pass into one another by such imperceptible shades, and their sensitive existence differs so widely from our own, that we have properly no measure by which to fathom their reasoning powers. As well might we hope to discover the origin of the *punctum saliens* in the incubated egg, as to determine the point where the dawn of intellect appears, or assign the boundary where instinct assumes the form of reason. Nothing is simple in nature: all that we see is the effect of prodigious art: means are accumulated for the production of remote ends, in a series extending far beyond the sphere of our limited optics. We can discern clearly but a few of the final causes in nature, and but a few of the powers that operate in their accomplishment.

Art. X. *Tables Barometriques Portatives, donnant les differences de Niveau par un simple soustraction,* &c. Par M. Biot. pp. 75. 8vo. Paris, 1811.

This little tract first appeared in the second edition of the *Astronomie Physique*, an elementary work published by the same ingenious author in three volumes, possessing very considerable merit, and which we may perhaps hereafter have occasion to examine. It is now, with some additional introductory matter, printed in a separate form, for the use of travellers, naturalists, and military surveyors, who are either unacquainted with the niceties involved in the general *formulæ* for computing heights barometrically, or who consider the ordinary mode of calculation as intricate, and find it inconvenient to carry along with them a complete table of logarithms, which becomes requisite in such operations. The utility of such aids to the geological observer, appears to have been felt in other parts of Europe; for we have seen a neat short piece in German, published nearly about the same time, and drawn up in a very popular manner, with a set of concise tables, by Benzenberg, who is advantageously known to the scientific world by his experiments on the declination of falling bodies towards the east, in consequence of their partaking of the rotatory motion of the earth.

The barometrical tables which Biot has constructed, are sufficiently simple and commodious; but, from their affected brevity, they need a farther application of proportional parts, which is often troublesome in practice, and is not very familiar to such as are imperfectly acquainted with calculation. This obvious defect might indeed be supplied by the help of other subsidiary tables. The quantities, besides, are all expressed after the new metrical system of the French; and it would be irksome to reduce them in every case to our standard. But, on the same principles, we might easily, if other expedients should not be preferred, form tables entirely adapted to the English measures.—Before we proceed, however, to the examination of these principles, our readers will permit us to pause, and to retrace the successive steps which led to the invention of the Barometer itself. The circumstances relating to this great discovery, which constitutes an epoch in the history of physical science, have, though now seldom noticed, been faithfully recorded. They exhibit the human mind struggling with inveterate prejudice, and gradually assuming the courage necessary for the adoption of truth; and thus combine to form a very interesting and highly instructive picture.

It is but justice to acknowledge, that we owe the rise of experimental philosophy to the obscure toils of the alchemists. This meritorious class of men, in the pursuit indeed of unattainable objects, and prompted often by the most visionary speculations, had yet the sagacity to perceive, that the only sure mode of investigation consists in the appeal to fact; and, not satisfied with vague observation, from which the ancients appeared to derive so little benefit, they laboured to extort the secrets of nature by that artificial exclusion of circumstances which afterwards obtained the name of *experiment*. The revival of letters, which was then beginning to irradiate the nations of Europe—to refine their taste, and correct their judgment—did scarcely, it must be confessed, contribute in any degree to the advancement of physical science. The Arabians, after a brilliant career of victory, sought to cultivate the arts of peace; and adopting with eagerness the geometry and astronomy of the Greeks, applied their persevering industry to improve those departments of knowledge which more immediately depend on the accession of facts, and the accumulation of details. They noted carefully the appearances of the heavens, and were enabled, from a comparison of the results, after the revolution of so many centuries since the times of Hipparchus and Ptolemy, to rectify in some essential points the theories of the Greek astronomers. They likewise applied themselves with diligence to the study of alchemy, which, in the decline of the Eastern empire, had begun to be cultivated at Alexandria, and afterwards at Constantinople. That dark science proved the more attractive to the Arabian inquirers, as they were particularly attached to the practice of physic; and therefore led, in the search after new and potent medicines, to the analysis of animal, vegetable, and mineral substances. They discovered the art of distillation, with other useful processes; and invented various chemical vessels and apparatus, which still retain their names.

By the conquest and occupation of Spain, the Arabians, under the appellation of Moors or Saracens, carried their science into Europe. The invaluable art of ciphering, joined to a taste for alchemical researches, was liberally communicated to their Christian visitors. A number of ingenious individuals dispersed through different countries, yet united by similarity of views, were thus induced to relinquish the ancient practice of loose observation and random conjecture, and to apply themselves assiduously, in the recesses of their elaboratories, to a scrupulous investigation of the combinations of Nature.

In their laborious inquiries, the alchemists were often prompted, indeed, by motives less honourable than those of a refined curiosity; but they sought for the possession of facts, and only borrowed so much of theory as would serve to invest their discoveries with a sort of mysterious glare. The early sages of Greece had distinguished matter into the four primary elements of earth and water, air and fire, which, by their various composition, were supposed to produce the animated spectacle of the universe. Earth and water were considered as ponderous and inert; but air and fire, endued with elastic virtue, were imagined to possess the qualities of lightness and activity. Fire, contained in all bodies, and developed in the operations of nature or art, was conceived to be derived by emanation from that diffusive shining fluid, which, under the name of ether, occupied the highest heavens, and constituted the substance of the celestial orbs. But Aristotle and other philosophers, holding ether to be altogether distinct from culinary fire, were disposed to regard it as a fifth element, of a pure and incorruptible nature; which gave occasion to the famous *quinta essentia*, or *quintessence* of the schoolmen. The alchemists, adopting these notions, accommodated them to their own particular views. To the elements commonly received, they joined the active ingredients of *mercury* and *sulphur*. Quintessence was represented by *spirit* and *elixir*: the former, drawn off by the application of fire, exhibited the animating principle of each body; and the latter, extracted by the combined action of heat and humidity, showed its concentrated and most select qualities. Following out these ideas therefore, it was quite natural, though in the highest degree chimerical, for such enthusiasts to fancy their elixir to be capable of prolonging, to indefinite extent, the term of human life.

The alchemists, or philosophers by fire, as they were called, had the merit of forming the first associations for the prosecution of experimental inquiries. The obscure sect known by the fanciful title of *Rosicrucians*, and which sprung up in Germany, a country long noted for its mysticism and its skill in the processes connected with mining, appeared on the whole to tread in the right path of induction. Their tenets insensibly spread over the Continent, and took root in the matured soil of Italy, where philosophy, coming to succeed the cultivation of letters, wore a more attractive garb. The religious controversies agitated about that period, which led to the memorable schism in the Catholic Church, and which, by their hostility to the elegancies of life, and their baneful influence on the general morals, visibly retarded the progress of society, were yet in the end not altogether unfavourable to the bold and active spirit of physical research.

Baptista Porta, a Neapolitan nobleman, who flourished about the close of the sixteenth century, was particularly distinguished by his zeal in promoting such pursuits. Having spent many years in travelling over Europe to gain information respecting natural objects, on his return home he invited a few individuals of a similar taste, who regularly assembled at his house, and occupied themselves with making new experiments. These meetings, however, gave umbrage to the watchful jealousy of the clergy; and they were at length suppressed by a mandate from the Court of Rome. But to that humble association we are probably indebted for the discovery of what is called the radiation of cold; one of the most interesting facts in the range of modern physics. It seems to have been detected about the year 1590, and is first mentioned in the seventh edition of Porta's *Magia Naturalis*. From the description there given of this curious experiment, we learn, that it must have been performed before the invention of the thermometer. A ball of snow being placed at some distance in front of a concave speculum or metallic reflector, and the eye held in the focus, a glare of whiteness was perceived; and, on shutting the eyelid, an intense cold was likewise felt. *—The example of Baptista Porta was imitated in other parts of Italy, where the Papal authority was less respected; and academies, for the promotion

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* Some of our readers will be glad to see the original words.

'Si quis candelam in loco ubi spectabilis res locari debet, opposuerit, accedet candela per aërem usque ad oculos, ut illos calore et lumine effendet, hoc autem mirabilius erit, ut calor, ita *frigus reflectitur, si eo loco nix objiciatur, si oculum retigerit, quia sensibilis, etiam frigus percipiet.* Sed res admirabilior est, quod idem speculum non solum calorem et frigus, sed vocem refringet.'—*Magia Naturalis*, XVI. 4.

of natural science, were successively instituted under the patronage of different princes, especially those of the illustrious House of Medici.

