, would not only have detracted greatly from the spirit of the author, but would have seriously interfered with M. LALANNE'S valuable graphic delineations, all of which are constructed for the centesimal scale; such a conversion would have involved the re-construction of the several delineations; and the reader would thus have been deprived of the authentic curves as they have been accurately constructed by the talented French mathematician. Therefore, as temperatures will be set before the reader in terms to which he is not habitually familiar, it may not be amiss to give him as much facility as possible for the ready interpretation of these expressions.

The height of the thermometer will, as we have said, always be expressed in centigrade degrees. In addition to what is to be gathered from the text, let him remember that, as 5 centigrade equal 9 of FAHRENHEIT'S degrees, each centigrade degree is equal to 1°⅘ or 1°,8 of FAHRENHEIT'S scale; so that, whenever he finds mention made, as he will very frequently, of a rise or fall of 1° in the temperature, he can appreciate the effect on FAHRENHEIT'S scale, by regarding the change as equal to 1°,8.

If the converse case is taken, and he desires to compare, as possibly he may, the effect of a change of 1° F., with the results contained in any of the tables in this treatise, he will have the following value: 9° F. = 5° C.; and, therefore, 1° F. = 0°,55 centigrade.

### NOTE *b*. (*vide* p. 14.)

The tables contained in pp. 15 to 18 are expressed in centigrade degrees, each one of which, as was explained in the previous note, is equal to 1°,8 of FAHRENHEIT'S scale; but, as the zero of the centigrade (which corresponds to the freezing point) is numbered 32° on FAHRENHEIT'S scale, it is obvious that, after every conversion from the table into FAHRENHEIT'S scale, 32° must be added. As illustrations from the table before us, pp. 15, 16, take October at eleven o'clock, when the temperature is 8°,00 C.

$$8^\circ \times 1{,}8 = 14{,}4 + 32 = 46^\circ{,}4 \text{ F.}$$

September, at the 23d hour:—

$$17^\circ \times 1{,}8 = 30{,}6 + 32 = 62^\circ{,}6 \text{ F.}$$

e It is very desirable to be able readily to affect approximate conversions, without recourse to any thing further than mental calculation; fortunately, a very simple process presents itself. It consists merely in doubling the tabular number, and deducting one-tenth of the product; of course, adding 32 as usual; if the whole of the operation is retained, the result is accurate; but, when the decimal figures are omitted, an approximate value of much general use is obtained. For example, in the cases given above:—

$$8 \times 2 = 16 - 1{,}6 = 14{,}4 + 32 = 46{,}4$$
$$17 \times 2 = 34 - 3{,}4 = 30{,}6 + 32 = 62{,}6$$

To take other cases; December, at the 21st hour:—

$$1{,}99 \times 2 = 3{,}98 - {,}398 = 3{,}582 + 32 = 35{,}582$$

Or, for a rough approximation:—

$$1{,}9 \times 2 = 3{,}9 - {,}39 = 3{,}51 + 32 = 35{,}51$$

A few more approximations, followed by the real values, will further illustrate the operation:—

April, 10h. $8{,}9 \times 2 = 17{,}8 - 1{,}78 = 16{,}02 + 32 = 48{,}02$
real value $= 16{,}074 + 32 = 48{,}074$

June, 15h. $10{,}79 \times 2 = 21{,}6 - 21{,}6 = 19{,}44 + 32 = 51{,}44$
real value $= 19{,}422 + 32 = 51{,}422$

Jan., 8h. $-2{,}05 \times 2 = -4{,}1 - {,}41 = -3{,}69 + 32 = 28{,}31$
real value $= -3{,}69 + 32 = 28{,}31$

The above rule is merely given for the convenience of the reader; to enable him, as he reads, to convert in a moment one value into the other some: such device is called for, because, when we have been long accustomed to think, as it were, in a beaten track, it is somewhat a difficult task to remodel our confirmed habit. As the converse case does not here come into requisition, it may be passed over.

## NOTE c. (*vide* p. 61.)

The distinction given in the text between *gases* and *vapours* is true under ordinary circumstances: but *gases* do not always remain in the gaseous state; for, when subjected to great pressure, many of them have been condensed into a liquid form. For these discoveries, we are indebted to the skill and perseverance of FARADAY. His mode of manipulation is thus described in brief by Mr. BRANDE.*

"Mr. FARADAY condensed the gases by exposing them to the pressure of their own atmospheres. He put the materials for producing them into a strong glass tube, a little bent in the middle and hermetically sealed. When necessary, heat was applied; and, when the pressure within became sufficient, the liquid made its appearance at the empty end of the tube, which was artificially cooled to assist in the condensation. In these experiments much danger is incurred, from the bursting of the tubes; so that the operator should protect his face by a mask, and his hands by thick gloves. He succeeded in liquifying the following gases, which, it will be seen, require various degrees of pressure for the purpose:—

---

* *Vide* BRANDE's *Manual of Chemistry*, p. 186.

| | Pressure in atmospheres. | | Pressure in atmospheres. |
|---|---|---|---|
| Sulphurous acid | 2 at 45°F. | Sulphuretted hydrogen | 17 at 50° F. |
| Chlorine | 4 ,, 60 | Carbonic acid | 36 ,, 32 |
| Cyanogen | 4 ,, 60 | Muriatic acid | 40 ,, 50 |
| Ammonia | 6,5 ,, 50 | Nitrous acid | 50 ,, 45 |

*Carbonic Acid Gas.*—Of these gases there is one, carbonic acid, with which we have become familiar in a *solid* form. The condition for its assuming this form presents the most forcible illustration we have of a great law in nature, which plays a most important part in the domain of meteorology, namely, the absorption of heat during evaporation, and the consequent production of cold. Carbonic acid, in the gaseous state, is a colourless, aëriform fluid, perfectly unrespirable, of a specific gravity represented by 1,52, air being 1. It is a compound of carbon and oxygen, and is produced abundantly in all cases of combustion; it is also exhaled from the lungs. Porter, ale, champagne, and many mineral waters, derive their briskness from the presence of this gas, which is grateful to the digestive organs, though deleterious to the lungs. It exists in small quantities in the atmosphere; less than ,01 per cent. It is artificially procured by acting on marble with dilute muriatic acid; or, on a large scale, by acting on chalk with dilute sulphuric acid.

*Liquid Carbonic Acid.*—After Faraday's researches had exhibited carbonic acid in this new form, M. Thilorier devised apparatus for producing it in large quantities, and in safety; Mr. Addams, of Kensington, has greatly improved upon these instruments; and he now manufactures it on a large scale, and even as an article of commerce; for he tells me that he has actually sent it in the solid form to America. We are not called upon in this Treatise to enter into the details of the process:—Let the reader imagine a strong iron cylinder, four feet long and two inches internal diameter, of sufficient strength to resist 4000lbs. on the square inch. Bicarbonate of soda, water, and sulphuric acid, are placed in this cylinder; and, when all the valves are secured, it is inverted so as to mix the ingredients. The generation of the gas immediately commences; and, as it has no means of escape, it exerts the pressure of its own elasticity on itself, and is compressed into a liquid, the specific gravity of which is lighter than that of the solution of sulphate of soda, now contained in the vessel, so that it floats on the surface. By connecting this vessel with a receiver, of a similar character as to strength, the liquid carbonic acid is distilled off spontaneously; which process is accelerated by a mechanical contrivance introduced by Mr. Addams.

*Solid Carbonic Acid.*—When we reflect that the liquid acid is held down by a pressure of not less than thirty-six atmospheres, we can readily imagine the force with which it would escape, when the orifice is open, and the rapidity with which it would expand. Indeed, so great and so rapid is its change of form, that, while one part passes into the normal gaseous state, another part is actually frozen, on account of the immense quantity of heat abstracted during the violent evaporation. By a little contrivance this frozen portion is retained in a *draw-out box;* it resembles snow in appearance; when handled, it does not feel very cold, although actually 148° below the zero of Fahrenheit: nor does it under these circumstances freeze mercury. The cause of this anomaly is the extreme difficulty of bringing foreign bodies into contact with the acid; a film of its own vapour, which is entirely void of conducting power, and has very little capacity for heat, intervenes. But when a little ether is added, contact is effected, and the most intense cold is developed. Mr. ADDAMS froze ten pounds of mercury in less than eight minutes: he also kept a large lump of the solid carbonic acid in a red hot crucible for one minute, and then froze with it a pound of mercury. These phenomena are an extreme case of the effects of evaporation, of which we shall see the various phases in the course of this volume.

## Note *d.* (*vide* p. 78.)

Prof. DANIELL's hygrometer consists of a glass tube bent twice at right angles; it has a thin glass bulb at each end; one of the bulbs, B, contains ether, and also the bulb of a small and very delicate thermometer included in one arm of the instrument. As all air is excluded from the tube, its entire space is filled with the vapour of ether. The other bulb, A, is tightly covered with a piece of fine muslin. The method of using the instrument is to let a few drops of good ether fall upon the muslin of the bulb A; the quick evaporation of the ether cools the bulb, and the cold thus produced condenses the ethereal vapour contained in the bulb: but the place of the condensed vapour is supplied by a fresh portion arising from the ether inclosed in the bulb B, and the temperature of this latter bulb B is reduced by the act of evaporation; the included thermometer indicates the amount of this reduction. Now, as the ether continues evaporating from the muslin of the bulb A, the condensation within A, and the evaporation within B, with the consequent production of cold, goes on, so that the temperature of B continues falling; and, like any other cold body, it has a tendency to increase the deposition on its surface of any moisture which may be contained in the air; the time, or rather the temperature, at which this deposition will occur, entirely depends on the hygrometric state of the atmosphere.

"In very humid atmospheres the thermometer will scarcely have fallen a degree before a ring of moisture is evident on B, coinciding with the surface of the included ether, and being the point of lowest temperature: in dry atmospheres, on the other hand, it will be necessary to reduce the temperature of the included thermometer by the continuous evaporation of ether from the covered bulb, many degrees, before the ring of dew is visible. Now, the temperature at which this ring of dew is deposited, or the *dew-point*, may be accurately read off upon the interior thermometer, by observing the degree at which it stands *at the moment of the first appearance of the ring of dew;* and this observation may be corrected or verified by again observing the temperature or degree at which *the ring of dew vanishes:* these two observations seldom differ more than a degree or two, and the mean may be assumed as correct; for the errors, if any, must lie in opposite directions. There is a second or external thermometer attached to this instrument, which shews the temperature of the air at the time of making the observation; and the difference between the two thermometers at that time gives the exact temperature required for the deposition of the aërial moisture, or is the dew-point;

the extent of this difference is as the dryness of the air, and may thus be used as an hygrometric term. On one day, for instance, the external thermometer being 60°, the internal fell 48°, before the ring of dew appeared; on another day, the external thermometer stood at 66°, and the internal had only fallen to 64°, when the dew-ring appeared; here, therefore, the degree of dryness might be called 12° in the former, and 2° in the latter case. It is obvious, then, in regard to this instrument, that it furnishes a very ready and exact method for the determination of *the dew-point*.

"By means of the dew-point accurately ascertained," Mr. DANIELL observes, "many points of the utmost interest to chemical and meteorological science may be determined. By mere inspection of tables properly constructed, we can at once determine the elasticity and density of the aqueous vapour,—its weight in a cubic foot of the air,—the degree of dryness, either upon the thermometric or the hygrometric scale, and the rate of evaporation; when the air is saturated, the precipitation is instantaneous, *i. e.* the dew-point coincides with the temperature of the air. In this country, the degree of dryness measured in thermometric degrees seldom reaches 30°; that is to say, the dew-point is seldom 30° below the temperature of the air; but in the Deccan, with a temperature of 90°, the dew-point has been seen as low as 29°, making the degree of dryness 61°.

"The more accurate mode, however, of expressing the moisture of the air from an observation of the temperature and dew-point, is by the quotient of the division of the elasticity of vapour at the real atmospheric pressure, by the elasticity at the temperature of the dew-point; for, calling the term of saturation 1000, as the elasticity of vapour at the temperature of the air is to the elasticity of vapour at the temperature of the dew-point, so is the term of saturation to the observed degree of moisture. Thus, with regard to the observation in the Deccan,

$$1{,}430 : 0{,}194 :: 1000 : 135.$$

"The fourth term is the degree of moisture, or the hygrometric scale."*

## NOTE *e*. (*vide* p. 10.)

A simple and very effectual method of preparing a thin film that will endure for several hours, and thus give ample time for studying the order and extent of the several coloured rings or belts is this:—A four or six-ounce vial is one-third filled with rain or distilled water, and into it is placed a piece of yellow soap, not larger than a pea. The contents of the vial are now brought to the boiling point, or nearly so; and while, by this means, all the atmospheric air is expelled from within, the vial is closed and removed from the source of heat; and, when cold, is ready for use. The mode of using it is to give it a short horizontal shake (the exact method of which will be learned from a few attempts), so as to form a film across the vial; if cleverly shaken, a single film may be obtained. Such a film is rarely quite parallel to the horizon, it dips slightly: so that the water slowly flows to the lower end; and, after a minute or more, coloured bands

---

* *Vide* BRANDE's *Manual*, p. 449. Also DANIELL's *Essays*.

make their appearance at the upper edge: these travel gently onward, and are followed by others: the earlier belts are narrow, the later are much wider. The whole film is soon occupied by the coloured belts; and in due course they all pass onward, and successively disappear at the lower edge of the disc. The respective colours pass into each other through the intermediate tints. After the coloured belts, there arrives a broad belt of white, which is succeeded by a black belt, that terminates the phenomena; but the transition from the white to black is sudden, and is distinctly defined by a straight line. Words are inadequate to express the beauty of these tints when viewed by reflected light, or looked *at*; nor is language able to enumerate the various hues. When viewed by transmitted light, or looked *through* (and this requires a little management), the complementary colours are seen. I have had a film of this kind in existence for ten or a dozen hours; at the end of which period, all the coloured belts and the white had passed away, and nothing remained but a black disc, which, by transmitted light, was white.

### NOTE *f*. (*vide* p. 149.)

The following description of the actinometer is extracted from the Instructions published by the Royal Society:—

"This instrument consists of a large hollow cylinder of glass soldered at one end to a thermometer-tube, terminated at the upper end by a ball drawn out to a point and broken off, so as to leave the end open. The other end of the cylinder is closed by a silver, or silver-plated cap, cemented on it, and furnished with a screw, also of silver, passing through a collar of waxed leather, which is pressed into forcible contact with its thread, by a tightening screw of large diameter enclosing it, and working into the silver cap, and driven home by the aid of a strong steel key or wrench, which accompanies the instrument.

"The cylinder is filled with a deep blue liquid (ammonio-sulphate of copper), which ought to have been prepared some months beforehand, as it deposits a sediment when fresh, however clear or carefully filtered. This sediment, if deposited in the interior of the instrument, may be washed out with weak muriatic acid, which should itself be removed by water before refilling the instrument; and the ball at the top being purposely left full of air, and the point closed with melted wax, it becomes, in any given position of the screw, a thermometer of great delicacy, capable of being read off on a divided scale attached. The cylinder is inclosed in a chamber blackened on three sides, and on the fourth, or face, defended from currents of air by a thick glass removable at pleasure.

"The action of the screw is to diminish or increase at pleasure the capacity of the hollow of the cylinder, and thus to drive, if necessary, a portion of the liquid up into the ball, which acts as a reservoir; or, if necessary, to draw back from the reservoir such a quantity as shall just fill it, leaving no bubbles of air in the cylinder.

"*To use the instrument*, examine first, whether there be any air in the cylinder, which is easily seen by holding it level, and tilting it, when the air, if any, will be seen to run along it. If there be any, hold it upright in the left hand, and the air will ascend to the root of the thermometer-tube. Then, by alternately screwing and unscrewing the screw with the right hand, as the case may require, it will always be practicable to drive the air out of the cylinder into the ball, and suck down liquid, if any, from the ball to supply its place, till the air is entirely evacuated from the cylinder, and the latter, as well as the whole stem of the thermometer-tube, is full of the liquid in an unbroken column. Then, holding it horizontally, face upwards, slowly and cautiously unscrew the screw, till the liquid retreats to the zero of the scale.

"The upper bulb is drawn out into a fine tube, which is stopped with wax. When it is needed to empty, cleanse, and refill the instrument, liquid must first be forced up into the ball, so as to compress the air in it. On warming the end, the wax will be forced out, and the screw being then totally unscrewed and the liquor poured out, the interior of the instrument may be washed with water slightly acidulated, and the tube, ball, &c. cleansed, in the same way; after which the wax must be replaced, and the instrument refilled.

"*To make an observation with the actinometer*, the observer must station himself in the sunshine, or in some sharply terminated shadow, so that, without inconvenience, or materially altering his situation, or the exposure of the instrument in other respects, he can hold it at pleasure, either in full sun or total shadow. If placed in the sun, he must provide himself with a screen of pasteboard or tin plate, large enough to shade the whole of the lower part, or chamber of the instrument, which should be placed not less than two feet from the instrument, and should be removable in an instant of time. The best station is a room with closed doors, before an open window, or under an opening in the roof into which the sun shines freely. Draughts of air should be prevented as much as possible. If the observations be made out of doors, shelter from gusts of wind, and freedom from all penumbral shadows, as of ropes, rigging, branches, &c., should be sought. Generally, the more the observer is at his ease, with his watch and writing-table beside him, the better. He should have a watch or chronometer beating, at least, twice in a second, and provided with a second hand; also a pencil and paper ruled, according to the form subjoined, for registering the observation. Let him then grasp the instrument in his left hand, or, if he have a proper stand (which is preferable on shore or in a building),* otherwise firmly support it, so as to expose its face perpendicularly to the direct rays of the sun, as exactly as may be.

"The liquid, as soon as exposed, will mount rapidly in the stem. It should be allowed to do so for three or four minutes before the observation begins, taking care, however, not to let it mount into the bulb, by a proper use of the screw. At the same time the tube should be carefully cleared (by the same action) of all small broken portions of liquid remaining in it, which should all be drawn down into the bulb. When all is ready for observation, draw the liquid down to zero of its scale, gently and steadily; place it on its stand, with its screen before it, and proceed as follows:—

"Having previously ascertained how many times (suppose 20) the watch beats in five seconds, let the screen be withdrawn at ten

---

* "This may consist of two deal boards, eighteen inches long, connected by a hinge, and kept at any required angle, by an iron pointed at each end. The upper should have a little rabbet or moulding, fitting loosely round the actinometer, to prevent its slipping off."

seconds before a complete minute shewn by the watch, suppose at $2^h\ 14^m\ 50^s$. From $50^s$ to $55^s$, say 0, 0, 0, ... at each beat of the watch, looking meanwhile that all is right. At $55^s$ complete, count 0, 1, 2, ... up to 20 beats, or to the whole minutes, $2^h\ 15^m\ 0^s$, keeping the eye not on the watch, but on the end of the rising column of liquid. At the 20th beat read off, and register the reading. Then wait watching the column of air above the liquid, to see that no blebs of liquid are in it, or at the opening of the upper bulb, which will cause the movement of the ascending column to be performed by starts, till the minute is nearly elapsed.

"At the 50th second begin to watch the liquid rising; at $55^s$ begin to count 0, 1, 2, up to 20 beats, as before, attentively watching the rise of the liquid; and, at the 20th beat, or complete minute ($2^h\ 16^m\ 0^s$), read off, and instantly shade the instrument, or withdraw it, *just out* of the sun and penumbra. Then register the reading off, and prepare for the shade observation. All this may be done without hurry in 20 seconds, with time also to withdraw the screw if the head of the column be inconveniently high in the scale, which is often required.

"At the 20th second prepare to observe, at the 25th begin to count beats, 0, 1, 2, . . . . 20; and at the 20th beat, *i. e.* at $2^h\ 16^m\ 30^s$, read off, and enter the reading as the initial shade reading. Then wait, as before, till nearly a minute has elapsed, and at $2^h\ 17^m\ 20^s$, again prepare. At $17^m\ 25^s$ begin to count beats; at $17^m\ 30^s$ read off, and enter this *terminal* shade reading, and if needed withdraw the zero. Again wait $20^s$, in which interval there is time for the entry, &c. At $17^m\ 50^s$ remove the screen, or expose the instrument in the sun; at $55^s$ begin to count beats, and at the complete minute, $18^m\ 0^s$, read off, and so on for several alternations, *taking care to begin and end each series with a sun observation*. If the instrument be held in the hand, care should be taken not to change the inclination of its axis to the horizon between the readings, or the compressibility of the liquid by its own weight will produce a very appreciable amount of error......"

"A complete actinometer observation cannot consist of less than three sun and two shade observations intermediate; but the more there are taken the better, and in a very clear sunny day it is highly desirable to continue the alternate observations for a long time, even from sunrise to sunset, so as to deduce, by a graphical projection, the law of diurnal increase and diminution of the solar radiation, which will thus readily become apparent, provided the perfect clearness of the sky continue—an indispensable condition in these observations, the slightest cloud or haze over the sun being at once masked by a diminution of resulting radiation.

"To detect such haze or cirrus, a brown glass applied before the eye is useful; and by the help of such a glass, it may here be noticed that solar halos are very frequently to be seen when the glare of light is such as to allow nothing of the sort to be seen by the unguarded eye.

