BOARD OF EDUCATION

CATALOGUE OF THE COLLECTIONS IN THE SCIENCE MUSEUM

SOUTH KENSINGTON

WITH DESCRIPTIVE AND HISTORICAL NOTES AND ILLUSTRATIONS

METEOROLOGY

1922

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PREFACE

The Science Museum, with its Collections and Library, aims at affording illustration and exposition in the fields of mathematical, physical, and chemical science, as well as their applications to astronomy, geophysics, engineering, and to the arts and industries generally. To that end the Museum includes objects which are of historical interest as marking important stages in development, and others which are typical of the applications of science to current practice.

A Museum of Science was contemplated as an integral part of the Science and Art Department from its beginning in 1853, and in 1857 collections illustrating foods, animal products, examples of structures and building materials, and educational apparatus, were brought together and placed on exhibition.

The first of the Engineering Collections, that of Marine Construction was formed in 1864, when the Royal School of Naval Architecture was established at South Kensington, and the ship models belonging to the Admiralty were transferred to the Museum from Somerset House, where they had previously been. This collection of ships of war was of great historical interest, and with the assistance of private donors and by purchase it was rapidly increased by the addition of many models of mercantile ships as well as of later ships of war, with the result that when the Admiralty removed their models to the Royal Naval College, Greenwich, in 1873, an important collection still remained at South Kensington. Engineering and Manufactures were first included in 1867, from which time the development of this portion of the Museum advanced steadily; but the transfer of the Museum of the Patent Office to the Department of Science and Art in 1883 added to the collection many machines of the highest interest in the history of invention and greatly increased its scope and value.

The collections of scientific instruments and apparatus were first formed in 1874, but it was only after 1876 that they became of importance. The Special Loan Collection of Scientific Apparatus which was held in that year in London brought together examples of all kinds from various countries, and a large number of these were acquired for the Museum.

In 1893, many Mining and Metallurgical objects were transferred to South Kensington from the Museum of Practical Geology in Jermyn Street, and these have subsequently been largely added to.

Mention should be made, too, of certain special Collections: The Watt Collection was presented to the Patent Museum in 1876 and contains original models made by James Watt; the Maudslay Collection, consisting of models of marine engines and machine tools, was purchased in 1900; and in 1903 a valuable collection of engine models, portraits, etc., was bequeathed by Bennet Woodcroft.

The Museum Collections are being continually increased by gifts and loans, and also by the purchase of such examples as are required to illustrate the application of science and the development of various types of instruments, machinery, etc.

Notes.—A large number of objects in the Collections have been photographed. Selected prints from the negatives may be seen in guard books at the entrance stiles. Particulars of available prints and lantern slides may be obtained by personal application at the entrances or by letter addressed "The Director, The Science Museum, South Kensington, S.W.7."

A compressed air service furnishes the power for driving such of the machines as are shown in motion, and the service is available daily from 11 a.m. (Sundays 2.30 p.m.) till closing time. Where practicable, these objects are fitted with self-closing air valves, by means of which Visitors may start them at will. Other objects are arranged so that Visitors may work them by other means, and there are a few that can be shown in motion only by an attendant.

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CATALOGUE of the Collections in the Science Museum, South Kensington.

Numerical references in the text refer not to the page but to the serial numbers placed at the beginning of each catalogue title. When an object is illustrated the reference to the plates of illustrations is given immediately after the title. The number at the termination of each description is that under which the object is registered in the Museum Inventory. If the object has been photographed, the Inventory number is followed by the negative number; and where a lantern slide exists, the letters "L.S." are added.

METEOROLOGY.

Meteorological phenomena occurring in the atmosphere have attracted the attention of man from the earliest times, but the first regular observations were probably due to the Greeks, who, in the fifth century B.C., fixed almanacs known as parapegmata, on public columns, giving usually the wind direction, while during the same century, Anaximander of Ionia defined wind as "a flowing of the air." Philo of Byzantium and Hero of Alexandria in the third century B.C. described a primitive kind of thermoscope, but from that time to the beginning of the seventeenth century little progress was made. In the eleventh century A.D. Arabian geometers estimated the height of the atmosphere as 92 km. from observations of the duration of twilight, but it was not until five centuries later that European astronomers re-determined it.

The development of meteorology may be said to fall into five fairly well-defined periods, the first of which dates from the earliest times to about A.D. 1600. During this period certain qualitative observations were made, but the lack of instruments rendered the observations unreliable and inaccurate. The only quantitative observations known to have been made during this period are rainfall records made in Palestine during the first century A.D. and in Korea from 1442.