In this ferment of inquiry, Galileo arose, fitted alike by the gifts of nature and the lights of education to be the founder of experimental science. His elegant genius was invigorated by the study of the Greek geometry; and he conceived the happy and prolific idea, of employing that refined instrument to explore facts and combine the results.—The mutual opposition of the principal sects of antiquity had in general most fatally discouraged the application of mathematical reasoning to the system of the material world. The adherents of the Academy, who cultivated geometry with ardour and brilliant success, regarded it as pure intellectual contemplation: but the followers of Aristotle, while they neglected that noble study, yet recommended the appeal to external observation, as the only sure ground of natural philosophy. The towering mind of Archimedes, indeed, had anticipated the road of discovery. The philosopher of Syracuse not only improved the powers of geometrical analysis, and widely extended its dominion, but he applied it most successfully to some elementary parts of mechanics and hydrostatics. This however was a solitary instance, unheeded by the industry of succeeding ages. The ingenuity of Galileo prepared a complete revolution in science. The simple experiments by which he established the laws of motion, when exhibited by him on a grand scale before the Senators of Venice in the public arsenal, appeared so contrary to common apprehension, as to fill the beholders with wonder and surprise. These laws, detected near the surface of our globe, were transferred by Galileo to the celestial spaces; and the publication of his *Dialogues*, which unfold the process of induction, and which are not less distinguished by fineness of conception than by the beauty of arrangement and composition, form a new era in the annals of philosophy. It was the fame of that work, which, by provoking the jealousy and perhaps envy of the clerical order, occasioned the memorable persecution, and dragged the geometer in his declining years before the dark tribunal of the Inquisition. *

Near the same period, a progress of a less aspiring kind, but conducted on similar principles, was made in a different quarter. Stevinus, mathematician to the famous Prince Maurice,

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* The war-whoop was first sounded against Galileo, in a furious sermon preached by a mendicant friar, from a text which he had converted into a pun. '*Viri Galilæi, quid statis aspicientes in cælum?*'—'*Ye men of Galilee, why stand you gazing up into heaven?*' Acts I. 11.

about the beginning of the seventeenth century, revived, in the Netherlands, where the practice of engineering was then better understood than in any other part of Europe, the mechanical discoveries of Archimedes, and determined the conditions of equilibrium both in solids and liquids. But pneumatics, or the science of the statical action of air, was still uncultivated. Though various machines immediately depending on the operation of that fluid had already been constructed, yet its fundamental properties remained unknown, or utterly misconceived. The weight of the air, its pressure and elasticity, were all equally overlooked.

In a neighbouring country, the genius of discovery took a higher flight. Germany has the honour of giving birth to Kepler; a man of transcendent capacity, who, to unrivalled acuteness and penetration, joined the most indefatigable perseverance, urged onwards by a powerful though fiery and irregular imagination. His life was a continued scene of toil, vicissitude, and misfortune. Kepler had neither wealth nor leisure sufficient to enable him to pursue experimental researches himself; but he exerted all his talents in examining the observations of others, and in tracing the secret analogies which might connect their seemingly discordant parts. In his early attempts to explore the relations subsisting between the periods and distances of the planets, he was indeed unsuccessful; having wasted his prolific ingenuity in working on the dreams of the Pythagoreans concerning figure and number. The labours of Tycho Brahé at last supplied him with a vast collection of correct though multifarious observations; and, with redoubled ardour, he set immediately about the task of arranging, digesting, and comparing those invaluable materials. He had embraced the Copernican system of the world as the most consonant to reason; but he was soon convinced that the eccentrics and epicycles which it had retained would not exactly correspond with the phenomena. Pursuing still farther his inquiries, he found that no combination of circles, which the ancients had fondly regarded as alone befitting the celestial movements, could be reconciled with the observations actually recorded. Kepler, now driven from every hold, at once abandoned those inveterate notions; and prosecuting a train of most involved and irksome calculations, unassisted then by the powerful aid of logarithms, which the immortal Napier had just invented, he after trying a variety of hypotheses, finally in 1618 obtained a glimpse of the true constitution of the heavens. In relating that happy conclusion, his fervid genius breaks forth in a burst of enthusiasm, exclaiming in the language of Virgil—*sera, tamen respexit inertem!* It was hence ascertained, that the planets, describing equal areas in equal times, revolve in ellipses about the sun, which occupies the focus; and that the cubes of the mean distances are proportional to the squares of their periods;—two fundamental laws, which the still superior sagacity of Newton afterwards reduced to the single principle of gravitation;—thus finely harmonizing the system of the universe.

The lofty discoveries of Kepler being carried to Italy, kindled fresh ardour. Galileo had been invited, with a munificent appointment, to live under the patronage of Cosmo dei' Medici; and, occupied intensely with astronomical pursuits, but occasionally unbending his mind with elegant recreation, he passed almost the whole remainder of his days at the villa of Arcetri near Florence, in a style of comfort and even splendour. The telescope was recently come in aid of the powers of vision, and the Tuscan philosopher had, from some obscure hints, reinvented and improved that exquisite instrument, which he directed assiduously to the phases of the heavenly bodies. New worlds were thus disclosed, which reflected triumphant evidence on his former investigations. But in the midst of this brilliant career, Galileo was not altogether indifferent to the objects more immediately connected with his earlier studies. It was especially interesting to estimate the action of mechanical force in the equilibrium of fluids.

The ancient philosophers generally believed the air to possess inherent levity. A few indeed, probably deceived by the facility with which the particles of a fluid move among themselves without betraying any weight, imagined it to have a quality of absolute indifference, and to be neither light nor heavy. Aristotle, who affected originality of conception, held that air is naturally heavy, without perceiving at all the consequences to which this opinion leads. In confirmation of his tenet, he goes so far as to allege, that a bladder gains weight by being blown; an observation which he certainly had never made; for if the bag was filled with a fluid like the surrounding atmosphere, it would weigh exactly the same as before; and if we suppose it even to contain an admixture of carbonic gas from the lungs, the difference thus occasioned would be so extremely minute, as to escape the detection of any balance constructed in ancient Greece. In opposition, likewise, to the doctrine of Democritus and Epicurus, the philosopher of the Lyceum held the existence of a *plenum*; and maintained, that a void is, in the nature of things, impossible. The admission of certain *occult qualities* furnished him with an explication of the phenomena, as easy and ready as the practice of some of our common-sense metaphysicians, who, cutting short all inquiry, are accustomed, when they meet with any difficult appearance, to regard it as an ultimate fact. These principles, being clothed besides with figurative expressions, were calculated to engage the fancy, and to satisfy a vague and indiscriminating curiosity. The observation was familiar, that the lower end of a syringe being dipt in water, on drawing up the plunger, it was immediately followed by the rise of the liquid; and Aristotle imagined, that he assigned the actual cause of suction when he ascribed it to *nature's abhorrence of a void.* This physical axiom, with other tenets of the Peripatetic sect, was, under the designation of the *fuga vacui,* embraced by the schoolmen, who blended with it their own theological visions. To create a void, they maintained, was barely within the circle of Omnipotence; but exceeded the utmost powers of angels or devils. In the progress of the arts, however, an incident about this time occurred that shook the received creed, and finally uprooted an opinion which had been strengthened by the implicit consent of ages. Some workmen, employed by the Grand Duke of Tuscany, had occasion to sink a well of unusual depth, to which they adapted a lifting pump; but, notwithstanding infinite pains taken by them to secure the joints, and render the machinery perfect, they found, after repeated trials, and to their great surprise and mortification, that with all their efforts they could never make the water to rise in the barrel of the pump, higher than 18 palms, or about 32 feet. In this dilemma they were directed to consult with Galileo, whose talents commanded universal respect and admiration. The Tuscan philosopher, though he devoted himself chiefly to the observation of the heavens, had yet made some important steps in the science of Pneumatics. He was the first who ascertained the weight of air by experiment; and, considering the delicacy of the operation, and the rudeness of the apparatus at that time, he made a tolerably near approach to the truth. By means of a syringe, he forced a large quantity of air into a copper vessel fitted with a valve, and found how much weight the vessel had thereby gained; he then let out the condensed air under a glass receiver filled with water, and measured the bulk of the fluid now displaced. He thus found, that air is 400 times lighter than water, being about double the true estimate. It may to us appear singular, that Galileo, knowing air to be capable of such a degree of compression, should not have perceived that its particles must have previously been divided, by proportional interstices: the idea of interspersed vacuities was less difficult in the conception than that of an absolute and separate void. Still more strange, we may think, it was, that having determined the weight of air, he did not pursue the consequences, and infer the existence and effects of atmospheric pressure. He stopt on the verge of a grand discovery. Such, even where capacity shines pre-eminent, is the slow and gradual progress of the human mind!