"It is, as observed, essential that the instrument be exposed a few minutes to the sun, to raise its temperature in some slight degree. If this be not done, owing to some cause not very obvious, the first triplet of observations (sun, shade, sun) will give a radiation perceptibly in defect of the truth, as will become distinctly apparent on continuing the series. But it may be as well for a beginner to commence at once reading, as soon as the instrument is exposed, and reject the first two triplets, by which he will see whether he has all his apparatus conveniently arranged, and get settled at his post...."

"The unit of solar radiation to be adopted in the ultimate reduction of the actinometric observations is the *actine*, by which is understood that intensity of solar radiation, which at a vertical incidence, and supposing it wholly absorbed, would suffice to melt one millionth part of a metre in thickness, from the surface of a sheet of ice, horizontally exposed to its action, per minute of mean solar time; but it will be well to reserve the reduction of the radiations, as expressed in parts of the scale to their values in terms of their unit, until the final discussion of the observations...."

"The actinometer is also well calculated for measuring the defalcation of heat during any considerable eclipse of the sun, and the Committee would point out this as an object worthy of attention; as many eclipses, invisible or insignificant in one locality, are great, or even total, in others. The observations should commence an hour at least before the eclipse begins, and be continued an hour beyond its termination, and the series should be uninterrupted, leaving to others to watch the phases of the eclipse. The atmospheric circumstances should be most carefully noted during the whole series."

### NOTE *g*. (*vide* p. 176.)

The longitudes throughout the book are reckoned from the observatory at Paris, which is 2° 20′ 15″ east of London. To convert them into longitude from Greenwich, add the above value to east longitude, and subtract it from west.

### NOTE *h*. (*vide* p. 239.)

The scale of English barometers being divided into inches and decimals of inches, and that of the French into millimetres, it were well to have a mental process by which we can readily obtain approximate ideas of the number of inches contained in any given quantity of millimetres. We have given, in the introductory note (p. 539), and on the table which accompanies it, the actual value in English inches of each unit of millimetres. These values may be used for conversions in the manner described in the note alluded to. But for rough estimates, we may avail ourselves of two or three approximate general relations. For instance, the standard height of the barometer, for certain comparative operations, is given as 30 inches; this corresponds to 762 millimetres. An inch of mercury corresponds to 25,4 millimetres: and, therefore, one millimetre is equal to about one-twenty-fifth of an inch.

As the height of the mercurial column is always represented by several hundred millimetres, it would involve too much error to adopt the value one-twenty-fifth of an inch, without including a means of reducing this error to a minimum. The following plan is sufficiently simple, and will answer for ordinary purposes: The height of the mercurial column being given in millimetres, find the difference between the given height and the standard height of 762 millimetres; divide this difference by twenty-five, or, which amounts to the same thing, multiply it by four, and point off two figures for decimals. Then, as the case may be, either add this difference to 30 inches, or subtract it from that standard height.

### EXAMPLES.

$766^{mm} = 762 + 4 = 30$ in. $+ ,16$ in. $= 30,16$ in.
The true value is 30,157 in.

$681^{mm} = 762 - 81 = 30$ in. $- 3,24$ in. $= 26,76$ in.
The true value is 26,81 in.

$779^{mm} = 762 + 17 = 30$ in. $+ ,68$ in. $= 30,68$ in.
The true value is 30,669 in.

These results are nearer to the true values in proportion as the differences are less; it will be found that a difference of eighty produces a result differing from the truth by about one-twenty-fifth: so that by calling 80, 79, and 160, 158, the rule may become still more accurate; as, for instance:—

$602^{mm} = 762 - 160$
Call this $762 - 158 = 30$ in. $- 6,32$ in. $= 23,68$ in.
The true value is 23,70 in.

For low barometric ranges, as occasion may require, the standard of $685^{mm}$ equal to 25 inches might be adopted.

### NOTE *i.* (*vide* p. 335.)

The electricity of the atmosphere is a branch of meteorology, which has been cultivated on no settled and systematic manner until the present time. Indeed, the observations that have been made at the Kew Observatory, a description of which it is our present purpose to give, constitute so novel a feature in the science that Mr. RONALDS, whose whole time and talents appear to be enthusiastically devoted to perfecting them, says, in the Report submitted to the British Association at the meeting at York (1844), that they must be rather regarded as experimental and educational than otherwise. As the admirable arrangements at this observatory will form a model for the guidance of others, we will give them in detail; and will print, for the sake of illustration and general instruction, the Journal for the first fortnight of the month of August. The Report of the Association read at Cork (1843), says, "The Committee has paid more immediate attention to this subject on account of its importance in connexion with the system of simultaneous magnetic and meteorological observations now making on various points of the earth's surface, in the recommendation of which, the Association has taken so prominent a part. Hitherto, electrical phenomena have been little attended to at these observatories, from the want of knowing what instruments to recommend for the purpose, and how to interpret properly their indications. This want, the Committee has every reason to believe, will shortly be supplied, and arrangements be made for recording the electrical changes of the atmosphere at the various stations, with the same regularity and accuracy as the other meteorological phenomena."

The observatory was erected by Sir WILLIAM CHAMBERS for his Majesty George III. about 1780; it is on a little promontory in the Old Deer Park, Richmond, and about 724 feet from the Thames. The nearest trees, which are at some considerable distance, are thirteen feet lower than the top of the conductor, that we shall have presently to describe.

The room at the summit of the building, formerly employed as the small equatorial apartment, is now the principal electrical observatory: it is of wood, dome-shaped, and covered with sheet-copper. Through the centre of the dome a circular aperture has been cut, into which is fitted a smooth, mahogany-varnished cylinder.

The principal conductor or collector of electricity enters the atmosphere through this aperture; it consists of a conical tube of thin copper, sixteen feet high, screwed into a strong brass tube; the copper part is without, and the brass within, the building; the height of the apex is eighty-three feet above low-water mark. An inverted copper dish or *parapluie*, with a smooth ring on its edge, is fitted by a collar, &c. upon the rod, in order that rain may not enter by the aperture of the dome.

Within the apartment is a circular pedestal table, supporting at its centre a well-annealed glass pillar, the lower end of which is hollow and trumpet-shaped; and, being ground flat, it is firmly fixed to the table by eight strong bolts, passing through it and the table. The brass part of the conductor (four feet in length) is firmly fixed to the upper end of the glass pillar. This pillar, with its conductor of twenty feet in length, has been found to resist gales that were strong enough to blow down large trees in the neighbourhood; in order to decrease the probabilities of breaking, collars of leather are interposed where practicable between the glass and the table, &c. The hollowed portion of the pillar is of prime importance for the purposes of obtaining perfect insulation: a copper cone is fitted within this cavity; a piece of leather being interposed at the apex, and beneath the cone a small night-lamp is kept constantly burning for the purpose of warming the glass rod. Now, by this arrangement, the higher, and consequently more distant parts of the glass, are not so raised in temperature as to prevent the deposition of moisture from the atmosphere, with the attendant loss of insulation; and, again, the lower, and consequently nearer parts of the rod are so highly heated as to become, in a measure, conductors; but between these there always exists some zone, in the best possible state of temperature, in reference to existing circumstances, for insuring perfect insulation; and experience has shewn that this is actually the case. On the upper end of the conductor were formerly soldered two fine platinum wires; but these are useless as collectors, beside the means now adopted. The collector is an ascending stream of heated air from a small lantern, about six inches in height, and two and a half in diameter; being a simple chamber-lamp, covered with a fitly roofed tin cylinder. It is raised by a cord, passing over a pulley at the apex of the conducting-rod, and descending within the conductor to a reel inside the brass portion a little above the table: it is trimmed every six hours.

Where the conductor is attached to the pillar is a spherical ring, which carries four arms at right angles to each other. The arms are attached to the ring by means of a strong iron screw and plug; and at their further extremities they each support a ball, fixed by means of a similar screw. A cylindrical plug slides accurately into the balls, and is furnished with a clamping-screw, which goes through a sort of washer; so that a cross-arm, passing through both the ball and the plug, can be firmly clamped in any required position, without being galled. One of the chief objects in this arrangement is to insulate the conductor and the active parts of all the electrometers by one common insulation, viz. the glass pillar; and this is accomplished by the peculiar modifications made in the several instruments that we have now to describe.

Two VOLTA's straw electrometers, of the following construction, are employed:—A brass case, exactly two English inches wide internally, is furnished with thin plate-glass at the back and front only, the former being ground to semi-transparency; behind the latter plate is an ivory scale, the upper edge of which is an arc with a radius, corresponding to that of the straws, *i. e.* two Paris inches.

The scale of the instrument, No. 1, counts single degrees; and each degree of No. 2 corresponds to 5° of No. 1. The straws are suspended by fine hooks of copper wire to the brass rod of the instrument: the rod terminates above in a ring for suspension, with a knife-edge fitted accurately to a notch in one of the cross-arms of the conductor. This rod passes through a glass tube covered with sealing-wax, and fixed into the brass cap or cover of the electrometer: the cover is not *fixed* to the instrument; but when the ring is suspended on the cross-arm, and the base of the electrometer is placed on a little pedestal provided for it beneath, the cover is lifted perhaps half an inch above the instrument, and so remains freely suspended with its straws on the insulated system itself, and thus is not dependent for insulation, as in the ordinary instrument, on the mere glass shade in which the straws would be suspended; and as the under surface of the cap or cover is insulated from the case of the instrument by varnish, the instrument can be suspended from the cross-arm, or removed without disturbing the electricity of the general system. To the pedestal, on which the base of the electroscope is placed, is attached an arm one foot long, bearing a sight-piece, capable of adjustment, for viewing the scale and straws properly.

One of HENLEY's electrometers with VOLTA's improvements is used: it is supported on the conductor by a little tube, passing through a clamping ball and plug as before, which ball is clamped at right angles to the axis of a conical arm; the zero of the scale can, therefore, be accurately adjusted to coincide with the pendulum when in its normal state; and the pendulum can be made to rise in a plane cutting the axis of the conductor toward which the instrument is turned: these are essential conditions. This instrument is seldom used in the observations until VOLTA's electrometer, No. 2, has risen above 90° in terms of No. 1, that is, above 18° of itself. But, as the uncertainty and difficulty of measuring high tensions increases in rapid ratio, owing to several causes, less confidence must be placed in the values given by this instrument; it also requires, according to VOLTA, DELUC, and others, certain corrections for all degrees below the 15th, and above the 35th.

A galvanometer by GOURGON has been added to the instruments by Professor WHEATSTONE, and promises to become the nucleus of a very valuable assemblage of new facts: it has not been successfully applied in low intensities; but with high tensions, the needles have been strongly affected. Of this instrument, Mr. RONALDS says, "The galvanometer in some improved form, would perhaps supply that great desideratum in atmospheric electricity,—a means of denoting the *dynamic* effects, which are, perhaps, co-incident, if not identical, with the property discovered by BECCARIA, and called by him 'Frequency,'—a property of great importance possibly, when considered in relation to the various opinions and theories which have been, or still are, entertained, concerning the natural agency of atmospheric electricity in vegetation, animal life, the magnetism of the earth, aurora," &c. *Frequency* is a term used in reference to the time required by the conductor to recover a charge after it has been discharged.

The *discharger* for obtaining sparks, and for the necessary security against accident, is an improvement upon LANE's electrometer. A small vertical rod, terminating in a ball, descends from one of the arms of the conductor; immediately beneath is the ball of the discharger, also placed on a short vertical rod, to which a vertical motion, by an arrangement like that of the piston-rod of a steam-engine, can be given by means of a glass lever. This rod carries an index, which exhibits, on a properly graduated scale, the distance between the balls in every position. The degrees of the scale are of course not equal; but each one indicates an exact twentieth of an inch in the length of the spark. A tolerably near approximation is observed between the lengths of sparks, as measured by this instrument, and the degrees of tension exhibited by the HENLEY's electrometer. The base of this instrument is in intimate connexion with a riband of lead, that leads away to the gutters and pipes of the building, and so into the earth: the bases of the other instruments are likewise in connexion with the same system.

A BENNETT's gold-leaf electroscope is sometimes used for discovering the length of time that has elapsed between the alterations in *kind* of electricity during rain, &c.; and *very rarely* for ascertaining whether the conductor was charged or not on other occasions.

A *distinguisher* for determining at any moment, excepting with very low tensions, the nature of the charge of the conductor, is thus constructed: A wire terminating in a ball is fixed into a brass tube, over the brass tube is placed one of very thin glass; a shorter brass tube is placed outside the tube of glass, leaving three-fourths of an inch at each end uncovered; the uncovered part is coated with sealing-wax melted on: this arrangement is, in fact, a little Leyden vial. Thus prepared, it is inserted through the cover of a jar, and furnished with two gold leaves, so short, that they will not strike against the sides of the jar at their greatest distension. The cover of the jar is varnished. This distinguisher is charged every morning with negative electricity, and never fails to retain a good charge for twenty-four hours. When used, it is taken from the shelf, where it stands ready at hand, and is held toward the conductor: if the charge is positive, the leaves of the distinguisher begin to collapse; if negative, their divergence increases. The advantage of this mode of distinguishing is, that the operation can be performed without bringing the instrument into contact with the conductor; and, consequently, without in any way altering its tension, or injuring the gold leaves, however high the charge may be.

An *electrograph* of the kind first proposed by LANDRIANI, and since by **Bennett**, **Gersdorf**, &c., but of which no particulars were published before the year 1824, has also been employed for ascertaining roughly the nightly changes of the rod. A tin-plate is carefully coated with a surface of shell lac, as free from air-bubble flaws and inequalities as possible. This is placed on a triangular frame carried round horizontally by the hour arbor of a strong time-piece. A bent lever, the fulcrum of which is below the centre of gravity, is supported by a cross-arm of the conductor, and one end rests lightly on the resinous surface while it revolves. The plate, consequently, becomes electrised in and near the line of contact to an intensity proportionate to the charge of the conductor. After the disc has revolved beneath the point for the required time it is removed from the clock, a piece of chalk is held over it, and, being rubbed by a brush, the powder is allowed to fall on the disc. On shaking off the superfluous powder, the rest adheres to the electrised part (like **Lichtenberg**'s figures), and a graphic exhibition of the electric tension is exhibited. The hours at which the various parts of this figure passed under the conducting point are carefully noted on the circumference of the disc. Negative calotypes of some of these discs have been successfully taken by Mr. **Collen**, who says, that in a single morning many positive pictures might be taken from these; so that a sort of pictorial register of atmospheric electricity, of serene weather at least, might be speedily circulated among meteorologists.

Another arrangement, which appears to be in constant operation for night registering, is the following: An insulated vertical rod, with appendages in connexion with the conducting system, is carried by the arbor of a time-piece; it supports horizontal arms. Near this instrument are three **Volta**'s electroscopes, so placed that each shall be touched by the revolving arm, and receive a charge at a determinate hour. The charge is retained till morning with a trifling loss, for which an allowance is made of so much per hour, when the divergence of the leaves is measured and the value entered in the book.

Of the other instruments of the Observatory, some have been already described in this volume; on the others we may say a few words. The *vane* carries round with it a ring on which the winds are marked; a *fixed* index points to the wind that blows: the instrument can, therefore, be read more conveniently and with greater accuracy.—**Lind**'s anemometer, mentioned in the last column but two of the table, 559, &c., is a kind of siphon-shaped tube, one arm of which is furnished with an open mouth for exposure to the wind; it is filled with water, till the liquid in each arm stands at the zero of an attached scale; and, when the mouth is exposed to the wind, the liquid rises in one arm and falls in the other. "The sum of the two is the height of a column of water, which the wind is capable of sustaining at the time; and every body that is exposed to that wind will be pressed upon by a force equivalent to the weight of a column of water, having its base equal to the surface that is opposed, and its height equal to the altitude of the column of water sustained by the wind in the wind-gauge."*—The *balance anemometer* is described by Mr. **Ronalds** as the child of necessity; for no other means were adequate to measure the force of very light breezes, which are quite as important to *electro-meteorology* as stiff breezes, and even more so. On one arm of the balance-beam is suspended a scale-pan, and on the other is erected a light deal-

---

* *Vide* Royal Society's Instructions, p. 72.

board exposing a square foot to the wind. The force of the wind acting upon this board is estimated by the weights which must be placed in the scale to retain it in its normal position. The parts not to be acted on by the wind are protected by a screen attached.

These descriptions are correct to the month of October, 1844, when the author last visited the Observatory; they are chiefly drawn from Prof. WHEATSTONE'S Report, read at the Cork meeting of the Association in 1843; and from Mr. RONALDS'S, read at the York meeting in 1844; and from the author's personal observation.

A few words are necessary in explanation of the following table, illustrative of the manner in which the observations are recorded. In the column TIME, SR means *sun-rise*; SS, *sun-set*. In Electricity, under KIND, P and N mean *positive* and *negative*. Under PERIODICAL OBSERVATIONS, to the right of the degrees, V and H respectively indicate *Volta's* and *Henley's* electrometers; the letter D, which sometimes appears, indicates the striking distance, or *length of spark*, in inches. The other columns of the table explain themselves. On DAYS OF STORM, of which several occur in the period we have selected, continuous and multiplied observations are made: these observations are printed *en masse* in the *Storm Papers* which follow the table; of which we have given that of the last day of July, and those from the beginning to the 14th of August inclusive.

# ELECTRO-METEOROLOGICAL
# OBSERVATIONS.

## ELECTRO-METEOROLOGICAL OBSERVATIONS,

| TIME. | ELECTRICITY. | | | | | | | | BAROM. PRESSURE. | TEMPERATURE. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Day and Hour. Chronometer uncorrected. | Kind. | Periodical Observations. | Morning Min. and Max. | Afternoon Min. and Max. | Frequency. | Galvanometer. | Storms. | Serene Days. | Barometer uncorrected. | Max. and Min. Therm. | Dry Therm. |
| d. h. | | ° | ° | ° | | ° | | | in. | ° | ° |
| Aug. 1, SR | P | 27,5 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 25 V | .. | .. | .. | .. | .. | .. | 29,814 | 68 | 64 |
| 15 | N | 5 V | .. | .. | .. | .. | .. | .. | 29,808 | 48 | 58,75 |
| SS | P | 27,5 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | .. | 25 V | | | | | | | | |
| 8 | P | .. | 50 V | | | | | | | | |
| 15 | N | .. | .. | 5 V | | | | | | | |
| 19 | P | .. | .. | 55 V | | | | | | | |
| Aug. 2, SR | P | 22 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 47,5 V | .. | .. | .. | .. | .. | .. | 29,974 | 67 | 62 |
| 16 | N | 10 H | .. | .. | .. | .. | .. | .. | 29,918 | 46 | 66,5 |
| SS | P | 65 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 11 | P | .. | 4 V | | | | | | | | |
| 7 | P | .. | 50 V | | | | | | | | |
| 17 | P | .. | .. | 12 V | | | | | | | |
| 13,53 | P | .. | .. | 60 H | | | | | | | |
| ,, | P | .. | .. | $\frac{7}{10}$ D | | | | | | | |
| Aug. 3, SR | P | 90 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 25 V | .. | .. | .. | .. | .. | .. | 29,544 | 69,5 | 63,5 |
| 15 | | .. | .. | .. | .. | .. | .. | .. | 29,504 | 52,5 | 62,25 |
| SS | P | 25 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 7 | P | .. | 5 V | | | | | | | | |
| 9,15 | N | .. | 70 H | | | | | | | | |
| ,, | N | .. | $\frac{8}{10}$ D | | | | | | | | |
| 19 | P | .. | .. | 17 V | | | | | | | |
| 21 | P | .. | .. | 40 V | | | | | | | |
| Aug. 4, SR | P | 7 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 20 V | .. | .. | .. | .. | .. | .. | 29,774 | 65,5 | 63,5 |
| 15 | P | 6 V | .. | .. | .. | .. | .. | .. | 29,84 | 54,5 | 70,25 |
| SS | P | 32,5 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 6 | P | . | 6 V | .. | .. | .. | .. | .. | .. | .. | .. |
| 8 | P | .. | 25 V | | | | | | | | |
| 15 | P | .. | .. | 6 V | | | | | | | |
| SS | P | .. | .. | 32,5 V | | | | | | | |