The second period dates from the beginning of the seventeenth century, and commences with the invention of the thermometer and barometer, followed in 1639 by the first European rain gauge of

Benedetto Castelli. During the first half of this century, valuable work was done at Florence by the Accademia del Cimento, under the control of Ferdinand II, Grand Duke of Tuscany, who, in 1653, established meteorological stations throughout Northern Italy, and made the first attempt to establish an international system of meteorological observations.

During this period Halley, in 1686, published his celebrated memoir on the "Trade Winds," while in 1735 Hadley demonstrated the effect on these winds of the rotation of the earth. In 1749 Wilson of Glasgow, employed a kite to raise thermometers into the air, and thereafter kites and balloons were frequently employed to carry thermometers, barometers and hygrometers into the air in order to investigate the conditions of the upper atmosphere.

This second period in the history of meteorology is marked by the appearance of a large number of instruments and a consequent increase in the accuracy of observation of the atmospheric phenomena.

The third period which covers practically the first half of the nineteenth century, was one in which logical explanations of phenomena observed during the previous period were sought. Dove endeavoured to explain the wind system, assuming two major circulations in each hemisphere, while Maury reached similar conclusions on different assumptions. Redfield in America also considered the origin of cyclones, and Piddington discovered that the wind round a storm centre has an inclination inwards, and therefore travels in a spiral motion. The introduction of the synoptic chart by Brandes in 1820, and its subsequent development in America by Espy and Loomis also belong to this period.

During the fourth period, from 1850 to 1865, the first daily weather report was issued and sold to the public at the 1851 Exhibition in London, while meteorological services were organised in England by Fitzroy, in France by Le Verrier, in Holland by Buys Ballot, and in America by Ferrel.

In 1863, Sir Francis Galton published his Meteorographica, in which he considered atmospheric circulation round centres of low and high pressure, and deduced the existence of anticyclones.

The fifth or modern period commences with the developments due to Buchan in Scotland, Jelinek in Austria, Möhn in Norway, and Hildebrandsson in Sweden, and during this period there have been rapid advances in all branches of the subject.

Improved instruments have enabled observations to be taken with increased accuracy, and earlier hypotheses have been tested in the light of knowledge thus acquired, while meteorological services have been established in most countries, and as a result of their mutual association and collaboration, international exchange of meteorological information has become possible on a considerable scale.

The experimental exploration of the upper atmosphere has also been undertaken in many countries by means of kites, balloons, *ballons sondes* and pilot balloons, and as a result of these efforts Hildebrandsson and De Bort have been able to put forward the first theory of the circulation of the atmosphere to be based on actual observations.

THERMOMETERS.

Descriptions of apparatus which represent the primitive idea of the thermoscope are to be found in the writings of Philo of Byzantium, who lived in the third century B.C., and of Hero of Alexandria of a later though undetermined date.

These physicists demonstrated the expansion and contraction of air by temperature some 2,000 years ago, but there is no evidence that this apparatus was employed by either of them for measuring temperatures.

The next mention of the thermometer is found 1,800 years later in the writings of Galileo Galilei, to whom the invention of the instrument is attributed. There is abundant evidence that he used it in scientific research from about 1592, and laboured to improve its efficiency. Galileo's instrument was an inverted air thermoscope containing water in the stem, and provided with a scale of degrees, by means of which he determined the relative temperatures of different places, and of the same place at different seasons. His method of graduating cannot be ascertained, and was undoubtedly arbitrary. In concert with Galileo, Francesco Sagredo improved the instrument and substituted wine for water.

Sanctorius Sanctorius Justipolitanus between 1611 and 1624 applied the instrument to physiological researches, and tested the temperature of persons in a fever, while he also appears to have appreciated the value of fixed points for graduation.

The name "thermoscope" is first mentioned by Bianconi in 1617, and "thermometer" by Leurechon in his "Récréation mathématique (1642)," in which he gives a clear description of the instruments in use at the beginning of the 17th century.

Unfortunately these early and crude instruments, which were inverted thermoscopes, were subject to changes in atmospheric pressure and were really "baro-thermoscopes," no two of them being comparable.

The first mention of the instrument in this country is found in Bacon's "Novum Organon," 1620, in which he describes an inverted "heat glass" provided with a paper scale attached to the stem.