To the artificers who consulted him, Galileo replied, that though nature indeed abhors a *vacuum*, there is a certain limit to that horror, and which is equivalent to the pressure of a column of water eighteen palms in height. Conformably to this very flimsy hypothesis, he points out, in the last of his Dialogues, a method of determining the force or *virtu*, as he terms it, of a vacuum. A smooth hollow cylinder, with a piston fitting in it, and rammed close to the end, which is then exactly shut up, being held in an inverted position, additional weights are continually appended to the piston-rod, until it is pulled down.—The limitation of an inveterate prejudice was a direct step towards its final destruction. Galileo, on farther consideration, began to suspect the justness of the explication which he had given: but it was too late for him to attempt innovation. The philosopher, now far advanced in years, was besides loaded with bodily infirmities, and his spirit broken by the persecution he had suffered. Recommending it to his friend and pupil Torricelli to resume the investigation of the subject, he expired in 1642, the very year in which Newton was born. His uniform kindness and urbanity had rendered him extremely beloved; and his disciples, particularly Torricelli and Viviani, venerating his memory, caught the same taste, and followed similar pursuits. Both of them alike imbued with the elegance of the ancient geometry, the latter extended the boundaries of that science, while the former directed it chiefly to physical research. The happy idea of exhibiting the operation of the pump on a small scale, by substituting a column of mercury, which is nearly fourteen times heavier than water, was first communicated by Torricelli to his friend Viviani, who performed the experiment with success in 1643. He next repeated and varied it himself. The method which he adopted, brought very neatly together all the circumstances affecting the question. Having selected a glass tube of moderate width, and about four feet long, he sealed hermetically one of the ends, or closed it up under the flame of a blow-pipe; then, filling the tube with quicksilver, he applied his finger to the open end, and inverted it in a bason, containing likewise quicksilver, though covered with a portion of water: The mercury sunk instantly to about the height of thirty inches above the lower surface; but, on raising the tube a little, the mercury run all out, and its place was occupied by the water, which sprung up to the top, and filled the whole of the cavity. It was therefore proved that the water and the mercury were each supported in the tube by the same counterpoise, and which Torricelli after some hesitation concluded at last to be the weight or pressure of the external atmosphere. He now converted the mercurial column into a commodious instrument for observation; having bent the lower end of the tube and formed what has since received the name of the *syphon barometer.* With this instrument he next detected likewise the variation of the atmospheric pressure, which he communicated to his friend Ricci in the following year. The result of the whole was published in 1645. But Torricelli did not live to enjoy the renown of his great discovery; and this most promising genius was cut off by a fever in the flower of his age.

The prosecution of the subject was transferred to another genius of the highest order, and one of the finest and most original that France has ever produced; a genius which burst forth like a meteor, and after a few bright corruscations, was lost in darkness. Pascal had shown premature and extraordinary talents, which were encouraged by his father, himself a man of learning, and who lived in habits of intimacy with the philosophers of the capital. In the twenty-fourth year of his age, he happened to be residing at Rouen, where, through the medium of Father Mersenne, an able mathematician, who from Paris kept up an extensive and learned correspondence over Europe, he was made acquainted in 1646 with the famous Italian experiment, but without being informed of the conclusion which Torricelli had drawn from it. He immediately set about repeating it on a large scale. He had before suspected the accuracy of the principle, that 'nature abhors a vacuum,' and thought that many circumstances, and particularly the condensation and rarefaction of the air, point to a different conclusion, and prove at least, that it can be admitted only in a qualified sense. An opportunity was now presented for bringing the question to a decision. Pascal performed with that view a number of satisfactory experiments, of which we may select the most striking: 1. Having fitted a piston into a glass tube and rammed it quite down, he applied his finger close to the lower end, and plunged the whole under water; then drawing back the piston, which was done with ease, the finger felt strongly and rather painfully attracted, while an apparent vacuity was formed above it and continued to enlarge; but instantly, on removing the finger, the water contrary to its nature darted up and filled the whole of the cavity. 2. A glass tube about fifty feet long, sealed hermetically at one end, and filled with water, or rather red wine, to make it more visible, was inverted perpendicularly on a bason: the liquor immediately subsided, leaving a vacant space of fifteen feet; but on gradually inclining the tube again, it mounted higher, and continued to rise till it struck a sharp blow against the top of the glass. 3. A scalene syphon, with one leg fifty-five feet long and the other only fifty, being filled with water and planted on two basons containing the same liquid, and so placed that the shortest branch stood perpendicular; the water sunk in both to the same level, at the height of about thirty-four feet, without being attracted as usual to the longer branch: but the syphon being inclined below that level, both columns of the liquid united, and a flow towards the lower bason commenced; and restoring the syphon to its erect position, the water separated at the top, and subsided in each branch as at first. The same experiment was likewise performed, with quicksilver in a syphon, which had one leg ten feet long and the other nine and a half; this dense substance dividing itself into two columns, which remained suspended each to a height of near thirty inches. 3. A glass tube or syringe, with a piston nicely fitted to it and pushed quite down, had its lower end immersed in a bason of quicksilver: on gently pulling up the piston, it was close followed by the quicksilver, which continued to rise about twenty-nine inches, where it remained, leaving the piston then to form an apparent vacuity. In this state also, the syringe weighed exactly the same, whatever was the capacity of the vacant space. From these and a variety of similar experiments, Pascal drew his inferences with a caution which, we might now think, bordered on timidity. He concluded that all bodies have a reluctance to a visible separation, or that nature abhors an apparent void; that this reluctance is exactly the same for a great, as for a small interval or vacuity; and that the force is limited, and exceeds not the pressure of a column of water thirty-three feet in height. He next adventured a step farther, and inferred that this apparent vacuity was not filled by air lodged in the pores of the glass, or derived from external filtration; that it contained no subtile matter secreted from the atmosphere, and was not occupied by mercurial vapours or spiritous exhalations; in short that a real and absolute *vacuum* had been formed.

Pascal designed to compose a work relative to these inquiries; but thought proper in the mean time to publish a short extract, which appeared in 1647, and involved him in immediate controversy. Father Noël, rector of the Jesuits' college at Paris, keenly attacked that piece, armed with all the wretched contentious sophisms of the schools, and backed by the dogmas of the Romish church. He contended that the space above the mercurial column was corporeal, since it was visible and admitted light; that a void being a non-entity, cannot have different degrees of magnitude; that the separation produced in the experiments was violent and unnatural; and he *presupposed* that the atmosphere, like blood, containing a mixture of the several elements, the fire and the finer portion of the air were detached from it, and violently forced through the pores of the glass, to occupy the deserted space. To these fantastic and hypothetical objections, Pascal replied with that acuteness and strength of argument, which were afterwards displayed in his famous *Lettres Provinciales*. But it was much easier to confute than to convince an antagonist like Noël. The Jesuit quickly returned to the charge, and was ready, with his store of syllogisms, to meet every difficulty; to explain all that was already known, or that would ever be discovered. His former objections were again repeated and spread out; and in a tract of some length, published by him under an imposing form, and with the punning title of *le plein du vuide*, he dropt, in the bitterness of dispute, some expressions not very consistent with Christian charity, and which drew on his reverence a severe castigation from Pascal's father.

Though averse to abandon the maxims of antiquity, without the most cogent reason, the young philosopher had yet begun to perceive that the idea of abhorrence cannot in strict logic be applied to Nature, which is a mere personification and incapable of passion. He was therefore inclined by degrees to adopt the clear and disembarrassed opinion of Torricelli, with which he had now become acquainted. * But aware of the pliant and slippery disputation of the schools, he was anxious to devise an experiment which by its result might silence all opposition. In casting about for that purpose, it happily occurred to him, that, if the suspension of the mercury in the Torricellian tube were caused by the weight of the atmosphere, it would be affected by the quantity of the superincumbent mass, and must therefore diminish proportionally in the higher situations.

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* We cannot resist the pleasure of quoting a judicious remark, which Pascal makes on this occasion:—

'Ce n'est pas en cette seule rencontre, que quand la foiblesse des hommes n'a pu trouver les véritables causes, leur subtilité en a substitué d'imaginaires, qu'ils ont exprimées par des noms spécieux qui remplissent les oreilles, et non pas l'esprit: c'est ainsi que l'on dit, que la sympathie et antipathie des corps naturels sont les causes efficientes et univoques de plusieurs effets, comme si des corps inanimés étoient capables de sympathie et antipathie; il en est de même de l'antiperistase, et de plusieurs autres causes chimeriques, qui n'apportent qu'un vain soulagement à l'avidité qu'ont les hommes de connoître les verités cachées, et qui, loin de les decouvrir, ne servent qu'à couvrir l'ignorance de ceux qui les inventent, et à nourrir celle ed leurs sectateurs.'

He was no less fortunate in the selection of a convenient spot for the experiment, and in the choice of a judicious observer. In November 1647, he wrote to his brother-in-law, Perier (a counsellor who held an office of considerable trust in the province, and commonly resided at Clermont in Auvergne) explaining those views, and desiring him to note the altitude of the mercurial column at the base, and on the summit of the Puy de Domme, a lofty mountain which rose in the neighbourhood of that city to an elevation, as was estimated, of about 500 toises, but ascertained near a century afterwards, by the measurement of Cassini and Monnier, to be 557 toises, or 3565 English feet. Perier was prevented, by absence from home and other unavoidable impediments, from making the experiment until the 19th of September in the following year. Early in the morning of that day, he invited a few curious friends to meet him in the garden of a monastery situate in the lowest part of Clermont, where he brought a quantity of quicksilver, and two tubes sealed hermetically at the top. These he filled, and inverted as usual, and found the mercury in both to stand at the same height, of 26 inches and 3½ lines (28 inches English). Having left one of the tubes in this situation, he proceeded with the other towards the mountain, on the summit of which he repeated the experiment; when his party were astonished and delighted to see the mercury sink more than three inches under the former mark, and remain at the height of 23 inches and 2 lines (24.7 inches English). In his descent, he observed, at two several stations, the altitude of the mercurial column proportionally to increase; and after he returned to the monastery, it was found to be exactly the same as at first. Encouraged by the success of this memorable experiment, Perier tried the effect on one of the highest towers of Clermont, and discovered a difference of about two lines at an elevation of 20 toises. Intelligence of these very satisfactory results was quickly transmitted to Pascal, who, being then at Paris, did not fail to observe by himself similar effects on the top of a high house, and in the belfry of a church. Nor did he even hesitate to propose the observations with the barometer, for determining the difference in elevation of places, however distant, on the surface of the globe.