## AT THE OBSERVATORY, KEW, IN THE YEAR 1844.

| HUMIDITY. | | | RAIN & EVAPN. | | WIND. | | | MOON | GENERAL REMARKS AND OCCASIONAL OBSERVATIONS. |
|---|---|---|---|---|---|---|---|---|---|
| Wet Ther. below dry. | Dew Point below Dry. | Saussure's Hygrom. | Mean of Rain and Vapour Gauge. | | DIRECTION by Vane. | PRESSURE by Lind's Anemr. | PRESSURE by Balance Anemr. | Phases. | |
| ° | ° | ° | inches. E. | R. | | ° | grs. | | |
| .. | .. | .. | .. | .. | WSW | | | | At SR, fine and clear; at 5, fine and clear, with sunshine. From 6 to 13, fine, but cloudy, with sunshine. At 14, a shower of rain. At 15, general rain. At 16, 17, and 18, dull and cloudy. At 19, light shower of rain. At SS, fine, but cloudy. At 21 and 22, fine and starlight. |
| 3 | 20,5 | 70 | .. | .. | W | .. | 7000 | | |
| 1 | 12,5 | 86 | .. | .. | W | .. | 4000 | | |
| .. | .. | .. | 8 | .. | W | | | | |
| .. | .. | .. | .. | .. | WSW | | | | At SR, 5, 6, 7, and 8, fine and clear, with sunshine. At 9, 10, 11, and 12, fine, but cloudy with sunshine. At 13, fine, but cloudy. At 14, heavy rain. At 15, dull and cloudy. At 16 and 17, fine, but cloudy, with sunshine. At 18, SS, and 21, dull and cloudy. *Vide* Storms, Nos. 6 & 7, p. 566. |
| 3 | 14,5 | 73 | .. | .. | WNW | .. | 3000 | | |
| 3 | 14 | 63 | .. | .. | WSW | .. | 500 | | |
| .. | .. | .. | 8 | .. | SSW | | | | |
| .. | .. | .. | .. | .. | ESE | | | | At SR, dull and cloudy. At 5 and 6, general heavy rain. At 7, dull and cloudy. At 8, fine, but cloudy, with sunshine. At 9, light rain. At 12, fine, but cloudy. At 19 and SS, fine, but cloudy. At 21, heavy drops of rain. *Vide* Storms, Nos. 8 & 9, p. 567. |
| 1 | 7,5 | 85 | .. | .. | SSW | .. | 8000 | | |
| 2 | 19 | 76 | .. | .. | SSW | .. | 16000 | | |
| .. | .. | .. | 5 | .. | SSW | | | | |
| .. | .. | .. | .. | .. | W | | | | At SR and until SS fine, but cloudy with sunshine. The evening starlight. |
| 3 | 15,5 | 75 | .. | .. | WNW | 4 | 6000 | | |
| 5 | 20,5 | 63 | .. | .. | WSW | 3 | 7000 | | |
| .. | .. | .. | 23 | .. | WSW | | | | |
| .. | .. | .. | .. | .. | WSW | | | | |

## ELECTRO-METEOROLOGICAL OBSERVATIONS,

| TIME. | ELECTRICITY. | | | | | | | | BAROM. PRESSURE. | TEMPERATURE. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Day and Hour. Chronometer uncorrected. | Kind. | Periodical Observations. | Morning Min. and Max. | Afternoon Min. and Max. | Frequency. | Galvanometer. | Storms. | Serene Days. | Barometer uncorrected. | Max. and Min. Therm. | Dry Therm. |
| d. h. | | ° | ° | ° | | ° | | | in. | ° | ° |
| Aug. 5, SR | P | 27,5 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 60 V | .. | .. | .. | .. | .. | .. | 29,956 | 71,5 | 63,5 |
| 15 | P | 20 V | .. | .. | .. | .. | .. | .. | 29,856 | 47 | 67,5 |
| SS | P | 85 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| SR | P | .. | 27,5 V | | | | | | | | |
| 6 | P | .. | 75 V | | | | | | | | |
| 21 | P | .. | .. | 65 V | | | | | | | |
| SS | P | .. | .. | 85 V | .. | .. | .. | .. | .. | .. | .. |
| Aug. 6, SR | P | 4 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 20 V | .. | .. | .. | .. | .. | .. | 29,6 | 72,5 | 65 |
| 15 | P | 20 V | .. | .. | .. | .. | .. | .. | 29,63 | 57,25 | 67,5 |
| SS | P | 37,5 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| SR | P | .. | 4 V | .. | .. | .. | .. | .. | .. | .. | .. |
| 9,30 | P | .. | 55 H | | | | | | | | |
| 9,30 | P | .. | $\frac{5}{10}$ D | | | | | | | | |
| 13 | P | .. | .. | 5 V | | | | | | | |
| 16 | N | .. | .. | 5 V | | | | | | | |
| Aug. 7, SR | P | 16 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 25 V | .. | .. | .. | .. | .. | .. | 29,762 | 68 | 62,5 |
| 15 | P | 7 V | .. | .. | .. | .. | .. | .. | 29,736 | 52,25 | 62,25 |
| SS | P | 22,5 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| SR | P | 1 | 15 V | .. | .. | .. | .. | .. | .. | .. | .. |
| 11 | N | .. | 60 H | | | | | | | | |
| 11 | N | .. | $1\frac{5}{10}$ D | | | | | | | | |
| 15 | P | .. | .. | 7 V | | | | | | | |
| 12,20 | P | .. | .. | 76 H | | | | | | | |
| 12,20 | P | .. | .. | $1\frac{7}{10}$ D | | | | | | | |

AT THE OBSERVATORY, KEW, IN THE YEAR 1844—*continued.*

| HUMIDITY. | | | RAIN & EVAPN. | | WIND. | | | MOON | GENERAL REMARKS AND OCCASIONAL OBSERVATIONS. |
|---|---|---|---|---|---|---|---|---|---|
| Wet Ther. below dry. | Dew Point below Dry. | Saussure's Hygrom. | Mean of Rain and Vapour Gauge. | | DIRECTION by Vane. | PRESSURE Lind's Anemʳ. | PRESSURE by Balance Anemʳ. | Phases. | |
| ° | ° | ° | inches. E. | R. | | ° | grs. | | |
| .. | .. | .. | .. | .. | NNE | | | | At SR and 5, fine, with thin fog and sunshine. At 6, 7, 8, and 9, fine, with sunshine. At 11, 12, 13,and 14, fine, but cloudy, with sunshine. At 15, 16, 17, 18, 19, SS, 21, and 21,30′, general heavy rain. |
| 1 | 12 | 78 | .. | .. | SW | 3 | 210 | | |
| 3 | 14 | 75 | .. | .. | SSE | 2 | 4000 | | |
| .. | .. | .. | 4 | .. | E | | | | |
| .. | .. | .. | .. | 1 | | | | | |
| .. | .. | .. | .. | .. | SSW | | | | At SR and 5, dull and cloudy. At 6, light rain. At 7 fine, but cloudy. At 8, 9, 10, and 11, dull and cloudy. At 12, 13, 14, and 15, fine, but cloudy, with sunshine. At 16, a dark heavy cloud passed to eastward, fine, with sunshine. At 17, 18, and 19, fine, but cloudy, with sunshine. At SS fine, but cloudy. At 21 and 21,45′ clear and starlight.<br>*Vide* Storms, No. 10, p. 568.<br>At about 16 a heavy dark cloud passed to northward at a considerable distance from the observatory, and the conductor became negatively charged for a short time. The maximum of this charge was 5° of Henley. |
| 1,5 | 8 | 90 | .. | .. | SSW | 2 | 4000 | | |
| 3 | 14 | 72 | .. | .. | SW | 5 | 10000 | | |
| .. | .. | .. | .. | .. | SW | | | | |
| .. | .. | .. | .. | 1 | | | | | |
| .. | .. | .. | .. | .. | SW | | | | At SR., 5, and 6, fine and clear with sunshine. At 7, 8, 9, and 10, fine, but cloudy, with sunshine. At 11, beginning to rain. At 12 and 13, fine, but cloudy, with sunshine. At 14, heavy rain. At 15, 16, 17, 18, and 19, fine, but cloudy, with sunshine. At SS, fine, but cloudy. At 21 and 22, clear and starlight.<br>*Vide* Storms. No. 11, 12, 13, 14, and 15, p. 568, &c. |
| 3 | 16,5 | 74,5 | .. | .. | SW | 6 | 10000 | | |
| 1 | 11,5 | 83,5 | .. | .. | SSW | 4 | | | |
| .. | .. | .. | 13 | .. | WSW | | | | |

## ELECTRO-METEOROLOGICAL OBSERVATIONS,

| TIME. | ELECTRICITY. | | | | | | | | BAROM. PRESSURE. | TEMPERATURE. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Day and Hour. Chronometer uncorrected. | Kind. | Periodical Observations. | Morning Min. and Max. | Afternoon Min. and Max. | Frequency. | Galvanometer. | Storms. | Serene Days. | Barometer uncorrected. | Max. and Min. Therm. | Dry Therm. |
| d. h. | | ° | ° | ° | | ° | | | in. | ° | ° |
| Aug. 8, SR | P | 8,5 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 17,5 V | .. | .. | .. | .. | .. | .. | 29,712 | 67 | 61,5 |
| 16 | P | 5 V | .. | .. | .. | .. | .. | .. | 29,73 | 50,5 | 67 |
| SS | P | 19 V | .. | .. | .. | .. | .. | .. | .. | .. | . |
| SR | P | .. | 8,5 V | | | | | | | | |
| 8 | P | .. | 25 V | | | | | | | | |
| 15 | P | .. | .. | 5 V | | | | | | | |
| 13,26 | N | .. | .. | 50 H | | | | | | | |
| 13,26 | N | .. | .. | $\frac{4}{10}$ D | | | | | | | |
| Aug. 9, SR | P | 10 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 13 V | .. | .. | .. | .. | .. | .. | 29,872 | 68 | 62,5 |
| 16 | P | 10 V | .. | .. | .. | .. | .. | .. | 29,808 | 48 | 66,25 |
| SS | P | 30 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| SR | P | .. | 10 V | | | | | | | | |
| 8 | P | .. | 30 V | | | | | | | | |
| 13 | P | .. | .. | 9 V | | | | | | | |
| 21 | P | .. | .. | 50 V | .. | .. | .. | S | | | |
| Aug. 10, SR | P | 25 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 75 V | .. | .. | .. | .. | .. | .. | 29,7 | 68 | 56 |
| 15 | P | 35 V | .. | .. | .. | .. | .. | .. | 29,654 | 46,50 | 66,5 |
| SS | P | 75 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| SR | P | .. | 25 V | | | | | | | | |
| 9 | P | .. | 75 V | | | | | | | | |
| 14 | P | .. | .. | 22,5 V | | | | | | | |
| SS | P | .. | .. | 75 V | | | | | | | |
| Aug. 11, SR | P | 17 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 52,5 V | .. | .. | .. | .. | .. | .. | 29,9 | 68 | 60 |
| 15 | P | 30 V | .. | .. | .. | .. | .. | .. | 29,84 | 44 | 70,5 |
| SS | P | 20 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| SR | P | .. | 17 V | | | | | | | | |
| 8 | P | .. | 70 V | | | | | | | | |
| 21,30 | P | .. | .. | 7 V | | | | | | | |
| 18 | N | .. | .. | 50 V | | | | | | | |
| Aug. 12, SR | P | 7 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 50 V | .. | .. | .. | .. | .. | .. | 29,442 | 70,50 | 62,5 |
| 15 | P | 22,5 V | .. | .. | .. | .. | .. | .. | 29,534 | 50,25 | 66 |
| SS | P | 40 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 5 | P | .. | 45 V | | | | | | | | |

## AT THE OBSERVATORY, KEW, IN THE YEAR 1844—*continued.*

| HUMIDITY. | | | RAIN & EVAPN. | | WIND. | | | MOON | GENERAL REMARKS AND OCCASIONAL OBSERVATIONS. |
|---|---|---|---|---|---|---|---|---|---|
| Wet Ther. below dry. | Dew Point below Dry. | Saussure's Hygrom. | Mean of Rain and Vapour Gauge. | | DIRECTION by Vane. | PRESSURE by Lind's Anemr. | by Balance Anemr. | Phases. | |
| ° | ° | ° | inches. E. | R. | | ° | grs. | | |
| .. | .. | .. | .. | .. | WSW | | | | At SR and 5, fine and clear with sunshine. At 6, 7, 8, 9, 10, 11, and 12, fine, but cloudy, with sunshine. At 13, fine, with sunshine, distant rain. At 14, 15, 16, 17, 18, and 19, fine, but cloudy, with sunshine. At SS, fine, but cloudy, At 21 and 22, clear and starlight.<br>*Vide* Storms, Nos. 16 & 17, p. 570. |
| 1 | 12,5 | 81 | .. | .. | SW | 2 | 4000 | | |
| 5,5 | 23,5 | 60 | .. | .. | W | 6 | 11000 | | |
| .. | .. | .. | 21 | .. | W | | | | |
| .. | .. | .. | .. | .. | SW | | | | At SR and until 19, fine, but cloudy, with sunshine. At SS, fine, but heavy clouds. At 21 and 22, clear and starlight. |
| 3 | 17,5 | 72 | .. | .. | SW | 1 | 2000 | | |
| 5 | 26 | 61 | .. | .. | SW | 2 | 5000 | | |
| .. | .. | .. | 21 | .. | WSW | | | | |
| .. | .. | .. | .. | .. | SW | | | | At SR, 5, 6, and 7, fine, but cloudy, with sunshine. At 8 and 9, fine, but hazy, with sunshine. From 10 until 19, fine, but cloudy, with sunshine. At SS, fine, but cloudy. At 22, clear and starlight. |
| 0,5 | 11,5 | 84,5 | .. | .. | SW | 0 | 500 | | |
| 7 | 29,5 | 52 | .. | .. | N | 0 | | | |
| .. | .. | .. | 17 | .. | NE | | | | |
| .. | .. | .. | .. | .. | SW | | | | At SR, 5, 6, 7, 8, and 9, fine and clear, with sunshine. At 10, 11, 13, and 14, fine, but cloudy, with sunshine. At 15 and 16, fine, but cloudy. At 17, light rain. At 18, general heavy rain. At 19, dull and cloudy. At SS, dull and cloudy. At 21 and 21,30′, general rain. |
| 2 | 13,5 | 80 | .. | .. | SW | 0 | 1000 | | |
| 5 | 18 | 62 | .. | .. | SSW | 1 | 3500 | | |
| .. | .. | .. | .. | 13 | SSW | | | | |
| .. | .. | .. | .. | .. | S | | | | At SR and 5, light rain. At 6, heavy rain. At 7, 8, and 9, dull and cloudy. At 10, light rain. At 11, fine, but cloudy. At 12, light rain. At 13 and 14, |
| 1+ | 5,5 | 99 | .. | .. | S | 1 | 2000 | | |
| 1,5 | 9,5 | 81 | .. | .. | WNW | 2 | 4000 | | |
| .. | .. | .. | .. | 15 | WNW | | | | |

## ELECTRO-METEOROLOGICAL OBSERVATIONS,

| TIME. | ELECTRICITY. | | | | | | | | BAROM. PRESSURE. | TEMPERATURE. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Day and hour. Chronometer uncorrected. | Kind. | Periodical Observations. | Morning Min. and Max. | Afternoon Min. and Max. | Frequency. | Galvanometer. | Storms. | Serene Days. | Barometer uncorrected. | Max. and Min. Therm. | Dry Therm. |
| d h | | ° | ° | ° | | ° | | | in. | ° | ° |
| Aug. 12, 10,22 | N | .. | 15 H | | | | | | | | |
| ,, | N | .. | $\frac{3}{20}$ D | | | | | | | | |
| 14 | P | .. | .. | 15 V | | | | | | | |
| SS | P | .. | .. | 40 V | | | | | | | |
| Aug. 13, SR | P | 21 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | P | 32,5 V | .. | .. | .. | .. | .. | .. | 29,734 | 67,50 | 61,25 |
| 15 | P | 5 V | .. | .. | .. | .. | .. | .. | 29,642 | 54,25 | 64 |
| SS | P | 65 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 11 | P | .. | 12 V | | | | | | | | |
| 6 | P | .. | 42,5 V | | | | | | | | |
| 15 | P | .. | .. | 12 V | | | | | | | |
| 12,52 | P | .. | .. | 10 H | | | | | | | |
| Aug. 14, SR | P | 15 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 9 | N | 62,5 V | .. | .. | .. | .. | .. | .. | 29,434 | 66 | 57 |
| 15 | N | 40 V | .. | .. | .. | .. | .. | .. | 29,312 | 51,5 | 55,75 |
| SS | P | 15 V | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| 11 | P | .. | 2,5 V | | | | | | | | |
| 11,15 | N | .. | 50 H | | | | | | | | |
| ,, | N | .. | $\frac{5}{10}$ D | | | | | | | | |
| 21 | P | .. | .. | 5 V | | | | | | | |
| 13,20 | P | .. | .. | 10 H | | | | | | | |
| ,, | P | .. | .. | $\frac{1}{10}$ D | | | | | | | |

## AT THE OBSERVATORY, KEW, IN THE YEAR 1844—*concluded.*

| HUMIDITY. | | | RAIN & EVAPN. | | WIND. | | | MOON | GENERAL REMARKS AND OCCASIONAL OBSERVATIONS. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | DIRECTION | PRESSURE | | | |
| Wet Ther. below dry. | Dew Point below Dry. | Saussure's Hygrom. | Mean of Rain and Vapour Gauge. | | by Vane. | by Lind's Anemr. | by Balance Anemr. | Phases. | |
| ° | ° | ° | inches. E. | R. | | ° | grs. | | |
| | | | | | | | | | fine, but cloudy, with sunshine. At 15, light rain. At 16, 17, 18, 19, and SS, dull and cloudy. At 21 and 21,45′, fine and starlight.<br>*Vide* Storms, No. 18, p. 570. |
| .. | .. | .. | .. | .. | WSW | | | | At SR, 5, and 6, fine, but cloudy. At 7, fine, but cloudy, with sunshine. At 8, 9, 10, and 11, fine, but cloudy. At 12, general rain. At 13, light rain. At 14, 15, 16, and 17, general rain. At 18, fine, but cloudy. At 19, fine, but cloudy, with sunshine. At SS, fine, but cloudy. At 21 and 21,30′, fine and starlight with thin fog on the ground.<br>*Vide* Storms, No. 19, p. 571. |
| 1 | 11 | 81 | .. | .. | SW | 1 | 3000 | | |
| 0 | 8,5 | 85 | .. | .. | ESE | 0 | 500 | | |
| .. | .. | .. | .. | 29 | W | | | | |
| .. | .. | .. | .. | .. | SW | | | | At SR and 6, fine, but cloudy. At 7 and 8, dull and cloudy At 9, light rain. At 10 and 11, dull and cloudy. At 12, fine, but cloudy. At 13 and 14, light rain. At 15 and 16, general rain. At 17, fine, but cloudy, with sunshine. At 18, 19, and SS, and 21 and 21,30′, fine, but cloudy.<br>*Vide* Storms, No. 20, p. 571. |
| 0 | 7 | 95,5 | .. | .. | WSW | 1 | 2000 | | |
| 0 | 7,5 | 95 | .. | .. | NW | 2 | 4000 | | |
| .. | .. | .. | 10 | .. | NW | | | | |