Jean Rey in 1632 constructed a thermometer consisting of a small round flask having a long stem, and being almost filled with water. Expansion of the liquid by heat caused it to rise in the stem and register temperature, but it was still influenced by atmospheric pressure. It was Ferdinand II, Grand Duke of Tuscany, who first produced a thermometer, independent of atmospheric pressure about 1641. He made a thermometer of the usual form filled with alcohol, sealed it by melting the glass top, and graduated it by degrees marked on the stem. In 1657 he established in Florence the Accademia del Cimento, and the work of its members, published in 1667, includes a description of five different types of thermometers.

The earliest of these instruments had their stems graduated in intervals of 10°, with white enamel beads, the intermediate degrees being indicated with beads of green glass or black enamel, while the contained liquid was either water or spirits of wine.

In the case of thermometers having very long stems, these were made in the form of a spiral, while in other thermometers, the principle of the Cartesian divers was employed, the instrument consisting of a wide glass tube nearly filled with spirits of wine in which floated several glass bulbs adjusted to sink to different points in the tube as the temperature increased.

These thermometers were a great advance on the baro-thermoscopes, but their graduation left much to be desired, and as they depended entirely upon the skill of the workmen, different instruments gave results only approximately similar.

Similar thermometers were made in this country by Robert Boyle, who recognised the need for a standard permitting a comparison of different thermometers, and suggested the freezing point of aniseed oil as a fixed point in 1665, believing that the freezing point of water which had been suggested as a fixed point by his contemporary, Hooke, varied with geographical latitude.

Huyghens in 1665 suggested the two phenomena, the freezing point and boiling point of water, for fixing a standard, but only as alternatives, and it was not till four years later that Honoré Fabri proposed to divide the interval between two fixed points into equal parts, his two fixed points being snow in very cold weather and the highest heat of summer, while he divided the intervening space into eight equal parts. As we know, the upper point was ill-chosen, but the method was correct in principle. Dalencé in 1688 proposed a scale having as fixed points the freezing point of water and the melting point of butter, and suggested that a flattened bulb should be used, so that the liquid might attain the temperature of its surroundings more readily.

The boiling point of water was proposed as a fixed point by Halley, but it was Carlo Renaldini who, in 1694, first took the melting point of ice and the boiling point of water for two fixed points of thermometer scales and divided the space between them into twelve equal parts.

Wolf and Römer are both cited as the first to use mercury as a heat-measuring liquid, but in spite of these claimants, Daniel Gabriel Fahrenheit, in 1714, was undoubtedly the first to construct mercury thermometers having reliable scales, the method of construction of which he kept secret for some time. He had been making alcohol thermometers from 1709, and the graduations of his thermometers, both alcohol and mercury, were directly comparable, and were obtained by the use of three fixed points, namely (1) the temperature of a mixture of ice, water, and sal-ammoniac or sea-salt, in proportions now unknown; (2) that of a mixture of ice and water; and (3) that of the human body. He also made thermometers with cylindrical bulbs, in order to increase the sensitiveness of the instrument, the weakness of which was the somewhat vague definition of the three fixed points. Fahrenheit's original scale was graduated from $-90°$ to $90°$, but this he abandoned in favour of $0°$ to $24°$, and later $0°$ to $96°$, on the last named of which the melting point of ice and boiling point of water are $32°$ and $212°$ respectively. He does not appear to have used the boiling point of water as a fixed point nor to have considered dividing the scale between his zero and the boiling point of water into 212 parts.

Réaumur in 1730 sought to improve the thermometer, but in so doing ignored the labours of Fahrenheit and employed spherical bulbs. He ascertained that alcohol diluted with 20 per cent. of water expanded from 1,000 to 1,080 volumes between the freezing and the boiling point of water, so he took zero for the lower and 80 for the higher temperature, dividing the intervening space into 80 parts. Three years later De Lisle devised a thermometer on the same principle, but called the boiling point zero, and the freezing point 150°, while in 1740 Micheli Du Crest made alcohol thermometers, taking as his fixed points the temperature of the cellar of the Paris Observatory, and the boiling point of water, dividing the interval into 100 parts.

Anders Celsius of Upsala in 1742 proposed a scale with zero at the boiling point of water, and with 100° at the temperature of melting ice, which was inverted by Linnaeus, thereby establishing the "Centigrade Scale."