The experiment performed on the Puy de Domme being so striking and decisive, its fame was rapidly spread over Europe. It was not received, however, by the learned with that acclamation which it deserved: Their eyes were dazzled by the sudden light; but still they cherised the notions imbibed with their early studies. The same reluctance to the adoption of new truths was betrayed, as twenty years before had appeared in the question of the circulation of the blood, when no physician of emnence in Europe, above the age of forty, was known to have seriously believed in Harvey's grand discovery. The inferences of Pascal were evaded by the most wretched quibbles, and suppositions which utterly defied the power of argument. Father Mersenne, otherwise a man of some abilities, imagined that suction was caused by hooked particles interspersed in the atmosphere, and which drew the fluid along with them towards the general mass; and Father Linus, refining in absurdity, very gravely referred the suspension of the column to certain *funiculi* or invisible threads. But all this was not enough: The Jesuits of the College of Montferrand did not scruple, in their public theses, to pervert the expressions of Pascal, and dispute the originality of his experiments. The philosopher was justly incensed at their base conduct; and these repeated provocations, no doubt, served to give a keener edge to his wit, when he afterwards directed it with such powerful effect against that insidious and once formidable order of priesthood. He composed, in 1653, though they were not published till after his death, two short treatises ‘ on the equilibrium of liquors,’ and on ‘ the weight of the mass of air,’—remarkable by their neatness, perspicuity, and lucid order; for Pascal and Galileo have always been reputed the most elegant writers of prose in their respective languages. In these tracts, the laws of the equilibrium of fluids are beautifully deduced from a single principle, and which suggests a variety of original views and admirable remarks. The influence of the weight of the atmosphere is traced through all its gradations. A valuable machine is also described, that acts by compression, being founded on the hydrostatic paradox, and precisely of the same nature as Bramah's Press, for which a patent has been granted in this country. He concludes with an abstract of registers of the barometer kept during the years 1649 and 1650, by himself at Paris, by Perier at Clermont, and by Chanut, the French resident, at Stockholm; from which he infers, that the altitude of the mercurial column varies within certain moderate limits, and is generally higher in winter and during bad weather. But, after a transient gleam, distinguished by a fine mathematical discovery, Pascal, whose health was always infirm, sunk into feebleness and the most abject depression of spirits.

During this active period, Germany likewise contributed her share of discovery. The application of the elasticity of the air was understood from remote times. The action of the pop-gun is familiar; and the rudest savages have used from long reeds to blow or spit their poisoned arrows with terrible effect. Ctesebius of Alexandria had invented an engine, which, by the force of compressed air, hurled missile weapons. It was afterwards simplified and improved into the wind or air gun, which appears to have been well known in Europe as far back as the fifteenth century.* This instrument, however, was quickly superseded by the use of fire arms, introduced about that time; and it is now but seldom employed except by the Tyrolese hunters. From the wind gun, it might seem an easy and almost obvious transition to the air pump; for, if the valves of the piston were made to open outwards instead of inwards, as when sucking instead of forcing is used, they would cause the rarefaction in place of the condensation, of the fluid. But rarely has discovery taken the shortest or most direct road. Otto Gürické, to whom we owe the invention of this last and most important machine, was a wealthy burgomaster of Magdeburg, who amused himself with mechanical contrivances and curious physical inquiries. The belief in the impossibility of a vacuum having, with that of other scholastic tenets, gradually declined over Europe, it had been surmised, that the forming of a void was a task perhaps within the compass of human ingenuity. To effect this, was the great object of Gürické's ambition. He filled a wooden cask with water, and inserted, at the bottom of it, a small inclined sucking pump, which was worked vigorously by three stout men; a hissing noise was heard like that of boiling water, the air entered from above through the interstices of the wood, and water came out. He next took a smaller cask, with a sucker adapted to it, and placed it within a large one, having filled up the interval with water: On working the pump as before, the water was forced through the pores of the wood into the inner cask, and no farther effect was produced. Foiled in these attempts, he had then recourse to a copper ball, to the lower part of which an inclining sucker or syringe was fixed, and at last he succeeded in extracting the air. The operation of pumping was continued, until no more air was perceived to come out at the vent. On opening the cock, the air rushed in with violence; but the apparatus would continue tolerably tight for the space of a day or two. The construction was afterwards rendered more perfect with a sloping metallic syringe, the joints being secured in water. Such was the original form of the air-pump, which, though simple and rude, it long retained on the Continent. With that valuable machine Gürické made several interesting and very important experiments. One of these, intended to demonstrate the pressure of the atmosphere, and consisting of two hollow copper hemispheres, closely fitted,

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* In the armoury of Schmetau, an air gun of a bad construction was found, which bore the date 1474. Marin of Lisieux, in Normandy, a famous artist, made a capital one for Henry IV.

and from which the air is extracted, has been since known by the name of the Magdeburg Experiment. This he exhibited, in 1654, before the deputies of the empire and the foreign ministers, assembled at the Diet of Ratisbon. The action of two teams, comprising each a dozen horses, and made to pull in opposite directions, was insufficient to separate the hemispheres. It was now that Gürické heard, for the first time, of Torricelli's great discovery; and the intelligence must have been delightful to him who, by a route so different, had arrived at a similar conclusion.

The burgomaster of Magdeburg, after his return home, prosecuted a variety of kindred inquiries. Having fitted a vessel with a stop-cock, he carried it up to a height, and, on opening it, part of the contained air rushed out. The cock being shut, he reversed the experiment below, and a portion of the external air was observed to flow into the vessel. Gürické, having exhausted a large bottle, concluded from the loss of weight that the air is 970 times lighter than water: a very near approximation, especially when we consider the residuum of air which must have still remained in the bottle. He proposed to measure the variable pressure of the atmosphere, by weighing at different times a closed hollow ball of a foot in diameter—an instrument which, in the sequel, obtained the appellation of *Boyle's Statical Balance.* He took great pleasure in a sort of huge weather-glass which he had erected in his house: It consisted of a very long tube raised up the wall, and terminating in a tall and rather wide glass hermetically sealed, in which a toy of the shape of a man had been lodged: the whole being filled with water, and planted in a bason at the ground, the column instantly sunk to its proper elevation, leaving the toy floating at its surface; and the under part of the apparatus being concealed in the wainscotting, the little image, or weather-mannikin, as he called it, made its appearance only in fine weather. This whimsical piece of mechanism, under the name of *anemoscope*, or *semper vivum*, more than all his real discoveries, was admired by the ignorant populace; and Gürické was therefore shrewdly suspected of being familiar with the powers of darkness. His house having once been struck with lightning, it was regarded by the vulgar as an evident mark of the displeasure of heaven, for prying too curiously into the secrets of nature.

But it was scarcely of less importance to measure the temperature, than to determine the pressure, of the atmosphere. The weight of a given bulk of air depends on its density, and this density is materially affected by the degree of heat to which it is exposed. The indications of the barometer are in many cases imperfect, without the farther aid of the thermometer;

an instrument which, though invented sooner, took a much longer period to arrive at a state of improvement. The effect of heat in expanding various bodies, could not altogether escape the observation of early times. In air, that dilatation is most conspicuous, and appears to have been first noticed. Heron of Alexandria, about the third century of the Christian era, constructed an hydraulic machine, by which the air, confined within a receiver communicating by pipes with a bason of water, and exposed to the vicissitudes of day and night, caused the liquid alternately to rise and fall. It was that bulky and complex apparatus which, according to his own candid acknowledgment, suggested to Sanctorio, a learned Italian physician, the first idea of a thermometer. This ingenious person, born at Capo d'Istria in 1560, was many years a very distinguished professor of medicine in the University of Padua, where he seems to have directed his talents chiefly to the improvement of the practice of his profession, by borrowing and adapting to his purpose the aids of the mechanic arts. Pursuing those views, he was led to the beautiful and important discovery of insensible perspiration, having contrived the famous balance to ascertain readily the smallest difference in the weight of the human body, and for which he is treated with ignorant and misplaced ridicule, by a conceited writer in the Spectator. He proposed a variety of hygroscopes for ascertaining humidity, which so much affects the health; he applied the pendulum to determine the quickness of the pulse, forming what he called a *pulsiloge*, in which the string suspending a ball was gradually shortened till its vibrations corresponded with the beats; and lastly, to measure the heat of the skin, he reduced the apparatus of Heron into a compendious and convenient shape, being a hollow ball with a long narrow stem resting in a cup of water. This simple instrument he exhibited at his public lecture in 1595; and he continued for twenty years afterwards to show it annually, under some variety of form, to the numerous pupils who resorted for the benefit of his instructions from all parts of Europe. By help of his thermometer, Sanctorio made some curious observations; he measured the action of the sun-beams on its blackened bulb, and he imagined that he had been able to detect the heat of the moon's rays, in opposition to a prevailing opinion which attributed to them a certain cold and humifying quality.