## STORM PAPERS.

| TIME. | ELECTRO-METERS. | | | | | INCIDENTS AND REMARKS. | ANEMOMETER. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bennett. | Volta. | Henley. | Discharger. | Kind. | | Direction. | Force. | Thermometer. | Hygrometer. | Barometer. | Pluviometer. |
| | | | | in. | | No. 5.—July 31. | | | | | | |
| 3,30 | .. | 30 | .. | .. | N | Heavy rain. | WNW | 6° | .. | .. | .. | .. |
| 3,31 | .. | 90 | .. | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,32 | .. | 100 | .. | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,34 | .. | .. | 12 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,36 | .. | .. | 15 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,37 | .. | .. | 25 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,38 | .. | .. | 30 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,40 | .. | .. | 40 | $\frac{4}{10}$ | ,, | Rain a little lighter. | .. | .. | .. | .. | .. | .. |
| 3,41 | .. | .. | 20 | .. | ,, | ,, heavy. | .. | .. | .. | .. | .. | .. |
| 3,42 | .. | .. | 5 | .. | ,, | ,, lighter. | .. | .. | .. | .. | .. | .. |
| 3,43 | .. | .. | 40 | .. | P | ,, heavy. | .. | .. | .. | .. | .. | .. |
| 3,44 | .. | .. | 5 | .. | N | ,, lighter. | .. | .. | .. | .. | .. | .. |
| 3,45 | .. | .. | 20 | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| 3,46 | .. | .. | 5 | .. | ,, | ,, heavy. | .. | .. | .. | .. | .. | .. |
| 3,47 | .. | .. | 40 | .. | ,, | ,, lighter. | .. | .. | .. | .. | .. | .. |
| 3,53 | .. | 54 | .. | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| 3,55 | .. | 53 | .. | .. | ,, | Fine, cloudy, sun. | .. | .. | .. | .. | .. | .. |
| 4,4 | .. | 5 | .. | .. | P | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 6.—August 2. | | | | | | |
| 1,45 | .. | 27½ | .. | .. | P | Heavy shower of rain. | WNW | 3° | .. | .. | .. | .. |
| 1,50 | .. | .. | 2 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,51 | .. | .. | 10 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,53 | .. | 60 | .. | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,55 | .. | 30 | .. | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,56 | .. | 5 | .. | .. | N | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,57 | .. | 55 | .. | .. | P | Rain lighter. | .. | .. | .. | .. | .. | .. |
| 1,59 | .. | .. | 20 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 2 | .. | .. | 60 | .. | ,, | ,, heavier. | .. | .. | .. | .. | .. | .. |
| 2,10 | .. | .. | 10 | .. | N | ,, lighter. | .. | .. | .. | .. | .. | .. |
| 2,15 | .. | .. | 30 | .. | ,, | ,, ,, | W | .. | .. | .. | .. | .. |
| 2,1 | .. | .. | 40 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 2,2 | .. | .. | 40 | .. | ,, | ,, heavy. | .. | .. | .. | .. | .. | .. |
| 2,2 | .. | .. | 30 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 2,26 | .. | .. | 20 | .. | ,, | Fine, cloudy, and sun. | .. | .. | .. | .. | .. | .. |

| TIME. | ELECTRO-METERS. | | | | | INCIDENTS AND REMARKS. | ANEMO-METER. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bennett. | Volta. | Henley. | Discharger. | Kind. | | Direction. | Force. | Thermo-meter. | Hygrometer. | Barometer. | Pluviometer. |
| | | | | | | No. 7.—August 2. | | | | | | |
| | | | | in. | | | | | | | | |
| 3,25 | .. | .. | 25 | .. | N | Rain beginning. | WSW | 3° | .. | .. | .. | .. |
| 3,26 | .. | .. | 40 | .. | ,, | Very heavy drops. | .. | .. | .. | .. | .. | .. |
| 3,27 | .. | .. | 50 | .. | ,, | Rain heavy. | .. | .. | .. | .. | .. | .. |
| 3,30 | .. | .. | 55 | .. | ,, | ,, lighter. | .. | .. | .. | .. | .. | .. |
| 3,33 | .. | .. | 30 | .. | ,, | ,, heavy. | .. | .. | .. | .. | .. | .. |
| 3,37 | .. | .. | 20 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,38 | .. | .. | 20 | .. | ,, | ,, very heavy. | .. | .. | .. | .. | .. | .. |
| 3,40 | .. | .. | 40 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,41 | .. | .. | 40 | .. | P | Heavy rain: ball of Henley, vibrating between 40° and 50°. | .. | .. | .. | .. | .. | .. |
| 3,44 | .. | .. | 45 | .. | ,, | Rain heavy. | .. | .. | .. | .. | .. | .. |
| 3,47 | .. | .. | 45 | .. | ,, | ,, lighter, sun. | .. | .. | .. | .. | .. | .. |
| 3,48 | .. | .. | 45 | .. | ,, | ,, heavy, sun. | W | .. | .. | .. | .. | .. |
| 3,51 | .. | .. | 20 | .. | ,, | ,, very heavy, sun. | .. | .. | .. | .. | .. | .. |
| 3,53 | .. | .. | 25 | .. | N | ,, ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 3,54 | .. | .. | 40 | .. | ,, | ,, lighter, sun. | .. | .. | .. | .. | .. | .. |
| 3,55 | .. | .. | 40 | .. | ,, | ,, much lighter ,, | .. | .. | .. | .. | .. | .. |
| 3,56 | .. | .. | 40 | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| 4,10 | .. | .. | 10 | .. | ,, | Fine, cloudy, sun. | SSW | .. | .. | .. | .. | .. |
| 4,50 | .. | 6 | .. | .. | P | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 8.—August 3. | | | | | | |
| A.M. | | | | | | | | | | | | |
| 7,35 | .. | .. | 35 | .. | N | Heavy rain. | S | 2° | .. | .. | .. | .. |
| 7,36 | .. | .. | 40 | .. | ,, | ,, ,, | .. | 5° | .. | .. | .. | .. |
| 7,38 | .. | .. | 10 | .. | P | ,, ,, | .. | .. | .. | .. | .. | .. |
| 7,40 | .. | .. | 35 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 7,46 | .. | .. | 30 | .. | ,, | Ball vibrating between 35 and 40 Henley. | .. | .. | .. | .. | .. | .. |
| 7,47 | .. | .. | 40 | .. | ,, | Heavy rain. | .. | .. | .. | .. | .. | .. |
| 7,48 | .. | .. | 40 | .. | ,, | Rain lighter. | .. | .. | .. | .. | .. | .. |
| 7,50 | .. | .. | 20 | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 9.—August 3. | | | | | | |
| A.M. | | | | | | | | | | | | |
| 9,15 | .. | .. | 70 | .. | N | Heavy rain. | SW | 10° | .. | .. | .. | .. |
| 9,17 | .. | .. | 60 | .. | ,, | Rain lighter. | .. | .. | .. | .. | .. | .. |
| 9,18 | .. | .. | 40 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 9,19 | .. | .. | 55 | .. | ,, | ,, heavy. | .. | .. | .. | .. | .. | .. |

| TIME. | ELECTRO-METERS. | | | | | INCIDENTS AND REMARKS. | ANEMO-METER. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bennett. | Volta. | Henley. | Discharger. | Kind. | | Direction. | Force. | Thermo-meter. | Hygrometer. | Barometer. | Pluviometer. |
| | | | | in. | | | | | | | | |
| 9,20 | .. | .. | 40 | .. | N | Rain very heavy. | SW | 10° | .. | .. | .. | .. |
| 9,21 | .. | .. | 20 | .. | ,, | ,, little lighter. | .. | .. | .. | .. | .. | .. |
| 9,22 | .. | .. | 30 | .. | P | ,, much lighter. | .. | .. | .. | .. | .. | .. |
| 9,23 | .. | .. | 50 | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| 9,26 | .. | .. | 20 | .. | ,, | Fine, cloudy, sunshine. | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 10.—August 6. | | | | | | |
| 9,25 | .. | .. | 20 | .. | P | Heavy rain. | SW | 4° | 62,75 | 7° | .. | .. |
| 9,26 | .. | .. | 40 | .. | ,, | ,, ,, | .. | .. | .. | .. | 29,600 | .. |
| 9,30 | .. | .. | 55 | $\frac{5}{10}$ | ,, | ,, ,, | .. | .. | .. | .. | | .. |
| 9,32 | .. | .. | 20 | .. | ,, | ,, ,, | .. | .. | .. | .. | | .. |
| 9,35 | .. | .. | 40 | $\frac{9}{40}$ | N | ,, ,, | .. | .. | .. | .. | .. | .. |
| 9,36 | .. | .. | 30 | .. | ,, | Rain a little lighter. | .. | .. | .. | .. | .. | .. |
| 9,40 | .. | .. | 20 | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| 9,41 | .. | .. | 10 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 10 | .. | 5 | .. | .. | P | Dull and cloudy. | .. | .. | .. | .. | .. | .. |
| | | | | | | August 6. | | | | | | |
| | | | | | | *N.B.*—At about 4 P.M. a heavy dark cloud passed to northwind, at a considerable distance from the observatory, during which the rod become negatively charged for a short time, the *maximum* of which was 5° of the Henley electrometer. | | | | | | |
| | | | | | | No. 11.—August 7. | | | | | | |
| 10,59 | .. | .. | 25 | .. | N | Rain beginning. | WSW | 4° | 63,50 | 15° | .. | .. |
| 11 | .. | .. | 60 | $1\frac{5}{10}$ | ,, | Heavy rain. | .. | .. | .. | .. | 29,738 | .. |
| 11,1 | .. | .. | 60 | .. | ,, | ,, ,, | .. | .. | .. | .. | | .. |
| 11,4 | .. | .. | 35 | .. | P | Rain lighter. | .. | .. | .. | .. | | .. |
| 11,5 | .. | .. | 45 | .. | ,, | ,, much lighter. | .. | .. | .. | .. | | .. |
| 11,7 | .. | .. | 40 | .. | N | ,, ceased. | .. | .. | .. | .. | .. | .. |
| 11,17 | .. | .. | 5 | .. | P | Fine, but cloudy, with sun. | .. | .. | .. | .. | .. | .. |

| TIME. | ELECTROMETERS. | | | | | INCIDENTS AND REMARKS. | ANEMOMETER. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bennett. | Volta. | Henley. | Discharger. | Kind. | | Direction. | Force. | Thermometer. | Hygrometer. | Barometer. | Pluviometer. |
| | | | | | | No. 12.—August 7. | | | | | | |
| 0,20 | .. | .. | 75 | in. $1\frac{7}{10}$ | P | Heavy rain. | W | 6° | 64,50 | 11° | .. | .. |
| ,22 | .. | .. | 40 | .. | ,, | Rain lighter. | .. | .. | .. | .. | .. | .. |
| ,24 | .. | .. | 40 | .. | N | ,, ,, sun. | .. | .. | . | .. | 29,730 | .. |
| ,25 | .. | .. | 45 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | | .. |
| ,26 | .. | .. | 40 | .. | ,, | ,, much lighter. | .. | .. | .. | .. | | .. |
| ,27 | .. | .. | 45 | .. | ,, | Fine but cloudy, sun. | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 13.—August 7. | | | | | | |
| 0,45 | .. | .. | .. | .. | | | | | | | | |
| ,46 | .. | .. | 30 | .. | P | Rain beginning. | WSW | 5° | 63,50 | 13° | .. | .. |
| ,47 | .. | .. | 50 | .. | ,, | ,, heavy. | .. | .. | .. | .. | 29,740 | .. |
| ,48 | .. | .. | 55 | $\frac{7}{10}$ | ,, | ,, ,, | .. | .. | .. | .. | | .. |
| ,50 | .. | .. | 40 | .. | ,, | ,, much lighter. | .. | .. | .. | .. | | .. |
| 1 P.M. | .. | 70 | .. | .. | N | ,, ceased. | .. | .. | .. | .. | .. | .. |
| 1,2 | .. | .. | 2 | .. | ,, | Fine, cloudy sun. | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 14.—Aug. 7. | | | | | | |
| P.M. | | | | | | | | | | | | |
| 1,8 | .. | .. | 5 | .. | P | Rain beginning. | WSW | 5° | 63° | 14° | .. | .. |
| 1,9 | .. | .. | 40 | .. | ,, | No rain. | .. | .. | .. | .. | .. | .. |
| 1,10 | .. | .. | 60 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,11 | .. | .. | 65 | $1\frac{2}{10}$ | ,, | Light rain. | .. | .. | .. | .. | .. | .. |
| 1,13 | .. | .. | 60 | .. | ,, | Rain heavy. | .. | .. | .. | .. | .. | .. |
| 1,15 | .. | .. | 50 | .. | N | No rain. | .. | .. | .. | .. | 29,740 | .. |
| 1,16 | .. | .. | 60 | .. | ,, | Light rain. | .. | .. | .. | .. | | .. |
| 1,17 | .. | .. | 60 | .. | ,, | Rain very heavy. | .. | .. | .. | .. | | .. |
| 1,19 | .. | .. | 60 | .. | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,20 | .. | .. | 40 | .. | ,, | ,, little lighter. | .. | .. | .. | .. | .. | .. |
| 1,23 | .. | .. | 15 | .. | ,, | Rain ceased. | .. | .. | .. | .. | .. | .. |
| 1,30 | .. | .. | 4 | .. | ,, | Fine, with sunshine. | .. | .. | .. | .. | .. | . |
| | | | | | | No. 15.—Aug. 7. | | | | | | |
| 1,50 | .. | .. | 60 | .. | N | Rain beginning. | SW | 6° | 59° | 11° | .. | .. |
| 1,51 | .. | .. | 60 | .. | ,, | ,, heavy. | .. | .. | .. | .. | .. | .. |
| 1,52 | .. | .. | 65 | $1\frac{2}{10}$ | ,, | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,53 | .. | .. | 10 | .. | P | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,54 | .. | .. | 40 | .. | N | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,55 | .. | .. | 30 | .. | ,, | ,, a little lighter. | .. | .. | .. | .. | .. | .. |
| 1,56 | .. | .. | 30 | .. | ,, | Ball vibrating between 30 and 50. | .. | .. | .. | .. | .. | .. |

| TIME. | ELECTRO-METERS. | | | | | INCIDENTS AND REMARKS. | ANEMO-METER. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bennett. | Volta. | Henley. | Discharger. | Kind. | | Direction. | Force. | Thermo-meter. | Hygrometer. | Barometer. | Pluviometer. |
| | | | | in. | | | | | | | | |
| 1,57 | .. | .. | 20 | .. | N | Rain heavier. | SW | 6° | .. | .. | .. | .. |
| 1,58 | .. | .. | 35 | .. | P | ,, ,, | .. | .. | .. | .. | .. | .. |
| 1,59 | .. | .. | 40 | .. | ,, | ,, very heavy. | .. | .. | .. | .. | .. | .. |
| 2 P.M. | .. | .. | 10 | .. | ,, | ,, not so heavy. | .. | .. | .. | .. | .. | .. |
| 2,1 | .. | .. | 10 | .. | N | ,, lighter | .. | .. | .. | .. | .. | .. |
| 2,2 | .. | .. | 20 | .. | ,, | ,, heavy. | .. | .. | .. | .. | .. | .. |
| 2,3 | .. | .. | 40 | .. | ,, | ,, much lighter. | .. | .. | .. | .. | 29,732 | .. |
| 2,4 | .. | .. | 50 | .. | ,, | No rain. | .. | .. | .. | .. | | .. |
| 2,5 | .. | .. | 45 | .. | ,, | Heavy rain. | .. | .. | .. | .. | | .. |
| 2,6 | .. | .. | 50 | .. | P | ,, ,, | .. | .. | .. | .. | .. | .. |
| 2,8 | .. | .. | 50 | .. | ,, | Rain very heavy. | .. | .. | .. | .. | .. | .. |
| 2,10 | .. | .. | 20 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 2,12 | .. | .. | 30 | .. | N | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 2,15 | .. | 10 | .. | .. | ,, | ,, a little lighter. | .. | .. | .. | .. | .. | .. |
| 2,17 | .. | .. | 20 | .. | ,, | ,, much lighter. | .. | .. | .. | .. | .. | .. |
| 2,19 | .. | .. | 5 | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| 2,30 | .. | 37½ | .. | .. | ,, | Fine, with sunshine. | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 16.—Aug. 8. | | | | | | |
| 0,45 | .. | .. | 45 | .. | N | Heavy dark cloud, distant rain. | .. | .. | .. | .. | .. | .. |
| 0,48 | .. | .. | 50 | $\frac{5}{10}$ | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 0,50 | .. | .. | 35 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 0,54 | .. | .. | 10 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 17.—Aug. 8. | | | | | | |
| 1,26 | .. | .. | 50 | $\frac{5}{10}$ | N | Moderate shower of rain, sun. | WSW | 6° | 65° | 17° | .. | .. |
| 1,30 | .. | .. | 35 | .. | ,, | ,, ,, ,, ,, | .. | .. | .. | .. | 29,708 | .. |
| 1,31 | .. | .. | 20 | .. | ,, | ,, ,, ,, ,, | .. | .. | .. | .. | | .. |
| 1,32 | .. | .. | 15 | .. | ,, | Fine, cloudy, sun. | .. | .. | .. | .. | | .. |
| A.M. | | | | | | No. 18.—Aug. 12. | | | | | | |
| 10,15 | .. | .. | 5 | .. | N | Heavy rain. | SW | 3° | 62° | 8° | .. | .. |
| 10,17 | .. | .. | 10 | .. | P | ,, ,, | .. | .. | .. | .. | .. | .. |
| 10,20 | .. | .. | 12 | .. | ,, | Very heavy rain. | .. | .. | .. | .. | .. | .. |
| 10,21 | .. | .. | 15 | .. | N | Rain a little lighter. | .. | .. | .. | .. | .. | .. |
| 10,22 | .. | .. | 15 | $\frac{3}{20}$ | ,, | ,, much heavier. | .. | .. | .. | .. | .. | .. |

| TIME. | ELECTRO-METERS. | | | | | INCIDENTS, AND REMARKS. | ANEMO-METER. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bennett. | Volta. | Henley. | Discharger. | Kind. | | Direction. | Force. | Thermo-meter. | Hygrometer. | Barometer. | Pluviometer. |
| | | | | in. | | | | | | | | |
| 10,23 | .. | .. | 15 | .. | N | Rain very heavy. | SW | 3° | .. | .. | .. | .. |
| 10,24 | .. | .. | 10 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | 29,4 52 | .. |
| 10,25 | .. | .. | 10 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | | .. |
| 10,26 | .. | .. | 15 | .. | ,, | ,, much lighter. | .. | .. | .. | .. | | .. |
| 10,27 | .. | .. | 15 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | | .. |
| 10,30 | .. | .. | 10 | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 19.—Aug. 13. | | | | | | |
| 0,52 | .. | .. | 10 | .. | P | Heavy rain. | SW | 1° | .. | .. | .. | .. |
| 0,55 | .. | 60 | .. | .. | ,, | Rain lighter. | .. | .. | .. | .. | .. | .. |
| 0,57 | .. | 30 | .. | .. | ,, | ,, much lighter. | .. | .. | .. | .. | .. | .. |
| 1 P.M. | .. | 25 | .. | .. | ,, | ,, ceased. | .. | .. | .. | .. | .. | .. |
| | | | | | | No. 20.—Aug. 14. | | | | | | |
| 11,13 | .. | .. | 15 | .. | N | Rain beginning. | SSW | 6° | 53° | 8° | .. | .. |
| 11,14 | .. | .. | 30 | .. | ,, | ,, a little heavier. | .. | .. | .. | .. | .. | .. |
| 11,15 | .. | .. | 50 | $\frac{5}{16}$ | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 11,18 | .. | .. | 40 | .. | ,, | ,, very heavy. | .. | .. | .. | .. | .. | .. |
| 11,20 | .. | .. | 10 | .. | P | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 11,21 | .. | .. | 35 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 11,23 | .. | .. | 35 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | 29,334 | .. |
| 11,24 | .. | .. | 40 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | | .. |
| 11,27 | .. | .. | 20 | .. | N | ,, ,, ,, | .. | .. | .. | .. | | .. |
| 11,30 | .. | .. | 40 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 11,31 | .. | .. | 30 | .. | P | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 11,35 | .. | .. | 30 | .. | N | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 11,36 | .. | .. | 30 | .. | P | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 11,39 | .. | .. | 30 | .. | ,, | ,, ,, ,, | .. | .. | .. | .. | .. | .. |
| 11,40 | .. | .. | 45 | .. | N | ,, a little lighter. | .. | .. | .. | .. | .. | .. |
| 11,43 | .. | .. | 30 | .. | P | ,, again heavy. | .. | .. | .. | .. | .. | .. |
| 11,49 | .. | .. | 40 | .. | ,, | ,, somewhat lighter | .. | .. | .. | .. | .. | .. |
| M. | .. | .. | 35 | .. | N | ,, rain ceased. | .. | .. | .. | .. | .. | .. |

**The utter impossibility of noting down by one person any other instruments than the electrometers during a storm, *sometimes* is plainly perceptible in these sets of observations. But this circumstance is of far less importance even than that of not being able to give some kind of statement relative to the appearances, &c. &c. of the clouds and atmosphere in general. I have projected a storm-clock, which shall carry an index down the margin of the paper (about eighteen inches long, or more), in half an hour (or less), and propose to write the *principal* phenomena as they occur (a history of the storm), opposite to the point; by which means a great part of the time spent in reading a timepiece, and writing down the time, will be saved. But even then more than one observer will be necessary *sometimes*. The space of a few seconds even is sufficient to contain important changes. One person should be stationed on the leads outside of the dome, to give notice to another within, of the various phenomena which come under his notice.—FRANCIS RONALDS.**

Arrangements, of the same nature as those at Kew, have been made under the direction of the Astronomer Royal, at the Greenwich Observatory. They are thus alluded to in the Report read at the annual visitation, June 1, 1844 :—

" In the autumn of last year, I had an opportunity of examining the beautiful arrangements of the atmospheric electrometer at the Kew Observatory, which have been made under the superintendence of Prof. WHEATSTONE and FRANCIS RONALDS, Esq. It was impossible to see these without perceiving that considerable improvements might be made in our own, by following the same plan, with such alterations as the difference of local circumstances rendered necessary. The form which I have adopted may be generally described as follows: Two iron rods are suspended from the top of the mast to the ground, and are kept in a state of tension by weights hung in a pit. These rods serve as guides to a travelling frame, which carries a copper rod supported on a glass cone. A lamp is placed below the glass cone to keep it warm and dry ; and another lamp is attached to the top of the copper rod to collect atmospheric electricity. The frame is lowered twice every day for trimming the lamp, and is then raised again ; this operation is effected with a windlass and rope. The wire, by which the electricity is conducted from the copper rod to the electrometers within the building, is kept in tension by a lever with a weight at one end, which also serves for the electric conduction. During the operation of lowering or raising the frame, a self-acting reel (driven by a weight) coils up or delivers the wire, which is then detached from the lever. The metallic apparatus within the building is supported by a glass rod, whose ends are maintained in a state of warmth and dryness by small lamps. The electrometers are, the dry-pile apparatus (mentioned in the Report of last year), three expansion electrometers, and one HENLEY's electrometer ; there is also an apparatus for measuring the length of sparks. Judging from the long time through which the apparatus will preserve a trifling charge of atmospheric electricity, I conceive that its insulation is nearly perfect ; yet, from some unknown cause (not improbably the proximity of lofty trees), the indications are much less constant than those at the Kew Observatory.

" The galvanometer seems to be effected not more than once or twice in a year. The induction copper ball* gives no certain result.

" The OSLER's anemometer† performs well, except in the registration of the pressures, and the ordinary light winds.

" At the last visitation, the Board of Visitors recommended to the Board of Admiralty the erection of a WHEWELL's anemometer.‡ The Lords of the Admiralty immediately assented to this, and an instrument of this class was mounted in the last summer. With some small refittings it has worked extremely well."

## NOTE *k*. (*vide* p. 336.)

An apparatus is, by this time, completed at Kew, for collecting the electricity from rain. It consists of a large metal funnel, sup-

---

* *Vide* Peltier's Experiments, Note E, p. 493.

† *Vide* Note *y*. ‡ Ibid.

ported on a hollowed glass rod, fitted up with the copper tube and lamp for preserving insulation. It will be exposed to the heavens on the leads of the Observatory.

## NOTE *l.* (*vide* p. 336.)

The present state of our knowledge does not justify our rushing too hastily to conclusions respecting the causes (for there may be several) by which atmospheric electricity is produced. For my own part, I am inclined to think, with M. KAEMTZ, that friction is not altogether to be excluded from a place in our thoughts. This opinion is somewhat sanctioned by ARMSTRONG'S recent discoveries of the electricity of *effluent steam* and *effluent moist air;* and FARADAY'S *Experimental Researches* on the exciting causes.

When high-pressure steam is allowed to escape under favourable circumstances from a narrow jet, the *effluent vapour* corresponds to the glass plate of an electrical machine, and the *jet* to the rubber. Under these circumstances the vapour is highly positive, and the jet and attached boiler negative. *Dry* steam produces no electricity: it is therefore necessary so to arrange the jet that the steam shall become partially condensed before it reaches it; so that the steam may be regarded as the motive power, or mechanical means, by which the watery particles are rubbed against the jet. If these particles consist of water that has been rendered conducteous by the presence of certain chemical agents, they refuse to become excited, and are just in the condition of a glass tube that is rubbed with moist flannel; it discharges as fast as it charges. The quantity of electricity depends greatly on the character of the jet or rubber: of thirty substances, tried by FARADAY, *all* rendered the steam positive, although in various degrees; quill and ivory have very feeble powers; the metals are better; but hard woods have the greatest exciting power. Experience has now shewn that small cylinders of partridge wood, secured in the jet, form the best rubbers. If grease, or resin, or oil, is made to pass off with the watery particles, the effluent steam becomes negative, and the boiler positive; for, under those circumstances, the aqueous particles become enfilmed, and the rubbing surface is virtually oil or resin; and the phenomena correspond to a stick of sealing-wax rubbed against flannel.

These views of the friction of watery particles are still farther illustrated by the escape of condensed air. FARADAY condensed air in a strong copper globe. When he allowed common *undried air* to escape, the cooling, consequent on its expansion, condensed the moisture it contained, and the rush of air rubbed the aqueous particles, and produced an electrical excitation exactly similar to that produced by effluent steam. But, when he adopted chemical means of drying the air while it was within the globe, and then allowed it to escape, it was reduced to the condition of dry steam, and was perfectly inactive. This new source of electricity led me, when recently reviewing the subject, to make the following observations; the truth of which can only be tested when we have obtained a more close insight into these matters than we at present possess:—

"As the friction of watery particles is a discovery only just matured, the idea has not yet occurred of including it in the investigation of atmospheric electricity. Though the present state of our knowledge does not justify us to hazard an answer, yet we are called on to propose the question. Do the watery particles with which the atmosphere is charged acquire positive electricity as they are rubbed by the wind against the earth, and all it sustains, as hills, rocks, trees, &c. in the same manner as the stream of steam and water becomes positive by rubbing against the jet? If so, what connexion may not be traced between the hurricane winds of the tropics and the prevailing lightning-storms with which those regions abound? Does the friction together of two currents of air, charged to different degrees with moisture, develope the two electrical states?"*

### NOTE *m.* (*vide* p. 337.)

We would direct the attention of the reader to M. PELTIER's views of this matter, given in Note E of the First Appendix.

### NOTE *n.* (*vide* p. 342.)

The most extraordinary instance on record of an electrical fog is given by Mr. CROSSE, of Broomfield. Before repeating his description, it will be necessary to describe his arrangements for collecting atmospheric electricity. Poles are fixed on some of the loftiest trees on his estate. Cylindrical vessels of copper, with insulating glass rods, cemented within, are raised to the summit of these poles by a cord and pulley. The funnels hang bottom upward, so that the glass rod is protected from rain; to its lower end is fixed a cap and staple: to this staple a copper disc is hooked on, by a wire passing through its centre, so as to be about four inches from the mouth of the cylinder; the other end of the wire forms a second hook. An *exploring wire* is extended from pole to pole, and is secured by these hooks. Wind had disturbed the arrangements so, that at present the length does not exceed 1600 feet; but Mr. CROSSE is now about to make a very considerable increase in the length. A stout pole, furnished with an insulating cylinder (or, as he terms it, *funnel*), is erected outside his electrical room; this funnel forms the termination of the exploring wire, and from it a stout wire conveys the electricity through the window to a large brass ball, from which it is led to an insulated brass conductor. Arrangements are made for employing the electricity, or for carrying it away with safety. This apparatus is alluded to in the following description of an electric fog:—

"Many years since I was sitting in my electrical room, on a dark November day, during a very dense driving fog and rain which had prevailed for many hours, sweeping over the earth, impelled by a south-west wind. The mercury in the barometer was low, and the thermometer indicated a low temperature. I had at this time 1600 feet of wire insulated, which, crossing two small valleys, brought the electric fluid into my room. There were four insulators,

---

* Vide *Cabinet Cyclopædia*, Electricity, &c. vol. ii. p. 99.

and each of them was streaming with wet, from the effects of the driving fog. From about eight o'clock in the morning until four in the afternoon, not the least appearance of electricity was visible at the atmospheric conductor, even by the most careful application of the condenser and multiplier; indeed, so effectually did the exploring wire conduct away the electricity which was communicated to it, that when it was connected by means of a copper wire with the prime conductor of my eighteen-inch cylinder in high action, and a gold-leaf electrometer placed in contact with the connecting wire, not the slightest effect was produced upon the gold leaves. Having given up the trial of further experiments upon it, I took a book, and occupied myself with reading, leaving by chance the receiving ball at upwards of an inch distance from the ball in the atmospheric conductor. About four o'clock in the afternoon, whilst I was still reading, I suddenly heard a very strong explosion between the two balls, and shortly after many more took place, until they became one interrupted stream of explosions, which died away and re-commenced with the opposite electricity in equal violence. The stream of fire was too vivid to look at for any length of time, and the effect was most splendid, and continued without intermission, save that occasioned by the interchange of electricities, for *upwards of five hours*, and then ceased totally. During the whole day, and a great part of the succeeding night, there was no material change in the barometer, thermometer, hygrometer, or wind; nor did the driving fog and rain alter in its violence. The wind was not high, but blew steadily from the south-west. Had it not been for my exploring wire, I should not have had the least idea of such an electrical accumulation in the atmosphere: the least contact with the conductor would have *occasioned instant death*, the stream of fluid far exceeding any thing I ever witnessed, excepting during a thunder-storm. *Had the insulators been dry, what would have been the effect?* In every acre of fog there was enough of accumulated electricity to have destroyed every animal within that acre. How can this be accounted for? How much have we to learn before we can boast of understanding this intricate science?"[*]

M. PELTIER has lately published a memoir on the different species of fogs, of which the following is a *resumé:*—

"According to De LUC, B. DAVY, and J. HERVEY, a fall of temperature to the amount of about two or three degrees below that of the surface of the waters, or of the moist ground, is sufficient for the production of fog; and the fog is thicker, in proportion as this difference between the temperature of the air and that of the waters is greater. This theory possesses the greatest simplicity, but it is insufficient to explain the existence of a great number of fogs; and, as M. PELTIER observed, it is necessarily complicated by the effect of electric actions and re-actions. The first cause of this complexity is the formation of vapours at the surface of a body charged with resinous electricity,—vapours which consequently participate in this state, and are also resinous. The second cause is in the re-action of the resinous vapours of the vast current that is constantly advancing from the tropics towards the poles, in the high regions of the atmosphere.

"From these different influences there result, according to the author, three sorts of fogs, which are divided into five very distinct

---

[*] *Vide* NOAD's *Electricity*, p. 94.

species: the first is that of simple fogs; the second and third are those of resinous fogs; the fourth and fifth are those of vitreous fogs.

"*Simple fogs* are the product of the condensation of elastic vapours by the cooling of the air, when the latter has fallen several degrees below the temperature of the ground on which it rests; they are always moist, and they moisten the cold bodies that they touch. These fogs appear toward the end of a fine day; they rise slowly into the atmosphere, and remain at a very low elevation. They are of a dead white, and diminish the light without colouring it; and their surface is smooth and tranquil.

"It would seem that *resinous fogs* should be the more numerous, because as the terrestrial globe is a body charged with resinous electricity, the vapours that rise from it are resinous like itself. This species, however, is not common; the cause of transformation in the signs of the electricity is, in the very law itself, of electrical inductions. The earth repels the resinous electricity toward the higher strata, and thus renders the stratum that is nearest to the ground vitreous. In order that such a fog may remain in contact with the surface of the globe, it is necessary that another power should have a preponderance over the repulsion of the earth, or that this terrestrial repulsion should be reduced by a similar force acting in the contrary direction. The former effect is produced by the specific gravity which clouds sometimes acquire; and the latter, by the repulsive power of the highly resinous upper strata. Resinous fogs, produced by these two causes, are distinguished by particular qualities, which divide them into two different species.

"*Vitreous fogs* are also of two species, which present very distinct results. The first is that which occurs under a serene sky, without any other electric influence than that of the globe. This species has its lower portions more vitreous than the upper, and they are powerfully attracted by the globe. The other species is that which is formed under the influence of the masses of highly resinous vapours, which prevail in the upper strata. This latter has its upper portions more vitreous than the lower."*

## NOTE *o*. (*vide* p. 347.)

The explanation of ball-lightning has been always a subject of difficulty. Mr. SNOW HARRIS has recently traced it, in his *Treatise on Thunder-storms*, to very probable causes. We must premise that electric discharges have been divided by FARADAY into the spark, the brush, and the *glow*. The *glow* is described as a constant renewal of discharges, instead of an intermittent action. Now, Mr. HARRIS suggests that the ball-discharge possesses many features of resemblance to the glow; and, in addition, it possesses *motion*. The latter condition is readily admitted, inasmuch as the cloud, by which the discharge is carried, moves onward. These balls of fire are shewn to have acted as do lightning-flashes; and this is not difficult of explanation; for, when the cloud passes over any terrestrial object, by which the resistance to discharge is reduced within the striking distance, disruptive discharge must take place: the quiet glow, or

---

* Vide *Electrical Magazine*, No. VI. p. 416.

fire-ball, no longer exists, but is converted into a true and proper lightning-flash.

### NOTE *p*. (*vide* p. 354.)

Professor SCHOENBEIN, of Bâle, has, within these last few years, written several memoirs on the electrical odour, in which he has laid down certain new views. He considers the odour to arise from an elementary body that is liberated from combination by the electrolytic, or decomposing action of electricity; he calls this principle *ozone*. He considers ozone to possess the same electrical characters as chlorine, bromine, and iodine; and, according to his recent views, he considers nitrogen as a compound of ozone and hydrogen, analogous to hydrochloric acid. Indeed, a notice has lately been published, in which it is stated that he has actually decomposed nitrogen into hydrogen and ozone. But as the process is not yet published, nor the means by which he satisfies himself of having effected this analysis, we are not in a condition to pass an opinion upon it.

The general opinion of philosophers is against the existence of this ozone; they attribute the odour to other causes. M. DE LA RIVE ascribes it to the minute metallic particles which are detached from conductors during discharge. M. FUSINIERI has shewn the universality of these particles in electric discharges; and M. DE LA RIVE says that this explanation "rests on the existence of known facts, while the hypothesis of ozone is based on the existence of a body quite new, of a very peculiar nature, and which can be perceived neither by a near nor a distant examination, except by this odour which it is admitted to possess."* Until we possess this ozone in an isolated state we cannot help hesitating before we adopt the hypothesis.

### NOTE *q*. (*vide* p. 367.)

Mr. SNOW HARRIS has, during these last two years, communicated a series of articles to the *Nautical Magazine*, containing the statistics of the effects of lightning on 210 ships in the British navy. He has collected these notices from the dusty and deserted manuscript journals of the respective ships, in which they had wellnigh been consigned to oblivion. He gives the place of the ship, the effects of the discharge, the meteorological phenomena, and such other remarks as are necessary to render the history complete. The series of papers have just been published separately.

The cases before him have led him to several deductions on the meteorology of thunder-storms. He says:—

"The history of the different cases of electrical storms shews a general shifting and variable state of the wind, attended by alternate calms, and squalls, and heavy rain, which is not unfrequently converted into hail by the changes which take place in the temperature. The phenomena of these storms are such as to lead us to infer that, by the meeting of many currents of wind, a sort of intermediate impressed space is produced, in and about which the air assumes a variable and irregular motion, producing in many instances a complete vortex."

---

* Vide *Archives de l'Electricité*, July 1843.

Within and about this vortex the most violent electrical effects are produced; masses of vapours condense, and give forth terrific lightning and complete deluges of water. This vortex is sometimes stationary; at other times it moves in the direction of the resultant of the active forces. After the electrical and other meteorological changes have taken place, the progress of the storm may be arrested, and the conditions on which it depends vanish. In which case the original wind may return with fair weather; or the new direction of wind, which is the frequent concomitant of a storm, may be permanent, or may shift a few points. These storms seem to occupy but limited portions of the atmosphere, and seldom to extend to any great height. In illustration of the latter position he gives the case of the Desirée, at that time commanded by Admiral Ross, which had her main-topmast shivered to pieces, and her mainmast rent, during a storm at West Arbour, Port Antonio, October 8th, 1802. The storm "was witnessed by an observer, at his house on the hill, as taking place immediately under him, whilst overhead the sky was clear and tranquil."

Mr. Harris makes special allusion to the rapid formation of water, which is almost always coincident with these storms; and he seems to be of opinion, that the electricity in these cases, like heat under similar circumstances, is roused from a latent into an active state by the change of vapour into water. He has classified the respective accidents as to time and place; but as the results bear more upon the chances of damage to which our fleets are exposed, we need not refer to them further.

### Note *r*. (*vide* p. 367.)

Mr. Crosse, who has been for many years an attentive observer of the electricity of the atmosphere, considers a passing cloud as a succession of electrised zones, alternating from positive to negative; the effects being at a *minimum* at the borders of the cloud, and at a *maximum* at the centre. The conduct of an electrical cloud has been thus graphically described by him:—

"On the approach of a thunder-cloud to the insulated atmospheric wire (described in Note *n*, p. 574), the conductor attached to it, which is screwed into a table in my electrical room, gives corresponding signs of electrical action. In fair cloudy weather the atmospheric electricity is invariably positive, increasing in intensity at sunrise and sunset, and diminishing at midday and midnight, varying as the evaporation of the moisture in the air; but when the thunder-cloud (which appears to be formed by an unusually powerful evaporation, arising either from a scorching sun succeeding much wet, or *vice versâ*,) draws near, the pith balls suspended from the conductor open wide, with either positive or negative electricity; and when the edge of the cloud is perpendicular to the exploring-wire, a slow succession of discharges takes place between the brass ball of the conductor and one of equal size, carefully connected with the nearest spot of moist ground. I usually connect a large jar with the conductor, which increases the force of, and in some degree regulates the number of the explosions; and the two balls between which the discharges pass can be easily regulated, as to their distance from each other, by a screw.

After a certain number of explosions, say of negative electricity, which at first may be nine or ten in a minute, a cessation occurs of some seconds or minutes, as the case may be, when about an equal number of explosions of positive electricity takes place, of similar force to the former, *indicating the passage of two oppositely and equally electrified zones of the cloud:* then follows a second zone of negative electricity, occasioning several more discharges in a minute than from either of the first pair of zones; which rate of increase appears to vary according to the size and power of the cloud. Then occurs another cessation, followed by an equally powerful series of discharges of positive electricity, indicating the passage of a second pair of zones: these, in like manner, are followed by others, fearfully increasing the rapidity of the discharges, when a *regular stream commences*, interrupted only by the change into the opposite electricities. The intensity of each new pair of zones is greater than that of the former, as may be proved by removing the two balls to a greater distance from each other. When the centre of the cloud is vertical to the wire, the greatest effect consequently takes place, during which the *windows rattle in their frames*, and the bursts of thunder without, and the noise within, every now and then accompanied with a crash of accumulated fluid in the wire, striving to get free between the balls, produce the most awful effect, which is not a little increased by the pauses occasioned by the interchange of zones. Great caution must, of course, be observed during this interval, or the consequences would be fatal. My battery consists of fifty jars, containing seventy-three feet of surface, on *one side* only. This battery, when fully charged, will perfectly fuse into red-hot balls thirty feet of iron wire, in one length, such wire being $\frac{1}{278}$ of an inch in diameter. When this battery is connected with three thousand feet of exploring-wire, during a thunder-storm, it is charged fully and instantaneously, and, of course, as quickly discharged. As I am fearful of destroying my jars, I connect the two opposite coatings of the battery with brass balls, one inch in diameter, and placed at such distance from each other as to cause a discharge when the battery receives three-fourths of its charge. When the middle of a thunder-cloud is overhead, a crashing stream of discharges takes place between the balls, the effect of which must be witnessed to be conceived.

"As the cloud passes onwards, the opposite portions of the zone, which first affected the wire, come into play, and the effect is weakened with each successive pair till all dies away, and not enough electricity remains in the atmosphere to affect a gold-leaf electrometer. I have remarked that the air is remarkably free of electricity, at least, more so than usual, both before and after the passage of one of these clouds. Sometimes, a little previous to a storm, the gold leaves connected with the conductor will, for many hours, open and shut rapidly, as if they were panting, evidently shewing a great electrical disturbance.

"It is known to electricians, that if an insulated plate, composed of a perfect or an imperfect conductor, be electrified, the electricity communicated will radiate from the centre to the circumference, *increasing* in force as the squares of the distances from the centre; whereas in a thunder-cloud the reverse takes place, as its power *diminishes* from the centre to the circumference. First, a nucleus appears to be formed, say of positive electricity, embracing a large portion of the centre of the cloud, round which is a negative zone of equal power with the former: then follow the other zones in pairs, diminishing in power to the edge of the cloud. *Directly below this cloud*, according to the laws of inductive electricity, must exist, on the surface of the earth, a nucleus of positive or negative electricity, with its corresponding zone of positive, and with other zones of electrified surface, corresponding in number to those of the cloud above, although each is oppositely electrified. A discharge of the positive nucleus above into that of the negative below is commonly that which occurs when a flash of lightning is seen; or from the positive below to the negative above, as the case may be: and this discharge may take place, according to the laws of electricity, through any or all of the surrounding zones, *without influencing their respective electricities* otherwise than by weakening their force, by the removal of a portion of the electric fluid from the central nucleus above to that below: every successive flash from the cloud to the earth, or from the earth to the cloud, weakening the charge of the plate of air, of which the cloud and the earth form the two opposite coatings. Much might be said on this head, of which the above is but a slight sketch."*

To this we may add that, from some recent experiments on the phenomena of induction, FARADAY has been led to a very general illustration of the probable structure of a thunder-cloud. An insulated charged ball is suspended within an insulated ice-pail; the inductive effects of the ice-pail on external bodies are the same whether the ball be held concentric or eccentric, near the surface or near the bottom; and, finally, if the ball touch the pail so as to deliver up its charge, the inductive effect remains unchanged. If several ice-pails are placed one within the other, and preserved from contact by insulating sheets of shell-lac, the effects remain constant whether the charge be in the ball or in either of the pails. When several charged balls are used, their actions suffer no interference; but each acts independently of the other, and the sum of their individual powers is obtained.

"A curious consideration," says FARADAY, "arises from this perfection of inductive action. Suppose a thin uncharged metallic globe, two or three feet in diameter, insulated in the middle of a chamber; and then, suppose the space within this globe occupied by myriads of little vesicles or particles, charged alike with electricity (or differently), but each insulated from its neighbour and the globe; their inductive power would be such that the outside of the globe would be charged with a force equal to the sum of *all* their forces, and any part of this globe (not charged of itself) would give as long and powerful a spark to a body brought near it, as if the electricity of all the particles near and distant were on the surface of the globe itself. If we pass from this consideration to the case of a cloud, then, though we cannot altogether compare the external surface of the cloud to the metallic surface of the globe, yet the previous inductive effects upon the *earth* and its buildings are the same; and, when a charged cloud is over the earth, although its electricity may be diffused over every one of its particles, and no important part of the *inductric* charge be accumulated upon its under surface, yet the induction upon the earth will be as strong as if all that portion of force

---

* *Vide* NOAD's *Electricity*, p. 92.

which is directed towards the earth *were* upon that surface; and the state of the earth, and its tendency to discharge to the cloud, will also be as strong in the former as in the latter case. As to whether lightning-discharge begins first at the cloud or at the earth, that is a matter far more difficult to decide than is usually supposed; theoretical notions would lead me to expect that, in most cases, perhaps in all, it begins at the earth."[*]

### NOTE *s*. (*vide* p. 368.)

The present imperfect state of our knowledge of the phenomena of storms induces us to examine patiently every statement which may tend to throw light on the subject. We have seen in the previous note the characteristics of a storm-cloud, and the phenomena, to a certain extent, of its discharge; we have now to notice M. TESSAN'S views of the hydro-meteorological phenomena, concurrent with a violent discharge; and I must confess to a partiality towards this view, although in this I differ from M. KAEMTZ, as given in the text.