Soon afterwards, and evidently without any communication with Italy, the thermometer was re-invented in Holland, by Cornelius Drebbel, the son of a rich peasant at Alkmaer, and who, having from his childhood shown uncommon talents, received the benefit of a superior education. He excelled in framing curious pieces of mechanism, and was tempted by his exquisite skill to pursue the dream of the perpetual motion. In aiming at this visionary scheme, he had occasion to remark the effect of heat in dilating the volume of air; and, sometime before the year 1603, he produced an instrument resembling the simplest kind exhibited by Sanctorio, but holding dilute *aqua fortis* instead of water, that it might not by freezing burst the tube. This thermometer or weather-glass, as he considered it, was in 1605 brought over by him to England, where he resided several years. Being well received at Court, he amused King James with the sight of his chemical experiments and mechanical contrivances; and it deserves to be noticed, that he astonished the royal favourites, by performing, in their presence near Gravesend, a submarine navigation for the space of a mile under the Thames. Drebbel, who was ever mysterious and reserved, afterwards returned to the Continent, and appears to have spent the rest of his life as an adventurer among princes, and exposed to great perversity of fortune.

The members of the Academy del Cimento, founded at Florence in 1657, and supplied with liberal funds, were particularly active in the prosecution of physical researches. They first repeated the experiment of the concentration of cold by reflection, and marked the effect by means of the air-thermometer of Drebbel or Sanctorio. This instrument they were solicitous to improve. Instead of air, they substituted spirits of wine, a fluid of great expansibility; and to the tube they attached a scale graduated on a regular plan, but after no very fixed principles. The Florentine Academicians constructed, though unfortunately with different scales, three several kinds of thermoscopes or thermometers, as they were afterwards called. These instruments or *measurers of heat*, being copied by Italian artists, were, under the name of the *Florence Glass*, widely circulated over Europe; but, owing to their careless execution, they did not acquire any decided reputation.

Within the short space of less than forty years, the stores of science were thus enriched by the invention of four capital instruments—the barometer and thermometer, the telescope and microscope. Their application unveiled a new system of things, and at length established philosophy on sure and invulnerable principles. Before these helps were devised, the imagination wandered without guidance, and all was loose and baseless conjecture. But henceforward every fleeting hypothesis was subjected to the accurate standards of weight and measure. The invention of a philosophical instrument has indeed always commenced a chain of new discoveries, which extend themselves in a variety of directions. The remote objects are gradually brought nearer; our conclusions acquire greater precision and extent; and successive prospects rise before us, and expand in continual progression.

About this period, the new philosophy, with a taste for experimental knowledge, was introduced into England, which, in the progress of science and of the arts, had lingered more than half a century behind the Continent. Gilbert indeed had, early in the reign of James I., given a fine specimen of induction, in his treatise on magnetism; but his example had been suffered to pass away without rousing imitation. Bacon had next, with his capacious mind, embraced the whole circle of learning, and strongly urged the necessity of reforming it in every branch. While he exposed the futility of rearing hypotheses, he recommended the constant appeal to facts, and displayed the advantage, in experimental research, of employing instruments to assist the powers of observation. On the proper mode of conducting philosophical inquiries, he has left us some masterly sketches and striking remarks. Unfortunately, the vigorous intellect of Bacon wanted the graces of refinement, and the aids derived from a sedulous cultivation. He was still infected with a taste for the subtleties and endless subdivisions of the schools, and which the habits of his profession had a manifest tendency to rivet; and, scarcely acquainted with the bare elements of Geometry, that great instrument of philosophical discovery, he was ignorant and careless of the mighty revolution in science effected abroad. After his melancholy fall from the highest office in the state, he occasionally relieved his severer studies, and the tedious hours of solitude, by repeating experiments and processes of the simplest kind. He frequently mentions his weather-glass, or *calendare*, as he calls it, but which was really the same as what Drebbel had lately brought over from Holland. The specimens which Bacon has given of his method of induction—the essay on Heat, and that on Winds—were far from being happy or successful. They consist of a loose assemblage of observations and undistinguished facts, disfigured often by credulity, perplexed by nominal distinctions and the admixture of parallel or contrasted instances, and which, after all this parade, lead to no intelligible conclusion. From such examples we may suspect, that it is easier sometimes to strike out general and brilliant views, than to pursue the details of investigation with a minute and discriminating accuracy. The philosophical works of Bacon, however highly we may value them at present, remained long neglected both at home and abroad, and appear never to have had any sensible influence in hastening the progress of science. It is a circumstance extremely remarkable, that more than forty years after their publication, Dr Barrow, a man of profound learning, conjoined with great acuteness and ingenuity, having occasion, in his mathematical lectures, to enumerate those who had contributed to the advancement of philosophy, does not once mention the name of Bacon. Those works did not perhaps acquire their pre-eminent reputation in this country, till after the commendation bestowed on them by Dalembert, in the celebrated preface to the *Encyclopedie;* nor can it be altogether concealed, that those who have since been the most lavish in their praise of the Baconian philosophy, have seldom had the fortune to be much distinguished by their physical discoveries, or their intimate acquaintance with the nice and difficult art of experimenting.

But if England, with her usual reluctance to adopt any thing like improvement, was slow in entering the course, she soon developed her native energy, and thenceforth atoned for her past supineness, by running the most brilliant career. All the great discoveries in physics, and especially in astronomy, for near a century afterwards, were made in this island. A constellation of talents arose, of the very first order :—Wren, Wallis, Hooke, Halley, Gregory, and lastly Newton, the ornament of our species. The progress which these philosophers achieved, was moreover the fruit of their single and unaided exertions; for they could not receive much encouragement from the public; and they experienced none of that patronage which the governments of other countries are proud to bestow.

During the time of the Usurpation, many persons of family and education, who, in the course of the civil wars, had rendered themselves obnoxious to the ruling party, sought shelter on the Continent; and, being disengaged from public affairs, and having abundance of leisure, they became acquainted with the new philosophy, and by degrees acquired a relish for experimental inquiries. Moray, the first president of the Royal Society, Brounker, Boyle, and others, fall under that description. These respectable exiles, on their return home at the Restoration, imported into England a right taste for prosecuting scientific research. Prince Rupert, too, had the merit of introducing from Germany several ingenious arts, and established at Bristol the first glasshouse in the island. An association was soon formed with a view to philosophical inquiry, consisting of some distinguished nobility and gentry, joined to professional men and especially physicians, and incorporated by charter under the style of the Royal Society; a title easily conferred, and the only thing almost which it has ever owed to the bounty of the Crown. The labours of this illustrious body, from its total deficiency of means, were long very humble and obscure. The publication of the Philosophical Transactions, though without competition, and in the form of a periodical journal, was repeatedly suspended, owing to their very limited sale. That an institution, directed to the most useful purposes, should have languished for want of due support, is indeed a lasting reproach to the government and to the country. The records of its early proceedings disclose circumstances which are very humiliating. The munificence of the house of Norfolk, indeed, forms a splendid exception; but many of the chief nobility and gentry discontinued for years their small annual contribution, and, though most submissively reminded of their neglect, they had the meanness to refuse the payment of those arrears, and allowed their names to be erazed from the list of members. Under such discouragements, it is rather surprising that a mere voluntary association should from the beginning have been able to effect so much as it did.

One of the most diligent promoters of the Royal Society was Boyle; a man of great worth and benevolence of character, who, though not possessed of the higher energies of mind, nor exempt from credulity, very laudably devoted his time and his fortune to philosophical pursuits. His own writings are feeble, confused, and excessively prolix; but he had the merit of choosing Hooke for his operator, the most original and inventive genius of the age, who was not less ready in contriving pieces of mechanism, than skilled in the execution of them. He improved essentially the air-pump, by securing the joints with oil, instead of water, and substituting for the syringe a barrel, in which the piston was moved by rack-work. With this instrument, Boyle repeated and varied the experiments on the rarefaction of the air; and, by his frequent communications to the Society, he rendered the subject in some degree fashionable. Hooke, being afterwards engaged as curator to that learned body, supplied, from his activity and fertile resources, a continual succession of experiments, calculated both to amuse and instruct. Among other things exhibited before them, the filling of the Torricellian tube, or cane, as it was then called, and still deemed a novelty in England, was repeatedly tried with success; though several of the members appeared to hesitate, or to yield at best a reluctant assent to the capital inference drawn from it. Some steps were however made in the inquiry: the ascent of the mercurial column, from the effect of augmented pressure, was observed at the bottom of coal-pits, and at considerable depths under water near the mouth of the Thames.