M. TESSAN first refers to the homogeneous repulsion of similarly electrised particles; and considers that, if a lightning-cloud is constituted, as we have reason to believe, of such particles, it will swell out until this expansive tendency is *in equilibrio* with the pressure of the atmosphere; and if a cloud is highly charged with electricity, its dilatation will be very considerable. If, under such circumstances, a flash of lightning occurs, the cloud will be discharged in whole or in part of its electricity, and the exterior air, being no longer held *in equilibrio*, will press in upon the cloud, and reduce its dimensions. "The rushing of the air," he says, "must produce *in the region which it occupies a very strong and deep noise*, and determine, also, a great precipitation of vapour. So that this is the cause of the noise of thunder and the torrent of rain which follows it."[†]

This view takes for granted that the lightning precedes the rain; M. KAEMTZ is of the contrary opinion: he conceives, as we see in the text, that the *storm produces the electricity, and not the electricity the storm*. The question of priority, in this instance, is of considerable moment, and we therefore press upon our readers the following extract from the instructions published by the Royal Society in 1840:—

"The phenomena of ordinary thunder-storms may be thought to afford little matter for remark; and extraordinary ones will be noted of course. Yet there is one point to which we would wish that some attention might be paid,—it is the sudden rush of rain which is almost sure to succeed a violent detonation immediately overhead. Is this rain a *cause* or a *consequence* of the electric discharge? Opinion would seem to lean to the latter side; or, rather, we are not aware that the former has been maintained, or even suggested. Yet it is very defensible. In the sudden agglomeration of many minute and feeble electrified globules into one rain-drop, the quantity of electricity is increased in a greater proportion than the surface over which (according to the laws of electric distribution) it is spread. Its ten-

---

[*] Vide *Phil. Mag.* March, 1843.

[†] Vide *Comptes rendus de l'Acad.* May 5, 1841.

sion, therefore, is increased, and may attain the point, when it is capable of separating from the *drop* to seek the surface of the *cloud*, or of the newly formed descending body of rain, which, under such circumstances, and with respect to electricity of such a tension, may be regarded as a conducting medium. Arrived at this surface, the tension, for the same reason, becomes enormous, and a flash escapes.

"The following points should be observed with a view to this mode of regarding the formation of lightning. 1st. The actual electrical state of *that* rain which follows suddenly after a discharge originating vertically overhead.

"2d. Whether lightning occurs without rain, *in the immediate point where it originates*, or, at least, without a rapid formation and increase of cloud at that point.

"3d. Whether lightning proceeds from a cloud undergoing actual diminution from evaporation.

"4th. Whether the cumular clouds, already noticed as continually forming and raining in the calm latitudes, send forth flashes of lightning; and if so, under what conditions, and with what effects."

The order of the phenomena, in the case of this storm, which give rise to M. TESSAN's observations, is thus expressed: "The flashes of lightning, of a terrific brilliancy, succeeded each other with extreme rapidity, and were almost instantly followed by tremendous claps of thunder, which were themselves succeeded by deluging showers."

### NOTE *t*. (*vide* p. 387.)

Vegetable points possess extraordinary powers of conduction, in many cases far surpassing that of the metals themselves. This property is not generally recognised; it was laid down in J. WILLIAMS' *Climate of Great Britain*, and has been revived by Mr. PINE, of Maidstone, who made the observation that a *blade of grass* is a better conductor of electricity than a *steel needle;* and that the spines upon thorns, gooseberry-bushes, &c., and, indeed, the whole creation of buds and leaves, have the property of silently drawing off and conducting away electricity. As illustrations: a Leyden jar was repeatedly discharged by a vegetable point in $4^m\ 6^s$; while the same jar retained its charge for $11^m\ 18^s$ under the influence of a metallic point. A BENNETT's gold-leaf electroscope, furnished with a branch of the shrub called *Butcher's Broom*, was powerfully affected by a charged jar, at the distance of seven feet, while an instrument, fitted up in the usual way with a metal point, was not acted on until brought within a distance of two feet. A similar instrument gave indications of electricity, by the passing of clouds at great elevations, when other ordinary instruments were inactive.

### NOTE *u*. (*vide* p. 403.)

Messrs. FIZEAU and FOUCAULT have lately described experiments, in which they have exposed Daguerrian plates to rays of light, and have measured its intensity by the chemical effects. A silver plate is exposed to the vapour of iodine; it is then placed in a dark chamber, fitted with an achromatic lens: the rays of the sun are then allowed to impinge on five or six different spots of its surface, for different periods on each: the times corresponding to each spot are preserved. The plate is then exposed to the vapour of mercury, and a series of decreasing images is thus brought out; the time corresponding to the first, or nascent image, is noted. This time, with the aperture of the lens and the focal distance, are the data for deducing comparative measurements. The following equation gives the relation between the intensities of two luminous sources, in the most general cases:—

$$\frac{I}{I^1} = \frac{t^1 \text{ tong.}^2 a^1}{t \text{ tong.}^2 a}$$

I and $I^1$ are the relative intensities when a nascent image is produced in times $t$ and $t^1$, with the angles of the lens, as seen from the focus, respectively $a$ and $a^1$.

On the 2d of April, 1844, at fifteen minutes past eleven, and on the same day at forty minutes past noon, they obtained a *maximum* of intensity, which they called 1000. On the 20th of September, at two o'clock, under a pale blue sky, the intensity was 751. The lens they employed had a focal distance of forty-five inches; and its aperture could be varied by a diaphragm from ,051 to ,118 inch. They promise to repeat their experiments.

It will be observed, that these values represent the *chemical* intensities of the light; but other experiments had led them "to regard as very probable that the luminous radiations, emanating from different sources, but which produce white light, possess *optical* and *chemical* intensities in the same ratios."*

### NOTE *v*. (*vide* p. 446.)

The declination of the magnetic needle at Greenwich from the meridian of Greenwich at the present time is 24°.

### NOTE *w*. (*vide* p. 452.)

The exceeding brilliancy of the auroræ seen by M. LOTTIN, and alluded to in a note by M. BRAVAIS, inclines me to give plates of two of the most magnificent forms which they assumed, and also to take the following descriptive extract from LARDNER and WALKER'S *Electricity and Meteorology*, vol. ii. p. 225:—

"During the winter of 1838-9, M. LOTTIN observed the auroras at Bosekop, in the bay of Alten, on the coast of West Finmark, in the latitude of 70° N. Between September 1838, and April 1839, being an interval of 206 days, he observed 143 auroras: they were most frequent during the period which the sun remained below the horizon, that is, from the 17th of November to the 25th of January. During this night of seventy times twenty-four hours, there were sixty-four auroras visible, without counting those which were rendered invisible by a clouded sky, but the presence of which was indicated by the disturbance they produced on the magnetic needle.

"Without entering into the details of the individual appearances of these meteors, we shall here briefly describe the appearances and the succession of changes which they usually presented.

---

* Vide *Comptes Rendus*, April 22, 1844.

"Between the hours of four and eight o'clock in the afternoon, a light sea-fog, which almost constantly prevailed, extending to the altitude of from 4° to 6°, became coloured on its upper border, or, rather, was fringed with the light of the aurora, which was then behind it; this border became gradually more regular, and took the form of an arc of a pale yellow colour, the edges of which were diffuse, and the extremities rested on the horizon. This bow swelled upwards more or less slowly, its vertex being constantly on the magnetic meridian, or very nearly so. It was not easy to determine this with precision, because of the motion of the bow, and the great magnitude of the circle, of which it formed but a small segment: blackish streaks divided regularly the luminous matter of the arc, and resolved it into a system of rays; these rays were alternately extended and contracted; sometimes slowly, sometimes instantaneously; sometimes they would dart out, increasing and diminishing suddenly, in splendour. The inferior parts, or the feet of the rays, presented always the most vivid light, and formed an arc more or less regular. The length of these rays was very various, but they all converged to that point of the heavens indicated by the direction of the southern pole of the dipping needle. Sometimes they were prolonged to the point where their directions intersected, and formed the summit of an enormous dome of light.

"The bow would then continue to ascend towards the zenith: it would suffer an undulatory motion in its light; that is to say, that from one extremity to the other the brightness of the rays would increase successively in intensity. This luminous current would appear several times in quick succession, and it would pass much more frequently from west to east than in the opposite direction. Sometimes, but rarely, a retrograde motion would take place immediately afterwards; and as soon as this wave of light would run successively over all the rays of the aurora from west to east, it would return, in the contrary direction, to the point of its departure, producing such an effect that it was impossible to say whether the rays themselves were actually affected by a motion of translation in a direction nearly horizontal, or if this more vivid light was transferred from ray to ray, the system of rays themselves suffering no change of position.

"The bow, thus presenting the appearance of an alternate motion in a direction nearly horizontal, had usually the appearance of the undulations or folds of a riband, or flag agitated by the wind, as represented in Plate VII. Sometimes one and sometimes both of its extremities would desert the horizon, and then its folds would become more numerous and marked, the bow would change its character, and assume the form of a long sheet of rays returning into itself, and consisting of several parts forming graceful curves, as represented in Plate VIII. The brightness of the rays would vary suddenly, sometimes surpassing in splendour stars of the first magnitude; these rays would rapidly dart out, and curves would be formed and developed like the folds of a serpent; then the rays would affect various colours, the base would be red, the middle green, and the remainder would preserve its clear yellow hue. Such was the arrangement which the colours always preserved; they were of admirable transparency, the base exhibiting blood-red, and the green of the middle being that of the pale emerald; the brightness would diminish, the colours disappear, and all be extinguished, sometimes suddenly, and sometimes by slow degrees. After this disappearance, fragments of the bow would be reproduced, would continue their upward movement, and approach the zenith; the rays, by the effect of perspective, would be gradually shortened; the thickness of the arc, which presented then the appearance of a large zone of parallel rays, would be estimated; then the vertex of the bow would reach the magnetic zenith, or the point to which the south pole of the dipping needle is directed. At that moment the rays would be seen in the direction of their feet. If they were coloured, they would appear as a large red band, through which the green tints of their superior parts could be distinguished; and if the wave of light above-mentioned passed along them, their feet would form a long sinuous undulating zone, while, throughout all these changes, the rays would never suffer any oscillation in the direction of their axis, and would constantly preserve their mutual parallelisms.

While these appearances are manifested, new bows are formed, either commencing in the same diffuse manner, or with vivid and ready formed rays: they succeed each other, passing through nearly the same phases, and arrange themselves at certain distances from each other. As many as nine have been counted, forming as many bows, having their ends supported on the earth, and, in their arrangement, resembling the short curtains suspended one behind the other over the scene of a theatre, and intended to represent the sky. Sometimes the intervals between these bows diminish, and two or more of them close upon each other, forming one large zone, traversing the heavens, and disappearing towards the south, becoming rapidly feeble after passing the zenith. But sometimes, also, when this zone extends over the summit of the firmament from east to west, the mass of rays which have already passed beyond the magnetic zenith appear suddenly to come from the south, and to form with those from the north the real boreal corona, all the rays of which converge to the zenith. This appearance of a crown, therefore, is doubtless the mere effect of perspective; and an observer, placed at the same instant at a certain distance to the north or to the south, would perceive only an arc.

The total zone measuring less in the direction north and south than in the direction east and west, since it often leans upon the earth, the corona would be expected to have an elliptical form; but that does not always happen: it has been seen circular, the unequal rays not extending to a greater distance than from 8° to 12° from the zenith, while at other times they reach the horizon.

Let it, then, be imagined, that all these vivid rays of light issue forth with splendour, subject to continual and sudden variations in their length and brightness; that these beautiful red and green tints colour them at intervals; that waves of light undulate over them; that currents of light succeed each other; and, in fine, that the vast firmament presents one immense and magnificent dome of light, reposing on the snow-covered base supplied by the ground, which itself serves as a dazzling frame for a sea, calm and black as a pitchy lake; and some idea, though an imperfect one, may be obtained of the splendid spectacle which presents itself to him who witnesses the aurora from the Bay of Alten.

The corona, when it is formed, only lasts for some minutes: it sometimes forms suddenly, without any previous bow. There are rarely more than two on the same night; and many of the auroras are attended with no crown at all.

The corona becomes gradually faint, the whole phenomenon being to the south of the zenith, forming bows gradually paler, and generally disappearing before they reach the southern horizon. All this most commonly takes place in the first half of the night, after which the aurora appears to have lost its intensity: the pencils of rays, the bands and the fragments of bows, appear and disappear at intervals; then the rays become more and more diffused, and ultimately merge into the vague and feeble light which is spread over the heavens grouped like little clouds, and designated by the name of *auroral plates* (*plaques aurorales*). Their milky light frequently undergoes striking changes in its brightness, like motions of dilatation and contraction, which are propagated reciprocally between the centre and the circumference, like those which are observed in marine animals called Medusæ. The phenomena become gradually more faint, and generally disappear altogether on the appearance of twilight. Sometimes, however, the aurora continues after the commencement of daybreak, when the light is so strong that a printed book may be read. It then disappears, sometimes suddenly; but it often happens that, as the daylight augments, the aurora becomes gradually vague and undefined, takes a whitish colour, and is ultimately so mingled with the cirro-stratus clouds that it is impossible to distinguish it from them."

## NOTE *x*. (*vide* p. 461.)

The British Government have published the first of a series of volumes of *Observations on Days of Unusual Magnetic Disturbance, made at the British Colonial Magnetic Observatories, under the Department of the Ordnance and Admiralty.* The places of observation are St. Helena, Toronto, Van Dieman's Land, and the Cape of Good Hope. The following extract from the preface by Lieut.-col. SABINE, under whose superintendence the volume is published, contains distinct evidence of the connexion between auroræ and magnetic disturbance:—

"On examining the meteorological registers at the Toronto Observatory, with reference to the appearance of aurora on the twenty-four days of principal magnetic disturbance at that station (in 1840-1), it appears that, on thirteen days of the twenty-four, the aurora was visible; and that on the remaining eleven days, the sky was either densely overcast or heavily clouded, so that the aurora, though it might exist, could not be seen.

Jan. 18, Faint auroral light.
,, 27, Auroral light in north.
Feb. 9, Densely overcast.
,, 23, Faint auroral light.
Mar. 15, Bright aurora.
,, 22, Generally overcast.
May 10, Densely clouded, with rain.
July 19, Bright aurora.
,, 22, Heavily overcast, with thunder.
Aug. 16, Brilliant aurora.
,, 23, Faint aurora.
,, 26, Overcast, with haze.
Sep. 13, Aurora, with streamers and pulsations.
,, 21, Heavily clouded, with rain.
,, 25, Bright aurora.
Oct. 9, Brilliant aurora.
,, 25, Bright aurora.
Nov. 5, Faint auroral light.
,, 6, Densely clouded.
,, 11, Densely clouded, with rain.
,, 18, Brilliant aurora.
Dec. 3, Densely clouded, with rain.
,, 14, Densely clouded.
,, 30, Overcast, with dense haze.

"The connection between aurora and magnetic disturbance, each viewed as a local phenomenon, has often been remarked: the days, in the above list, on which both occurred together, were, however, days of disturbance at Prague and Van Dieman's Island, as well as at Toronto. It would seem, therefore, that we may view the occurrence of aurora at Toronto, on these occasions, as a local manifestation connected with magnetic effects, which, whatever may have been their origin, probably prevailed on the same day, over the whole surface of the globe."

### NOTE *y*. (*vide* p. 486.)

Plate IX. represents OSLER'S anemometer, as erected at the Royal Polytechnic Institution. The following description is from the *Quarterly Journal of Meteorology*, No. VI.:—

.... "An illustrated account of Mr. FOLLET OSLER'S anemometer, an instrument that is calculated, from its exceedingly ingenious construction, to elicit not only the admiration of the lover of mechanical contrivances, but also, from the important results obtained from its workings, the warmest thanks on the part of all meteorologists to Mr. OSLER.—We may here mention, that a somewhat similar instrument, constructed to effect the same results, was for two years in operation at Swansea, in Glamorganshire, originally designed by Mr. EDMONDS, a gentleman of eminent mechanical acquirements, and improved upon by Mr. GUTCH, on whose premises, at Swansea, it was erected, and now transferred to the Royal Institution in that town; the results for the two years are at present in the Society's library. An instrument that will faithfully register every momentary variation of the wind, force of the same, and fall of rain, was a very great desideratum in meteorological science, and the results already gained from the operations of this instrument have fully realised the anticipations that were at first formed of it. The advantages of this mode of operation are various and considerable—the eye is enabled to detect at a glance the relation between the various instruments; and it would certainly appear that we are enabled more easily to work out results from this system than by any hitherto devised means. The rise of the wind generally towards noon, or about 3 P.M., is very striking, especially as summer advances, and the almost total cessation of all currents at night, is plainly shewn; the order of succession of the various winds, and their rise and fall,—the circumstances that preceded, accompanied, and followed all the variations of the thermometer, barometer, and, in fact, all the changes of this most changeable of all climates, may thus be traced, where *figures* would give no idea at all. One of these most ingenious instruments may be seen in daily operation at the Polytechnic Institution, another is erected at the Institution at Birmingham, a third at Plymouth, and several have been sent to the foreign magnetic observatories.

"The instrument consists, first, of a vane, S; the one in use at Birmingham was fifteen feet long, being made of this length the better to ensure steady action. The shorter the vane, the broader the track is of *the course*, as the pulsations are greater. Mr. OSLER is of opinion that a long streamer at the end of a short vane would answer just as well, and perhaps better. A vane of a wedge-shape form, as in the figure, Plate IX. is the one now found best to answer the purpose, for a flat vane is always in a neutral line, and therefore is not found to be as accurate or sensitive.

"At the lower end of the tube, AA, is a small pinion, B, working in a rack, which works backwards and forwards as the wind presses the vane. To this rack a pencil, C, is attached, which marks the direction of the wind on a paper, DD, ruled with cardinal points, and so adjusted as to progress at the rate of half an inch per hour, by means of a simple contrivance connecting it with a clock.

"The pressure-plate, E, for ascertaining the force of the wind, is one foot square, placed immediately beneath and at right angles with the vane; it is supported by light bars running horizontally on friction rollers, and communicating with spiral springs, so that the plate, when affected by the pressure of the wind, acts upon them, and they transfer such action to a copper chain passing down the interior of the tube, indicating the direction or main tube, and passing over the bottom roller; a light copper wire is connected to this chain, communicating with the pencil, which thus registers the force of the wind upon the same paper as the direction is marked, being previously ruled in divisions indicating pounds; the pressure-plate is connected with a series of spiral springs. Mr. OSLER much prefers a spring to any other means for ascertaining the force of the wind, because it is of the highest importance to have as little matter in motion as possible, otherwise the momentum acquired will cause the pressure-plate to give very erroneous indications. The pressure-plate is as light as is consistent with strength, as also are the bars that carry it.

"The rain-funnel, U, is an apparatus exposing an area of 200 square inches, and is fixed on the roof of the building, as fairly exposed as possible. The water collected in it is conveyed by a tube through the roof down to the registering table, and into a glass vessel, H, so adjusted and graduated as to indicate a quarter of an inch of water for every 200 square inches of surface; *i. e.* 50 cubic inches. The rain-gauge is a glass vessel three inches and a half in diameter, and five inches and a half in the straight part of the body. Connected with this vessel is a radius bar, M, of which a magnified view is given in the lower part of the plate, holding a pencil point. When the gauge is full, it discharges its contents by a modification of the syphon, made as follows:—A glass tube, open at both ends, is cemented into the bottom of the cylindrical part of the glass reservoir, over this tube a large one, closed at the top (like a small bell-glass), is placed. The smaller tube thus forms the longest leg, and the larger tube the shortest leg of the syphon. This contrivance has a peculiar advantage over the common bent syphon; for as its tubes are both straight, and of considerable size, they are not likely to be clogged by the rain water, and are most easily cleaned by passing into them a copper wire, or a strip of cane or whalebone, having a bit of tow or sponge at the end. The mode in which the syphon is brought into action is sufficiently simple: the water, having risen to the level of the top of the inner tube, drops over into the little copper tilt in the globe, R, beneath the reservoir; this tilt is divided in half by a slip of copper, and placed upon an axis, not exactly balanced, but so that one end or other preponderates. The water then drops into the end of the tilt which happens to be uppermost, and, when quite full, it falls over, throwing the water into the pipe of the globe, in which the tilt is placed. In this way an imperfect vacuum is produced in the globe quite sufficient to produce a draught in the small tube of the syphon, or the longest leg; and the whole contents of the reservoir immediately run off into a glass vessel placed for their reception. The reservoir having been released from the water, certain weights, L, raise it to its original and proper height, and the radius-bar takes the pencil back to the zero point.

"The cost of one of these instruments, complete, is 50*l.*; they are manufactured by Mr. NEWMAN, in Regent Street, who has also effected several important improvements on the original one, as constructed by Mr. OSLER."