Among the first in Britain that attempted to measure the heights of mountains by observing the mercurial column, was George Sinclair, who had been professor of philosophy in the University of Glasgow, and appears to have lost his office in

1662, for declining to comply with the Episcopal form of church government, which was then violently thrust upon the people of Scotland. This very credulous but ingenious man, after his ejection, betook himself to the business of a mineral surveyor or practical engineer, and was employed in this profession by several proprietors of mines, and particularly by Sir James Hope, who, having sat in Barebone's parliament, was probably nowise averse to his Presbyterian scruples. Sinclair, in the years 1668 and 1670, observed the heights of Arthur's Seat, Leadhills and Tintoc, above the adjacent plains. He followed the original mode of carrying a sealed tube to the top of the mountain, where, filling it with quicksilver, and inverting it in a bason, he marked the elevation of the suspended column, and repeated the same experiment below; a very rude method certainly,—but no better was practised in England for more than thirty years afterwards. To the instrument fitted up in a frame, Sinclair first gave the name of *baroscope*, or *indicator of weight.* The favourite termination *scope* was afterwards changed into the more definite word *meter;* and the compound name *barometer*, therefore, signifies 'a measurer of the weight of the 'atmosphere.' *

In those rude attempts at measuring heights by the barometer, the atmosphere was regarded simply as an homogeneous fluid, and possessing the same density throughout its whole

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* Sinclair was author of a well known little book, entitled, *Satan's Invisible World Displayed*, and at a former period greedily devoured by the Scottish peasantry. In a quarto volume on 'Hydrostatics and the Working of Coal Mines,' printed in Holland in 1672, and published by subscription, he had strangely inserted *a true relation of the Witches of Glenluce.* But some very learned men of that age were guilty of like follies.—We are concerned to observe, that the celebrated James Gregory, who, with talents of the very first order, yet seems to have had a violent temper, and to have imbibed an hereditary attachment to royalism and episcopacy, should have stooped to attack an inoffensive and perhaps unfortunate man. He wrote a small tract against Sinclair's Hydrostatics, with the quaint title of the *Art of Weighing Vanity*, and under the thin disguise of Patrick Mather, archbeadle of the University of St Andrews. It is a production full of low scurrility, and memorable only for a short Latin paper annexed to it, containing the series first given to represent the motion of a pendulum. There is preserved in the British Museum a letter from Gregory to Collins, boasting of his project, and soliciting information with which to overwhelm his antagonist. It is curious however to observe, that with all his eagerness to heap ridicule on the poor author, he has never once touched on the absurd episode of the witches. Such was the temper of the times!

mass; a supposition which, in the case of moderate ascents, is not very erroneous, but which differs widely from the truth when the elevation becomes considerable. The next step towards improvement, was to conceive the density of the air to decrease regularly with its altitude, and thus form an arithmetical progression. On that hypothesis, the combined experiments of Galileo and Torricelli gave less than five miles for the height of our atmosphere, or about twelve miles, if we adopt the more correct observation of Gürické; whereas the calculation grounded on the limits of twilight and refraction, though not altogether unexceptionable *data*, represented this elevation to be at least forty-five miles. It was therefore essential to determine the relation between the density of the air and its elasticity, or the force with which it resists compression. Mariotte in France, and Townley in England, nearly about the same time, discovered that important law, and ascertained, by a set of accurate experiments, that the elasticity of this fluid is exactly proportioned to its density. The former, after some obscure allusion to logarithms, contented himself, in 1676, with regarding the decrease of density upwards, as nearly uniform. But the famous Dr Halley, a man of very superior talents and great versatility of genius, setting out from that experimental principle, subjected the rules of measurement by the barometer to geometrical investigation, and delivered in 1685 the beautiful theorem on which the calculation is now founded, and which establishes, that the heights being assumed in arithmetical, the corresponding densities of the air must follow a geometrical, progression. In fact, if we conceive the atmosphere to be divided into a multitude of equally thin horizontal *strata* or layers, it is evident that each successive *stratum* will, to the pressure of the superincumbent mass, add its own weight, which being as its density or elasticity, is therefore proportioned to the collective pressure; and consequently the densities continually increase downwards, exactly in the same way, and after a like progression, as money accumulates at compound interest, where a constant portion of the aggregate fund is regularly joined to the capital. But Halley, uniting practice with theory, observed in 1697 the mercurial column at the level of the sea, and on the summit of Snowdun, and found it to stand respectively at 29.9 and 26.1 inches; the height of the mountain being previously determined by a trigonometrical operation to be 1240 yards. He was thence enabled to conclude, that the air doubles its rarity for every three miles and a half of ascent.

In 1687, Newton resumed the problem of the gradation of atmospheric density, in his immortal *Principia*, and solved it with that generality which suited his penetrating mind. He there demonstrated, that admitting the particles of air, like other bodies, to have their weight or attraction diminished as the squares of their distances from the centre of the earth, if those distances be taken in harmonic progression, the corresponding densities of the atmosphere will form a geometrical one. * Since the diminution of attraction however, at the greatest height which we are able to reach, amounts only to the two thousandth part of the whole; this difference is too minute to be admitted in practice; and the simpler law first pointed out by the sagacity of Halley, is judged sufficiently accurate for every real purpose.

To apply the principle for calculating heights from barometrical observations, it was previously requisite to ascertain, by experiment, the coefficient expressing the precise relation between the density and elasticity of the air, or to determine the altitude of an equiponderant column of homogeneous fluid. This could be done in two ways; either by finding with accuracy the specific gravity of air, or by comparing trigonometrical measurements with the results obtained on a great scale by the barometer. But the discrepancies appeared very perplexing. Though experiments were now brought to greater nicety, different authors had represented air in all the intermediate degrees from 798 to 885 times lighter than water. This was owing chiefly to the omission of the influence of heat, which dilates the air so considerably, and alters the relation of its density and elasticity. It became necessary to introduce a new element into the computation of barometrical observations; and philosophers were again induced to turn their attention to the improvement of the thermometer.

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* The investigation may be given very concisely in the modern symbols. Let x and x' denote the heights of two stations above the surface, y and y' the corresponding densities of the atmosphere, a the measure of the air's elasticity, or the altitude of a column of homogeneous fluid, which by its weight could balance that elasticity, and r the radius of the earth. The density of the air being as the incumbent pressure, its decrement must evidently be proportioned to the weight of each superadded minute *stratum*, or to the density of this *stratum* multiplied into its thickness and force of attraction. Wherefore $-a\,d\,y = y\,d\,x\left(\frac{r}{r+x}\right)^2$, or $-\frac{a\,d\,y}{y} = \frac{r^2\,d\,x}{(r+x)^2}$, and the complete integral is $a \text{ Log.} \frac{y'}{y} = \frac{r^2}{r+x} - \frac{r^2}{r+x'} = \frac{r^2(x'-x)}{(r+x)\,(r+x')}$ If r be considered as indefinitely great in comparison with x, then $a \text{ Log.} \frac{y'}{y} = x'-x$, as in the common *formula.*

The great object was to bring the thermometers to speak the same language. To effect this, it was expedient to select a proper fluid, and to adopt an uniform and consistent scale. Air, spirit of wine, linseed oil, and lastly, quicksilver, were selected in succession. The temperature of cellars and deep caves, as indicating the natural heat of our globe, had long been thought invariable; but farther experience discovered the inaccuracy of that supposition, and showed it to be materially affected by peculiar circumstances, especially the latitude of the place, and its elevation above the level of the sea. Congelation, or rather the thawing of ice or the melting of snow, was then found to remain fixed; an important remark, which had first occurred to Gürické, but was overlooked till a considerable time afterwards. From that point therefore, the thermometers now constructed began their divisions. But three several methods of regulating the scales were successively adopted.

1. The most obvious mode, was to make the divisions on the stem to correspond with the decimal parts of the volume of fluid contained in the bulb. Amontons, a person of great ingenuity and mechanical contrivance, having found that air, whatever its density may be, dilates equally and uniformly by the application of heat, employed that fluid, under a state of high compression, for constructing a standard or universal thermometer. To a strong glass ball of three inches in diameter, he joined hermetically a tube of above six feet long, and which he bent back into a vertical position; then he introduced quicksilver, till this column, by compressing the included air, mounted very considerably in the tube, and stood at 51½ French inches, when the instrument was plunged in melting snow; but, immersing it in boiling water, the mercury rose to 73 inches. The intermediate degrees of temperature were marked at every inch and half inch, in the ascent of the mercurial column. This instrument, which was precisely of the kind now termed a *manometer*, served merely to regulate other thermometers of a smaller and more commodious construction. But, independently of heat, it was besides liable to be affected by the variation of atmospheric pressure; and Amontons evidently sought to avoid, or at least to diminish, that inconvenience, by opposing to such external action the concentrated elasticity of confined air. The error, however, occasioned by extreme change of weather, might still amount to half an inch, or to one of his divisions.—About the same time, or at the commencement of the eighteenth century, Newton himself cast a keen though rapid glance on the subject of heat, and proposed a thermometer of a much simpler and more elegant construction. For the fluid of expansion, he preferred linseed

oil, a very fixed substance. Reckoning the bulb to contain 10,000 equal parts, at the temperature of melting snow, the rise of the liquid in the tube was expressed by 256 parts at blood heat, by 725 at that of boiling water, and by 1516 at the fusion of tin. As these numbers appeared excessively large, he chose to mark the heat of the human body with 12 degrees, and reduced the other expansions, in the same proportion, to 34 and 71 of his degrees. But the primary divisions were not easily determined; and linseed oil, being a viscid liquid and apt to adhere to the tube, was afterwards laid aside.—It certainly is going back the stream of invention, to notice the thermometer which Reaumur produced in 1730, and which, though grounded on erroneous principles, soon acquired and still maintains a most extensive circulation. This instrument was large and clumsy, having a ball of two or three inches in diameter, and filled with a weak spirit of wine that held one third of water: the capacity being divided into 1000 equal parts, the degrees, after this scale, were counted upwards from the point of the artificial congelation of water, and the liquor was believed to reach to 80 at the moment when ebullition began. But spirit of wine, even though diluted, could never attain the heat of boiling water, and must itself have been thrown into ebullition many degrees below that limit.—Roëmer, the celebrated Danish astronomer, who made the fine discovery of the motion of light, first recommended quicksilver as the most proper fluid for the construction of thermometers; and Halley and Amontons had remarked, about the same time, that it expands uniformly with heat, and remains nearly stationary at the point of boiling water. Delisle of St Petersburg, set out from this principle, and produced in 1733 a descending scale. The mercury being distinguished into 10,000 parts, the corresponding contractions were marked on the stem, that of congelation being 153 degrees, or in round numbers 150.

2. An elegant and very ingenious method for graduating thermometers, was proposed in 1694, by Renaldini. He made use of quicksilver, and confined the scale between the usual limits of freezing and ebullition, ascertaining the intermediate divisions from the gradations of temperature observed in successive mixtures of boiling and gelid water, or the water flowing from ice; 11 pounds of gelid being joined to 1 of boiling water, 10 to 2, 9 to 3, and so on, till the termination of these changes. This kind of experiment is the more remarkable as it afterwards led to some very important conclusions respecting the laws of heat, and proved that quicksilver expands uniformly with equal additions of temperature, while spirit of wine swells constantly in a rising progression.

3. But the most accurate, and by far the simplest mode of regulating the thermometric scale, is founded on the equal division of the interval observed between two fixed points. Fahrenheit, to whose assiduity and skill this instrument owes its perfection, was a merchant at Dantzic, who, having failed in business, and being fond of mechanics and chemistry, had recourse to the making of thermometers, as the means of gaining a slender livelihood. At first he used spirit of wine, yet always constructed those instruments very small and uncommonly neat. But, not meeting with sufficient encouragement at home, he was induced, about the year 1720, to remove into Holland; and he spent the rest of his laborious life at Amsterdam. He now preferred quicksilver for filling his thermometers, and took the greatest pains in their accurate graduation. He seems to have begun with the favourite division of the mercury into 10,000 equal parts; of which he reckoned 64, from congelation or the temperature of ice dissolved in water, up to blood heat, and 32 downwards to what he conceived to be extreme cold, produced by the mixture of salt with snow, or rather of ice, water, and sal ammoniac. These numbers, giving an extent of nearly an hundred degrees to the whole scale, were very commodious, and suggested a system of continual bisection. Accordingly, the small mercurial thermometers from the hands of Fahrenheit himself, have their divisions engraved on a slip of paper neatly folded close to the stem, with the degrees numbered by pairs on each side, and the whole enclosed within a glass case hermetically sealed. The same plan was, many years after, followed by Wilson at London, and next at Glasgow, where this ingenious man engaged in the more extensive and lucrative concern of a type foundery. But Fahrenheit soon advanced a step farther. He remarked, in his numerous trials, that the heat of boiling water sensibly varies at different times, according to the state of the weather, but found it to remain always constant under the same atmospheric pressure. With the regulation of the barometer, therefore, at its mean altitude, another fixed point was determined, corresponding to the 212th division of his scale, or 180 degrees above the point of congelation. Thermometers divided in that way, were not only circulated over Holland and the north of Germany, but, from the eminence of the maker, they were generally introduced into this island, by the young men who at that time flocked to Leyden for the study of law and medicine.—The instrument owes its final improvement to Celsius of Stockholm, who, in 1742, placed the beginning of the scale at congelation, and divided the interval between it and the boiling

point into 100 degrees, and extending a portion of them downwards. This thermometer is exactly the same with what has been since called in France the *centigrade* or *centesimal*, and which, from the fitness and simplicity of its construction, deserves to be universally adopted.

The construction of the barometer itself underwent various modifications and improvements. A great object at first was to render its variations more perceptible, by enlarging the scale. With that view, Descartes proposed the compound barometer, in which the tube was swelled out near the top, and then rose with a narrow stem, holding water above the quicksilver. This instrument was afterwards improved by Hooke into the double barometer, a syphon tube being used with a slender branch, containing a column of coloured deliquiate potash instead of water. This ingenious person also constructed the wheel barometer, which is still in pretty general request. Morland and Ramazzini suggested the inclined barometer. The conical or pendant barometer was an elegant contrivance of Amontons, and appears not to be so well known as it deserves. And, lastly, John Bernoulli invented the horizontal or rectangular barometer, a specious yet imperfect machine. But these complex constructions are subject to much irregularity; and it has been found by experience, that the simple barometer, fitted with a proper Vernier, is after all the best and most accurate. The only modifications of it now in use, are the marine and the mountain barometers; the former contrived to prevent the agitation of the quicksilver from the rolling at sea, and the latter disposed in the most portable form, with nice adjustments for the measuring of heights.

Some perplexing sources of error in the indications of the barometer, were detected by degrees. The suspension of liquids in narrow tubes by capillary action, had long been observed. But this force has an opposite effect on a column of mercury, the particles of which having a stronger attraction to each other than to the sides of the glass, approach towards the general mass, and exhibit a convex, instead of a concave, surface. Accordingly, when the tube of the barometer is narrow, the quicksilver does not rise to the true height. This inaccuracy, however, is removed in the latest constructions; the surplus mercury being contained in a bag or box, and its surface always brought, by the pressure of a screw, to a constant mark in a smaller connecting tube, of the same width as the main column. —Another cause of discrepancy required more investigation. On washing the inside of a barometric tube with spirit of wine, for the purpose of cleaning it, the mercury, on filling it again, was perceived to stand unusually low; which effect seemed owing to the elasticity of the diffuse vapour collected within the vacant space at the top. The great object was, therefore, to discharge from the mercury every particle of air or moisture which might adhere to it. Cassini, early in the last century, boiled the quicksilver within the tube; and this capital improvement was, in the sequel, revived by Deluc, and is now generally practised. But even the boiling must be regulated; for if the mercury be too long exposed to the action of heat, it will suffer a partial oxydation, and will line the inside of the tube with a thin yellow crust, which attracts the column upwards. Laplace was evidently mistaken, in supposing the mercurial column to assume a horizontal surface, from being thoroughly purged by careful and continued boiling; since it can only proceed from a counteracting adhesion, similar to what obtains when the inside of the tube is rubbed with grease or oil.