WHEWELL'S anemometer was mentioned at Note *i*, p. 572.

"It exhibits, upon a diagram, not only the direction and the force, but the direction and integral effect of the wind, but which is more complex in its construction [than OSLER'S], and practically more liable to derangement.

"In it, a small set of windmill vanes, something like the ventilators of windows, are presented to the wind by a common vane, in whatever direction it may blow. The current, as it passes, sets these vanes in rapid motion; and a train of wheels and pinions reduces the motion, which is thence communicated to a pencil, traversing vertically, and pressing against an upright cylinder, which forms the support of the instrument: 1000 revolutions of the fly only cause the pencil to descend ,05th of an inch. The surface of the cylinder is covered with white paper, and the pencil, as the vane wavers, keeps tracing a thick irregular line, like the shadings on the coast of a map. The middle of the line may be easily traced, and it gives the mean direction of the wind, while the length of the line is proportional to the velocity of the wind, and the length of time during which it blows in each direction."*

An anemometer has been described in the *Athenæum* [Sept. 21, 1844], by Mr. GODDARD, late assistant at Lord WROTTESLEY'S observatory:—"The vane is double, similar to that of Mr. OSLER'S. It is fixed to and therefore turns with the perpendicular rod, which pierces the ceiling, reaching within a few feet of the ground, resting on the end or top of a cylinder of wood, round the circumference of which are placed, level with the top, a series of thirty-two glass cylindrical tubes of equal bore, the interstices being filled up neatly with putty or cement. Each tube represents a point of the compass; and they are intended to hold a coloured fluid, and are therefore sealed over at bottom, similar, in fact, to test tubes, only considerably larger; they are graduated so as to indicate the height of the fluid within them, which height depends *directly* on the *miles* of wind which has passed the vane in the twenty-four hours. Above the circle of tubes, in the apparatus which deposits the liquid into them, there is a contrivance affixed to the pressure-plate, by means of which the fluid is deposited at a variable rate, but always depending on the force on the pressure-plate at the moment. Thus, if, for instance, a drop per minute answered to a wind of one mile an hour, two drops per minute would shew a velocity of two miles an hour; fifty drops a minute, fifty miles an hour, and so on; and, as the tubes collect the

---

* *Vide* Report of Committee of the Royal Society, 1840, p. 71.

daily deposit, therefore, by simply reading off the daily elevation of the fluid, and noting the respective tube or tubes in which it is found, we have at once the number of miles of air which has passed the station, as well as the direction. To describe the apparatus by which the quantity of fluid is regulated, so as to flow in proportion to the wind's velocity, would require a diagram; but the general character is sufficiently obvious to give the meteorologist an idea of it. Mr. OSLER's clock is superseded by a clepsudra arrangement, and the spiral for the pressure-plate is replaced by the natural spring of water, which is far superior to any artificial spring."

But, among self-registering instruments, none seem more likely to advance the knowledge of meteorological phenomena, with giant strides, than the contrivances lately perfected by Prof. WHEATSTONE. I have been at some pains to possess myself of the details of this valuable union of mechanical and physical resources, in order to give correct views of the workings of these instruments. But, before describing one of the principal of these contrivances, I must explain another form of electricity, and its properties, of which mention has not yet been made in these pages. When plates of metal, zinc and copper, for instance, are immersed in acid water or other solution, and a metallic connection is established between them, a continuous electric action, popularly termed an electric *current*, is developed. The wire, by which the plates are connected, is endowed for the time with new properties: it has the power of deflecting the magnetic needle from its normal position, to a direction at right angles to itself; it has also the property of converting soft iron into a *temporary*, and steel into a *permanent*, magnet; for the latter purposes, the wire is of considerable length, is covered with cotton or silk, and coiled round the iron or steel. An electric current possesses various other properties; but as they are not concerned in the action of the instrument at present under consideration, we need not make any further allusion to them here.

The instrument about to be described registers the atmospheric changes by means of this property of a voltaic current to convert soft iron for the time being into a magnet.

Figure 1, Plate x. represents "The Electro-magnetic Meteorological Register," with all its parts complete: its height as it stands, with the frame, is about six feet. For the present, it is adjusted to register the range of three instruments, the barometer *a*, the thermometer *b*, and the psychrometer or wet-bulb thermometer* *c*; but it admits of the addition of two other instruments. It consist first of a regulator-clock, of which A is the pendulum and B the weight; to this clock are attached all the regularly recurring movements that require to be introduced; and, secondly, of a train, with an independent maintaining power, of which C is the weight, which is liberated and brought into play only at the moment when the observation is made. By the former arrangement the observation is *made;* by the latter it is *printed*.

In describing the action of the register, it will be enough to take the case of one instrument, the barometer for example, which, in the

---

* *Vide* p. 79.

present instance, is of the syphon construction; for what is true of that will be true of the rest. Bearing in mind what has been said of the power possessed by a voltaic current of converting iron for the time into a magnet, refer to Plate XI. fig. 2, which represents a somewhat distorted view of the back of the instrument. F is an electro-magnet, that is to say, a bent bar of soft iron, surrounded by a coil of insulated copper-wire; *k* is a keeper of soft iron, moving on a hinge at the right: in the figure it is represented in contact with the magnet, and the voltaic current is supposed to be passing: when the current ceases to pass the iron will cease to be magnetic, and the keeper will fall: in its fall, its lever-arm will strike against a peg on the lever *m*, and liberate the detent of the independent train, by which the printing is effected. So that the cessation of the current and the printing of an observation are synchronous.

The course of the current is as follows:—D is a small voltaic element, consisting of a plate of copper in sulphate of copper, and a porous tube, containing amalgam of zinc, in a cell two inches square: the current proceeds in the direction of the arrows, which are numbered in order; from the copper of the voltaic element along a covered wire (1), to the *rheotome* E, an instrument, which will be described presently; then, from the index to the section of the instrument to which the wire *g* is attached; along this wire (2) to the mercury in the longer arm of the barometer *a*, which is syphon-formed: down the mercury and round the bend (3) of the barometer to the reservoirs; up the thin wire (4 and 5) to the pulley *d*, which is affixed to a metal axis in metallic connection, of course, with the body of the clock: the path along the metal work of the clock may be shewn by the arrow 6; it thence enters the wire of the electro-magnet; and, having traversed this, it returns to the zinc of the cell by the wire 7. So long, then, as there is no break in this circuit, the electro-magnet F will retain its magnetism; but an observation will be made every time the circuit is broken. The wire 4, 5, is composed of two parts; the lower, which dips into the mercury of the barometer, is a piece of the fine steel wire of which the balance-spring of the smallest watches is made; the upper portion is a chain of a watch: the little weights, shewn on it in figure 1, are to keep it in a state of tension. Now, the axis on which the pulley *d* is supported is connected with the clock-train, and the chain is wound up by it; so that, at certain times, its terminating wire is drawn out of the mercury,—and thus, the voltaic circuit is broken, the keeper falls, and an observation is made. It is obvious that more or less of the chain must be wound up before the point leaves the mercury, according as the mercury of the barometer is higher or lower; and, therefore, if the relation between the position of the wire and the time as shewn by the dial is properly adjusted, the height of the barometer at a given time is obtained.

For this purpose the pulley *d* is in the outset made in such ratio to the range of the barometer, that in *five* minutes the point of the wire shall pass from the bottom to the top of the range,—a range, in the present instance, of *one inch and a half*. The axis is so connected with the clock-train that it winds up the wire for a space of *five* minutes; and is then thrown out of gear for the space of *one* minute, during which time the weights, assisted by another weight *e*, descend and restore the wire to its normal position, ready for a fresh ascent, and so on. So that the point of the wire leaves the mercury, and an observation is made once *every six minutes*. On the opposite side of the clock are two type-wheels, fig. 3, Plate XI. the motion of which exactly accords with the rise and fall of the above wire: the first type-wheel *o* is furnished with fifteen radii, each bearing a letter; it makes a complete revolution in thirty seconds, or two seconds for each letter; the second type-wheel, *p*, has twelve radii, ten of which present the digits, and the other two are blank; one radius of this wheel moves on for a complete revolution of the other, or in thirty seconds, so that a complete revolution is made in *six minutes*, being the exact time occupied by the barometer wire in ascending and descending: the ten radii, with the digits, correspond to the ten half-minutes or *five* minutes of the ascent of the wire, and the two blank radii, to the minute occupied in the descent of the wire, and during which no observation is made. It is, therefore, very evident, that if the voltaic cell is first charged, and connexions made, and the clock duly wound up and set, and these type-wheels and barometer wire placed in the normal position, the letter and figure shewn by the wheels will always correspond to a certain *time* and a certain *position* of the point of the wire;—to a certain *time*, because they travel with the clock-movement, —to a certain *position* of the wire, because the wire travels with the same clock-movement: and, during the *five* minutes constituting the complete cycle of the available motion of the type-wheels, the point of the wire will pass through a range of *one inch and a half*: and as the quickest type-wheel presents fifteen letters per half-minute, or 150 during the *five* minutes, 150 different heights of the mercury can be recorded, or variations equal to ,01 inch. During the course of the ascent of the wire, as already mentioned, it will, at some point or other, leave the mercury; and, by thus cutting off the voltaic current, will let the keeper fall from the magnet, and set free the independent train. With this train is connected a hammer *n*, fig. 3, which hammer is situated immediately behind the two indicating radii, and is now made to strike upon them, and print their indications on the cylinder *f*, fig. 1, in duplicate, by means of manifold paper. The cylinder *f* is mounted on an axis with a spiral screw; and by the clock-movement it revolves slowly, and is gradually carried along the axis; so that the successive observations are printed around the cylinder in a spiral direction.

Now, since each radius of the smaller type-wheel occupies *two* seconds in arriving at its place, it would often happen that the wire would leave the mercury during this very brief interval, and the consequence would be a blurred, imperfect impression; to obviate this, Mr. WHEATSTONE has attached to the instrument a species of *maintaining* apparatus, by which the current is *held on* for an instant after the wire leaves the mercury, whenever this happens *during the shifting* of the type-wheel: it consists of a rheotome G, fig. 2, not visible in the instrument itself, being behind the plate of the clock: it is a circle of sixty divisions, alternately brass and ivory, with a moving index; when the index is on the metal, connection is retained, when on the ivory, it is broken: the position of this instrument is such that the index shall touch the metal whenever the current is to be held on: it revolves once per minute.

But it is well known, that unless a keeper is placed very near a magnet it will not be attracted; in order to accomplish this, a small wheel *l*, fig. 2, is placed beneath the keeper, and made to revolve by the clock-movement: it is furnished with a little peg, that acts against a small lever, and gradually raises the keeper toward the magnet, during the inactive minute: as shewn in the figure, it has just elevated the keeper to its *maximum;* and now leaving it to be sustained by the magnet, it passes on in order that the keeper may have free space to fall when the observation is made.

From this description, we should almost be led to expect that a separate striking movement and type-wheels would be required for each instrument; but a very simple contrivance has enabled Mr. WHEATSTONE to register the indications of all the instruments by the same apparatus. E, fig. 2, Plate XI. is a rheotome, or *cutter-off of currents,* being a circle of ten sectors of brass insulated from each other by ivory: each sector has a small brass peg, to which the connecting wires are attached; the wires of the barometer, thermometer, and psychrometer, occupy *three* of these sectors; two sectors remain open for the attachment of other instruments; the remaining five are in common connection with the copper plate of the battery: the metal index completes the circuit, by connecting the right-hand sectors with one of those on the left. This index makes a complete revolution in *one hour;* and passes over each division in *six minutes;* during *five* minutes, which correspond to the ascent of the wire, it passes along the metal sector, and during the remaining *one* minute, corresponding to the fall of the wire, it passes over the ivory division to the next sector. Now, as each instrument is connected with a different sector, and each sector is insulated, only one instrument at a time is included in the circuit; so that, when the barometric observation is made, the index passes on to the next division, and introduces the psychrometer, for instance, into the circuit; and then passes on farther to the sector connected with the thermometer, and so on. In Plate X. fig. 1, are shewn the wires *h i*, and pulleys, by which the two last-mentioned instruments are included in the circuit; the range of both is from — 5° to + 95°: the scale, therefore, has a greater length than that of the barometer, and, consequently, the pulleys are larger, as shewn in the figure; in all other respects, the arrangements are similar. It will be seen, from the above description, that three observations are recorded in each eighteen minutes, one of the barometer, another of the thermometer, and the third of the psychrometer. The instrument requires no attention for a week, during which time it registers 1008 observations. The immersion of the wire in the mercury of the tubes, for the time being, slightly elevates the mercury; but as the *observation* is not made until the wire is leaving the mercury, no error is committed. As there is no necessity that the circuit should be completed with mercury, there are very few meteorological instruments to which this register cannot be applied. It is scarcely necessary to remark that the part containing the instruments must be properly exposed. We have mentioned that this register is for the Kew Observatory, where, we hope, very soon, to see it placed.

# INDEX

OF

# AUTHORS AND OBSERVERS

## CITED IN THIS WORK.

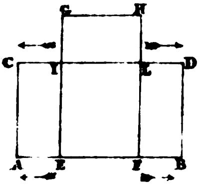
---

London : Moyes and Barclay, Castle Street, Leicester Square.

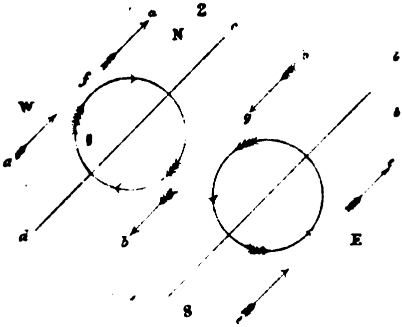
# KAEMTZ'S METEOROLOGY.

PL. II.

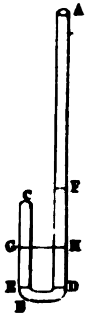
1



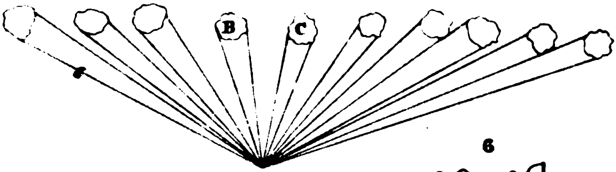
2



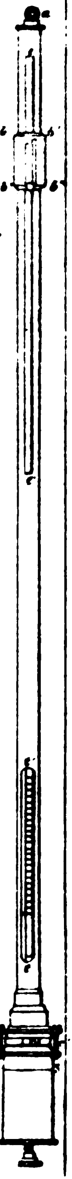
3



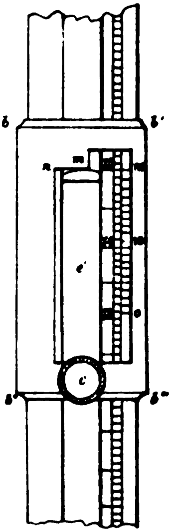
4



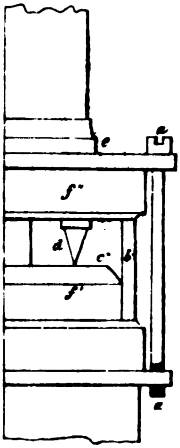
5



6

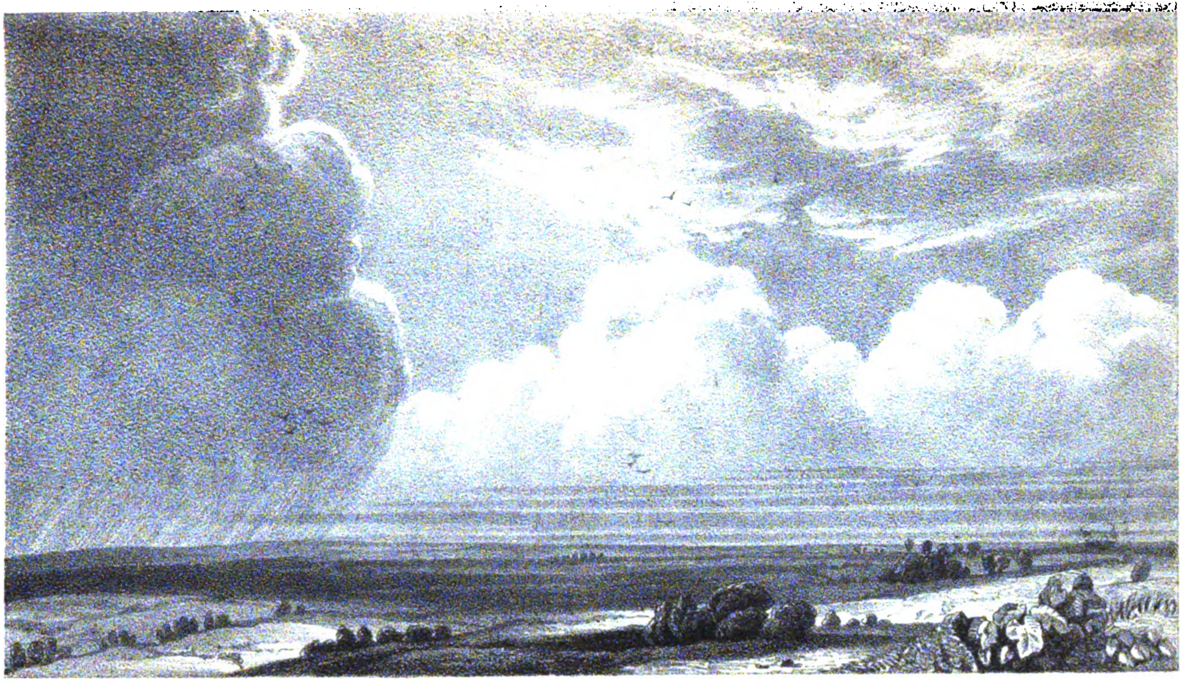


7



Haddeley litho 3 Wellington S^t Strand

London H. Baillière, 219, Regent S^t.