After the law of the progression of density in the atmosphere had been discovered, and the barometer and thermometer brought nearly to a state of perfection, nothing more seemed wanting towards ascertaining by their means the height of mountains. Yet still for many years was the application of the barometer to that object, though not entirely forgotten, suffered to make a very slow and doubtful advance. The rule which Halley gave, and which proceeded on the compensation of errors, was only a rough approximation. Reckoning water 13½ times lighter than quicksilver and 800 times heavier than air, it followed, that this fluid is 10800 times lighter than quicksilver; or that a column of air 900 feet in height, would correspond to the difference of an inch in the altitude of the mercury. Assuming 30 inches, therefore, as the medium range of the barometer, he instituted this proportion—As .0144765, or the arithmetical mean between the differences of the logarithms of 29 and 30 and of 30 and 31, is to the difference of the logarithms of the altitudes of the mercurial columns at the two stations, so is 900 to the observed height in feet. The result, computed in this way, was evidently the same as if the logarithmic difference had been multiplied by the constant number 62170, and which would correspond to an equiponderant atmospheric column of 27000 feet.—Daniel Bernoulli, who succeeded at a great interval of time, threw out, in his *Hydrodynamica*, some vague hypotheses respecting the constitution of the atmosphere, and rashly deviated from the principle of the geometrical progression of density. In this departure he was followed by Cassini and Horrebow, who inferred, from their partial observations, that the barometer is subject to irregularity; and that, near the surface of the earth, it obeys a different law from what obtains at great elevations. An important step however was, in 1753, made by Bouguer, an able mathematician and a very skilful and ingenious observer, who had been several years employed in measuring a degree on the stupendous ridge of the Andes. From the comparison of more than thirty distinct observations, he deduced a simple and elegant rule for computing heights by help of the barometer: It is, that the difference between the logarithms of the mercurial columns at the two stations being diminished by the thirtieth part, and the decimal point shifted four places back, will express the required elevation in toises. But Bouguer was persuaded, that this rule would not hold exactly in Europe, or in the lower regions of the torrid zone; and to explain the deviation, he had recourse to the forced supposition, that the particles of air have different degrees of elasticity, nearly similar to what Newton had formerly advanced, in attempting to reconcile theory with the actual propagation of sound. Lambert, a philosopher of great originality and penetration, afterwards published some excellent remarks on the comparison of barometrical measurements. But no material progress was made till 1755, when Deluc of Geneva resumed the subject, and carefully combined experiment with observation. For the space of upwards of fifteen years, he prosecuted his inquiries with persevering diligence, assisted by the peculiar advantages of local situation, in a city abounding with artists, and seated amidst lofty mountains. The discrepancies which had hitherto created so much embarrassment, proceeded chiefly from the inattention of observers to the disturbing influence of heat, and especially its effect in expanding the air, and consequently augmenting the elevation due to a given difference of atmospheric pressure. Deluc's first object was to improve the thermometer of Reaumur; and having ascertained, from a set of experiments like those formerly made by Renaldini and Brook Taylor, that quicksilver dilates equably by the accession of heat, he substituted this metallic fluid in place of spirit of wine. He next examined the expansion of air at different temperatures, and corrected the results by numerous observations, in which the barometer was combined with the thermometer, along the vallies and on the summits of the higher Alps. The *formula* which he thence deduced for the computation of barometrical measurements, was, in 1772, published in his *Recherches sur les Modifications de l'Atmosphere*, and seemed to attract, particularly in this island, a very considerable degree of notice. Maskelyne translated it into English measures, and Horsley commented on it. But what was more important, other accurate observers, prompted by Deluc's example, entered the same field of inquiry, and provided with instruments still finer and of much better construction. In 1775, Sir George Shuckburgh Evelyn visited the mountains of Savoy, and conjoined trigonometrical operations with corresponding observations by barometers and thermometers from the hands of Ramsden; and about this time likewise, General Roy, not only measured, with instruments made by that admirable artist, some of the principal heights in Scotland and Wales, but instituted a series of delicate manometrical experiments. From these combined observations and experiments, it followed, that, for each degree on Fahrenheit's scale, mercury expands the 5412th part of its bulk, and air at the rate of .00245; and, that the logarithm of the ratio of two atmospheric pressures, reckoning the first four figures integers, will express in English fathoms the difference of elevation adapted near the temperature of freezing water. It farther appeared, that the heat of the air decreases upwards nearly in a uniform progression. The mensuration of heights by the barometer, requires therefore two corrections, the one applied before, and the other after, the logarithmic subtraction. A barometer on the top of the mountain, and another at its base, are simultaneously observed, each having an attached thermometer indicating the heat of the quicksilver, and one detached and suspended freely to mark the temperature of the ambient air. In computing from these data, the upper mercurial column is enlarged to the density of the lower, or it receives an augmentation proportioned to its decrease of temperature: The difference between the logarithm of that corrected column, and of the one below, removing the decimal point four places back, gives the *approximate height* of the mountain; to which the final and most important correction is made, being the expansion of the air above the point of congelation, as estimated from the mean of the detached thermometers. General Roy besides proposed a farther modification, depending on the diminished gravity, and consequently increased altitude, of the equiponderant atmospheric column, in the lower latitudes, caused by the influence of centrifugal force, and indicated by the length of the pendulum. Several years thereafter, Professor Playfair, in a learned paper, inserted in the first volume of the Transactions of the Royal Society of Edinburgh, examined all the circumstances affecting barometrical measurement, and discussed each question, with that ingenuity and precision which might be expected from his distinguished abilities. At nearly an equal interval of time, the celebrated Laplace, in his *Mechanique Celeste*, resumed the subject; and availing himself of the most recent experiments, without omitting the slightest consideration that could affect the result, he gave a very general solution—laborious indeed, and excessively complicated. Biot now follows the same track, and engages in a complete investigation of the problem. His process however, it must be confessed, is circuitous, and appears, notwithstanding its display of analytical resources, to be rather clumsy and inelegant. Nor can we help blaming that affectation of accuracy beyond what the nature of the subject will admit,—which is often remarked in the later mathematical productions of the Continent. Conditions are assumed, only to be afterwards rejected; and the result, obtained with all this expense of labour, is finally softened down into a manageable form. In the present state of physical science, precise experiments are more wanted than the powers of a refined calculation. Yet Biot attempts, by blending hypotheses with imperfect observations, to estimate the minute effects of humidity, in modifying the degree of atmospheric pressure. From some careful experiments performed by him in conjunction with Arrago, he concludes, that air, at the point of congelation, and under a mercurial pressure of .76 *metres* or 29.922 inches, is in the latitude of Paris 10463 times lighter than water at its lowest contraction; which, being reduced to the level of the sea, gives a coefficient of 18334 *metres* or 60148 feet. The numerous observations that Ramond lately made among the Alps, afford, after reduction, almost the same quantity, or 18336 *metres*, corresponding to an equiponderant column of 26124 feet. But, for the sake of convenience, Biot, adjusting the whole to an elevation of 1200 *metres*, at which the barometric measurements usually commence, modifies the coefficient into 18393 *metres* or 60346 feet, and abridges the complex expressions into the final result,

$$18393\,(1 + .002837 \cos. 2\psi)\left(1 + \frac{2\,(T + t)}{1000}\right) \log. \frac{H}{h};$$

where ψ denotes the latitude of the place, T and t the temperatures indicated by the detached thermometers, and H and h the corrected altitudes of the mercurial columns. To this *formula* the barometric tables are adapted, being so framed as to facilitate the computation of each distinct part.

These tables, with a little practice and address, will be found to give us, independent altogether of logarithms, very considerable facility in calculating the measurements of the barometer. The operation might be still further abridged, by omitting the correction derived from the variation of gravity along the surface of the globe, as the difference, reckoning from the mean latitude of 45° to the equator on the one hand, and to the pole on the other, is equivalent only to the 352d part of the whole; and therefore scarcely exceeds the effect of a single degree of

Fahrenheit on the height of an atmospheric column. But, till the various circumstances which alter the volume of air have been more precisely determined, we are inclined to prefer the method of calculation briefly stated by Professor Leslie in the second edition of his *Elements of Geometry*, and which is remarkable for its simplicity and neatness. The centigrade thermometer is there used, being evidently the best adapted to barometrical observations. ‘ Mercury expands about the 5,000dth ‘ part of its bulk, for each degree of the centesimal scale; hence, ‘ the *previous correction*, or the small addition to the upper co- ‘ lumn will be found, by removing the decimal point four places ‘ to the right, and multiplying by twice the difference of the at- ‘ tached thermometers.’ The difference between the logarithm of this corrected column and of the lower mercurial column, being multiplied by 60,000, exhibits in feet *the approximate height*. But the chief and *subsequent correction*, depends on the temperature of the air. Since air expands by heat twenty times more than mercury; ‘ if the approximate height be multiplied by ‘ twice the sum of the degrees on the detached thermometers, ‘ the product will give the addition to be made.’ It would be easy to conjoin with this plan of computation the influence of the variation of gravity. The centrifugal force, being as the square of the cosine of the latitude, is therefore, according to the best observations confirmed by theory, proportioned to the mean temperature; and since this force amounts to the 176th part at the equator, where the medium heat is 29 centesimal degrees—it hence appears that the final correction would be obtained, if before the multiplication, to twice the sum of the degrees on the detached thermometers were added the fifth of the mean temperature of the place at the level of the sea.

A very near approximation, however, is attainable by simple arithmetic, without employing logarithms at all. The rule delivered in the work already quoted, was drawn from geometrical principles only; but it easily follows from the first terms of the series for the logarithm of the ratio of two numbers, depending on the relation between their sum and difference combined with the double of the *modulus*, which, in reference to our atmosphere, is about 26,000 feet. ‘ As the sum of the mercurial columns ‘ is to their difference, so is the constant number 52,000 to the ‘ approximate height.’ This rule may be deemed sufficiently accurate perhaps for elevations not exceeding a mile; but it may be easily extended higher, by assuming intermediate measures.

The computation of barometrical measurements is most expeditiously performed, by help of a sliding rule contrived for that purpose. An instrument of this nature, manufactured by Cary of London, seems to unite every practical advantage, being very manageable, and exhibiting the result with only two settings of the slider. Accompanied by a barometer of the lightest and and most portable kind, it would prove a very useful implement to the geological traveller. The mountain barometer, which we owe to the zeal of Sir H. Englefield, is tolerably commodious; but a simpler and much lighter instrument might be devised, on the principle of the conical barometer. To multiply the chances of observation is a great object; and in such cases, accuracy may to a moderate degree be sacrificed for convenience. Physical geography would acquire prodigious improvement, if by means of the barometer, sections or profiles of countries were made, and a system of distant levelling conducted in different directions.

Much however still remains to be done. That the temperature decreases uniformly in ascending the atmosphere, is an assumed principle; but the observations of Saussure, compared with those of Humboldt, betray an evident deviation, and prove that the decrements of heat increase in the greater elevations. The manometrical experiments of Roy are far from being unexceptionable. They were made on dry and moist air; a distinction which appears extremely vague. He besides mistook a dilatation produced by the continual addition or solution of humidity, for the usual expansion of air which had been previously damped. On the ingenuity of Mr Dalton, we would bestow unqualified praise; but knowing the very rude and imperfect apparatus with which he generally contents himself, we cannot avoid regarding his numerical results as mere conjectural approximations, which often do credit, indeed, to his sagacity. Gay-Lussac has so closely followed Dalton, that their marvellous coincidence, in points hardly susceptible of such nicety, and contradicted by the tenor of more extensive analogies, is not the best calculated to remove all suspicion. We should on this occasion have hazarded a few remarks, if we had not already abused the patience of our readers. When quantities are concerned, it is the most difficult by far to perform accurate experiments; nor is the merit of procuring such results ever fully appreciated. The more improved branches of physical science are hastening to that stage which Astronomy has long attained, where individual exertions are but of little avail; and where, to reach the higher degrees of perfection, the support of powerful associations, or the liberal and efficient patronage of the State, become indispensably necessary.