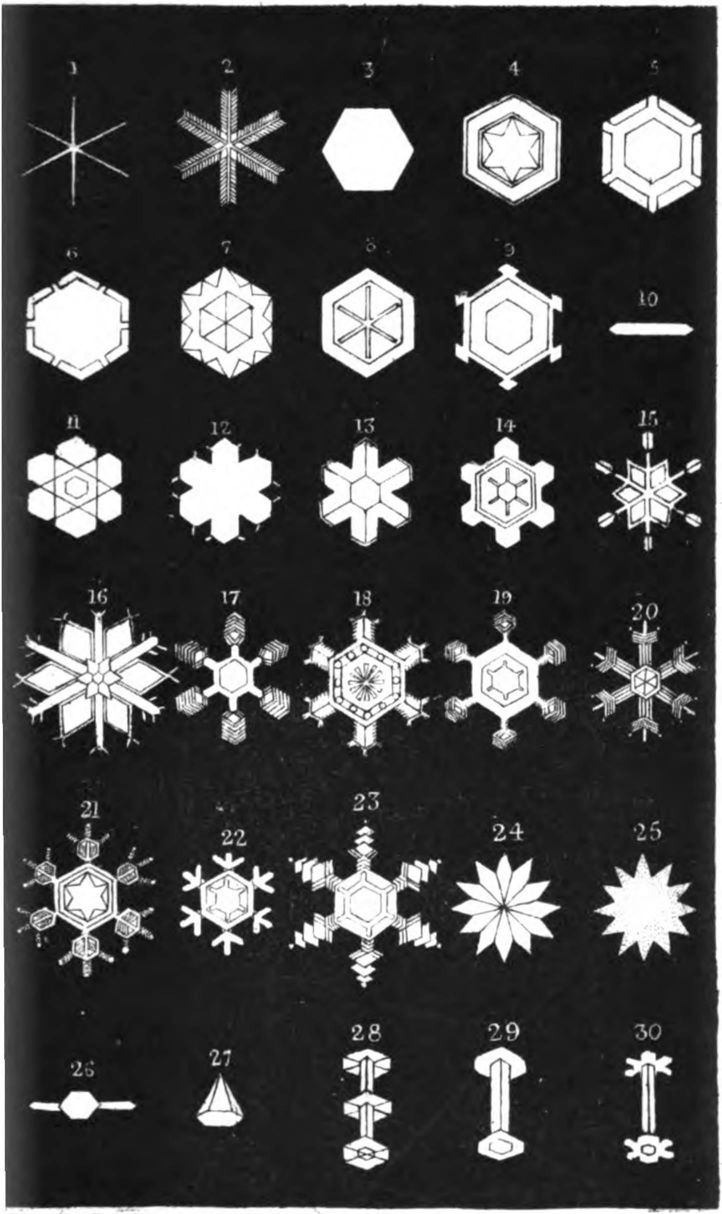
Madeley, litho 3 Wellington S^t Strand

*Stratus* *Cirrus* *Cumulus* *Nimbus*

London H Baillière 219 Regent S^t

# KAEMTZ'S METEOROLOGY.

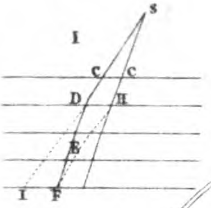
**PL. IV.**



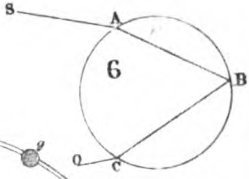
Madeley litho 3 Wellington St Strand

London: H. Baillière 219 Regent Street

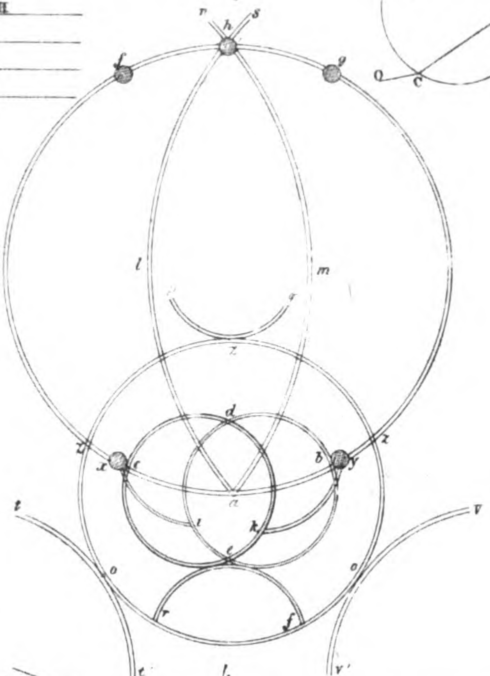
I



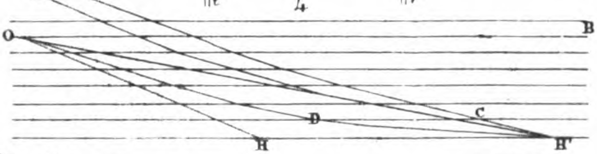
6



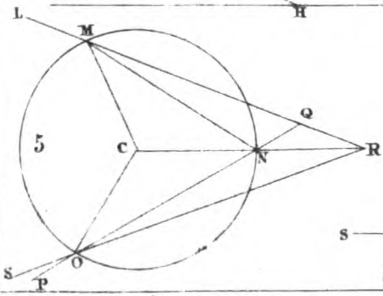
3



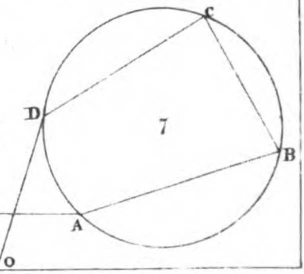
4



5



7

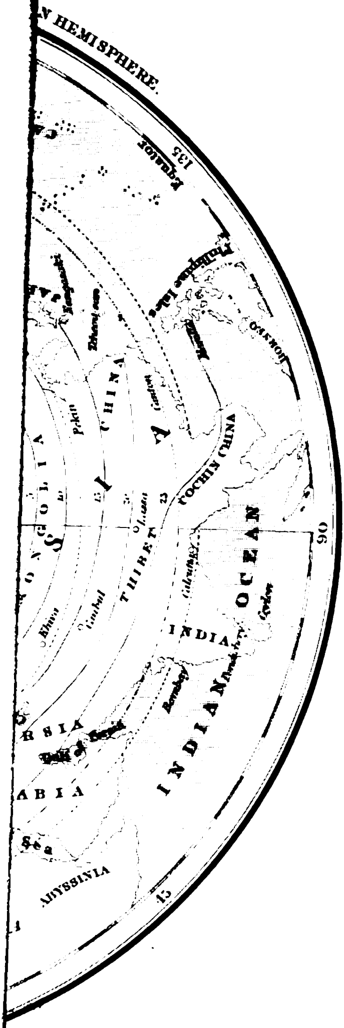


[illegible] lith 3 Wellington St. Strand

London: H. Baillière, 219, Regent St.

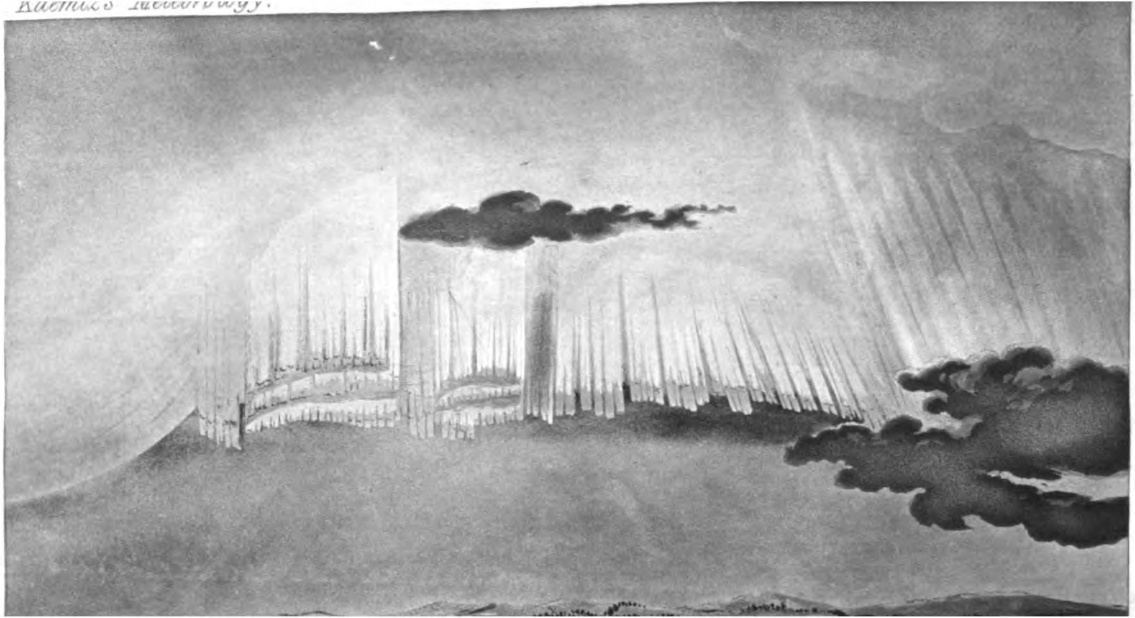
Kit

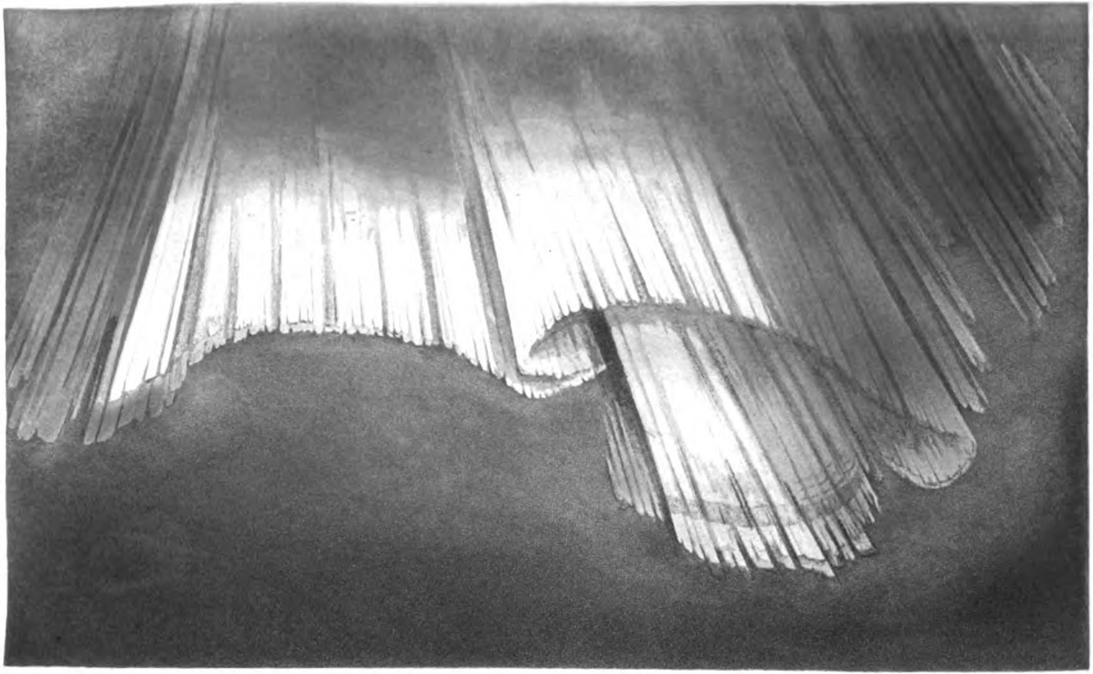
Plate VI.



N HEMISPHERE.
135
Equator
Philippine Isles
Borneo
Kamschatka
CHINA
Canton
Pekin
A S I A
COCHIN CHINA
90
THIBET
Lassa
Calcutta
OCEAN
Ceylon
INDIA
Pondicherry
Bombay
INDIAN
RSIA
Gulf of Persia
ABIA
Sea
ABYSSINIA
45

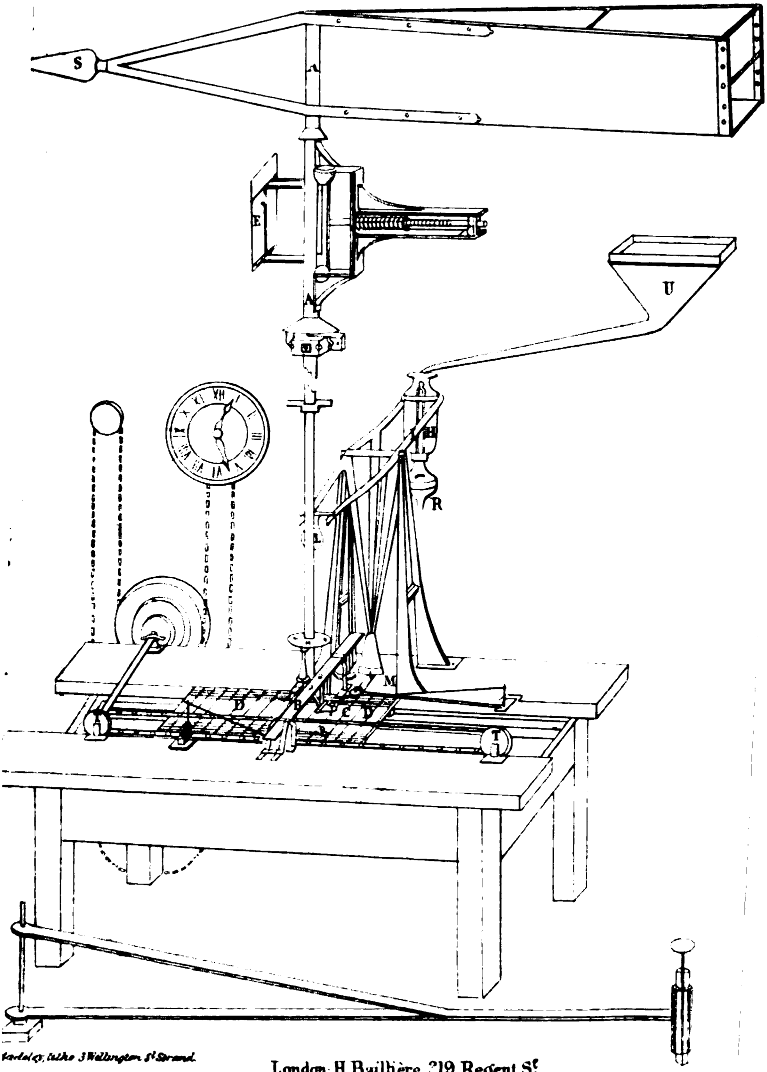
Kaemtz's Meteorology.





Aurora at Bossekop.

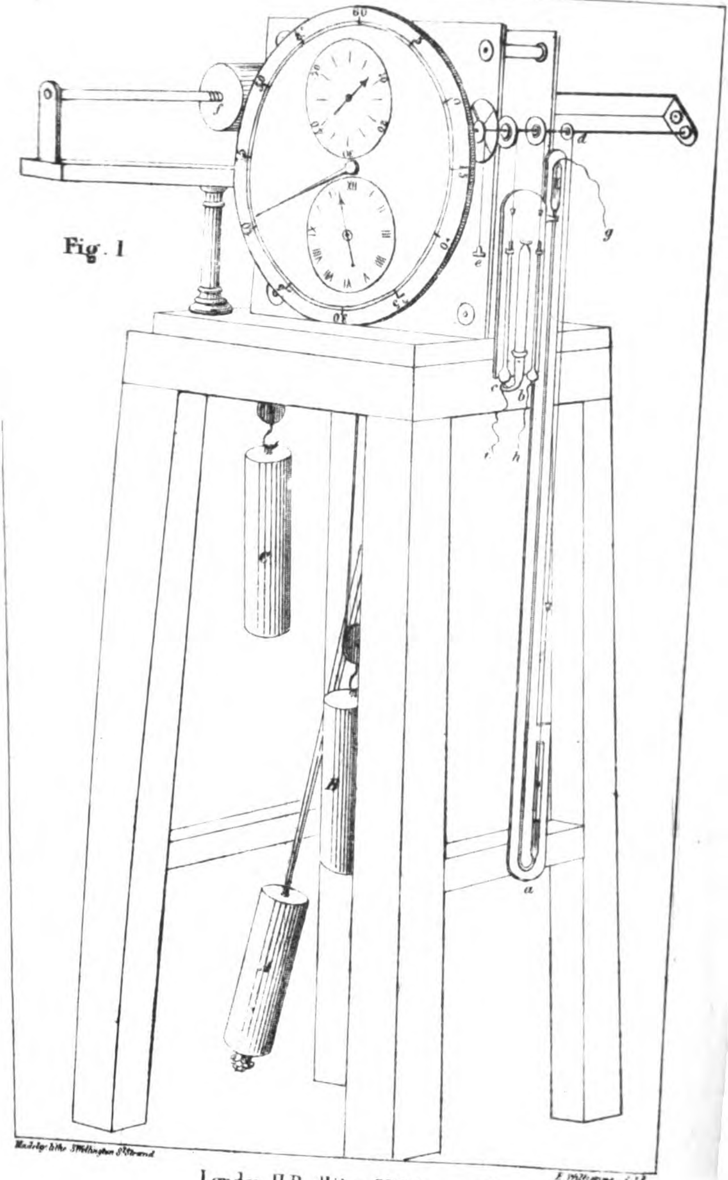
PL. IX.



Kardel&s, litho 3 Wellington St Strand.

London H. Baillière, 219, Regent St.

Fig. 1



Madeley lith. 3 Wellington St. Strand

F. Williams del.

London H. Baillière 219 Regent St.

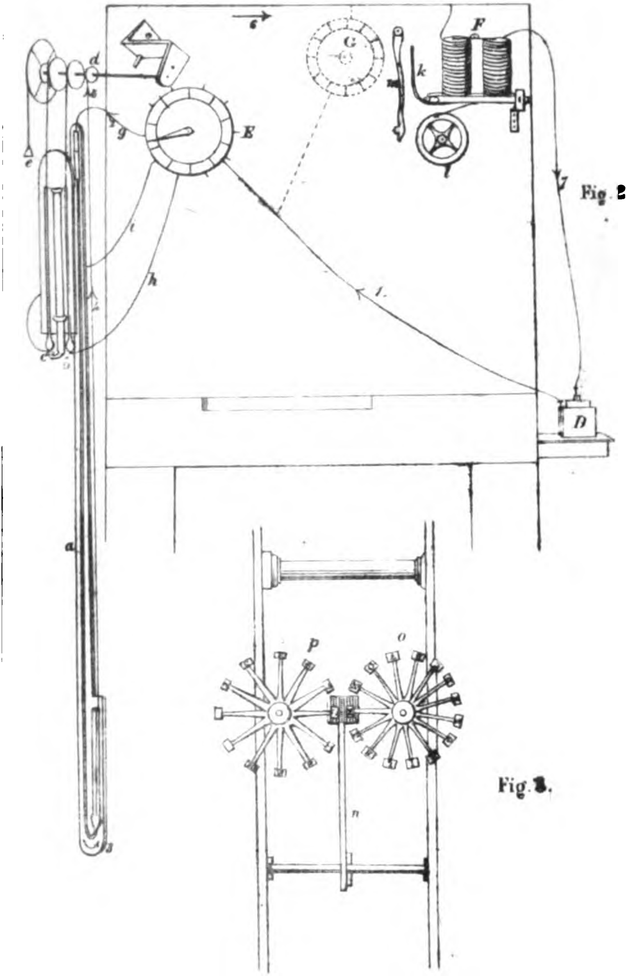


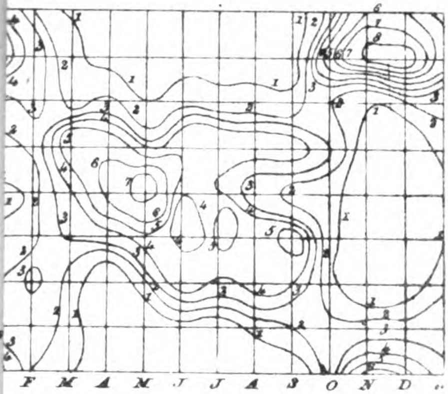
Fig. 2.

Fig. 3.

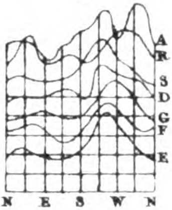
[illegible] Wellington St Strand
Williams del!
London H. Baillière. 219, Regent St

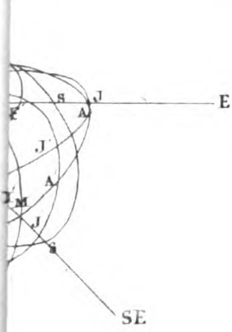
(App. Pl. 1.)

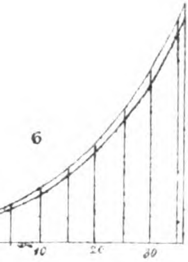
4.



5.

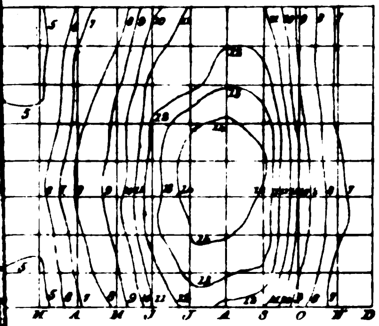




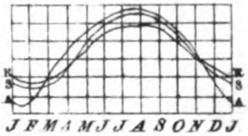


6

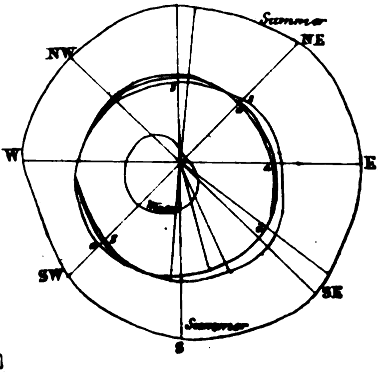
9.


M
A
M
J
J
A
S
O
N
D
5
5
13
24

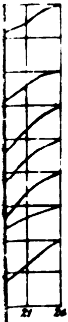
14.


K
S
A
J F M A M J J A S O N D J

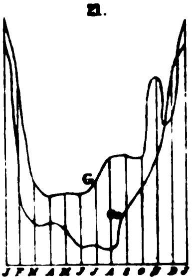
17


N
Summer
NE
NW
W
E
SW
SE
Summer
S

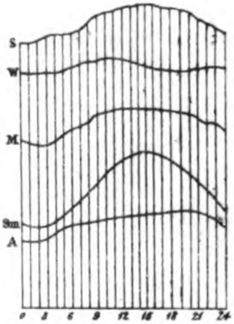
(App Pl 3.)



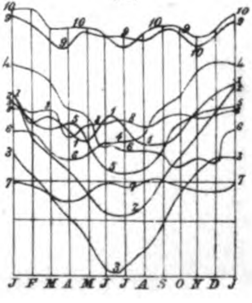
28.



29.

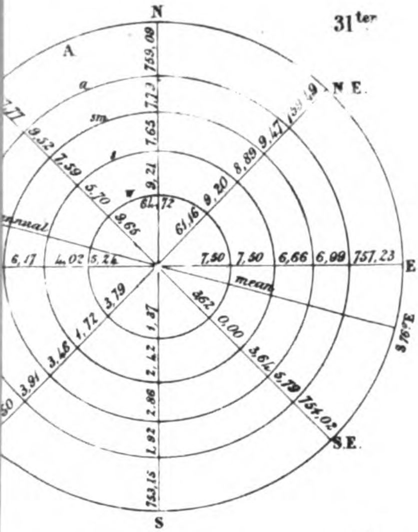


30.

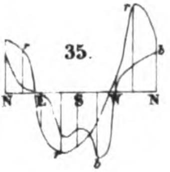


Madeley lithe

31ter

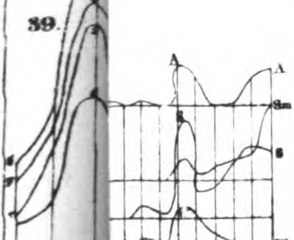


35.

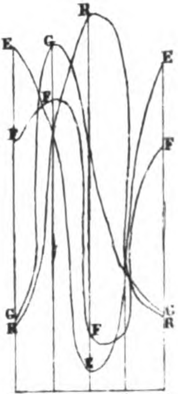


37.

39.



42.



Maddy Litho.