It is of interest to note that none of these thermometers has exactly the same scale as was originally devised by the one whose name it bears, nor is any of them in popular use in the country in which it originated. The centigrade scale is used by scientists, but the use of the Fahrenheit scale is so firmly established in the English-speaking countries that the general adoption of the centigrade scale has been prevented.

Metallic thermometers employing the expansion of a metal bar as an indicator were first made by Muschenbroek, while Crichton in 1803 made use of the distortion produced by heat in a plate or bar composed of two metals of different expansive co-efficients soldered together, and about fifty years later, Hermann and Pfister of Berne produced their spiral thermometer, which marks maximum and minimum temperature. Self-registering thermometers were first made at the Accademia del Cimento, at Florence, while at the end of the seventeenth century, Bernouilli, and in 1757 Cavendish, proposed maximum and minimum thermometers of very imperfect construction. These instruments were improved by Six in 1782, when he produced his maximum and minimum thermometer, a combined instrument which was followed in 1794 by Rutherford's separate instruments for indicating maximum and minimum temperatures respectively. In 1832 Phillips suggested a maximum thermometer, in which a portion of the mercury column was separated from the main column by a bubble of air, but this instrument was superseded by Negretti and Zambra's constricted-tube thermometer.

One of the earliest clock-recording thermometers is that of Blackadder in 1826, while in 1842 Wheatstone invented an instrument by means of which a record of the temperature was obtained electrically at frequent intervals. At a later date Negretti and Zambra arranged a stand of twelve thermometers, one of which was released at hourly intervals by a clock, the temperature being automatically recorded, while in 1856 Beckley introduced a self-recording photographic thermometer.

These instruments have now given place to thermographs, in which a continuous temperature record is obtained on a clockwork drum, actuated by either a compensated strip of metal or a sac filled with spirit.

Regnault in 1847 constructed gas thermometers, while in the following year Kelvin proposed an absolute scale of temperature, the degrees of which denote exactly equal amounts of heat. On this scale the melting point of ice and the boiling point of water under normal conditions are 273·2° and 373·2° respectively.

1. THERMOMETERS BY MICHELI DU CREST. Presented by Prof. Dr. E. Hagenbach-Bischoff.

This photograph represents five old thermometers by Micheli du Crest, 1754; the small one is an alcohol thermometer with the Florentine scale.

Inv. 1876–733.

2. STANDARD MERCURIAL THERMOMETER. Made by Dollond. Lent by The Royal Society.

This thermometer, which dates from about the latter part of the eighteenth century, is a standard instrument made for the Royal Society.

It consists of a large spherical bulb at the end of a capillary tube 24 in. long, mounted on a thick brass scale which is graduated in half degrees from −20° to 535° F., on both sides of the stem. The brass scale is cut across at the 40° F. graduations, the lower portion being hinged to the upper. There are three standard points of reference on this thermometer, namely, freezing point of water, boiling point of water, and the melting point of tin.

Inv. 1893–137, S.M. 1448, L.S.

3. STANDARD MERCURIAL THERMOMETER. Made by Adams, Fleet Street. Lent by G. J. Symons, Esq., F.R.S.

This old standard thermometer was made by Adams of Fleet Street, and dates from about the end of the eighteenth century.

It is a mercury-in-glass instrument having a spherical bulb and a long and fairly large capillary tube, thereby securing a wide temperature range. The thermometer is mounted on a brass scale graduated in intervals of 20° from −30° to 710° F., and upon which are indicated the melting and boiling points of various substances, and other fixed temperatures. Inv. 1893–139.

4. STANDARD MERCURIAL THERMOMETER. Made by Troughton & Simms. Lent by The Royal Society.

This standard mercurial thermometer was made by Troughton and Simms for the Royal Society during the first half of the nineteenth century, and a label attached inside the box refers to the instrument as R.S. No. 7.

It is a mercury-in-glass thermometer mounted on a brass scale graduated in half degrees from 0° to 215° F., and enclosed in a mahogany box. Inv. 1893–136.

5. MERCURIAL THERMOMETER. Made by Pastorelli. Lent by The Meteorological Office.

The graduations range from −60° to +100° F. There is no inscription at the back of the frame to show on what expeditions it was employed, but it is said to have been used on H.M.S. "Fox," in 1857. Inv. 1908–90.

6. THERMOMÈTRE FRONDE. Lent by L. Casella, Esq.

This instrument is a modification of the *thermomètre fronde* originally designed by Arago in 1830 for ascertaining the true temperature of the air without a thermometer screen.

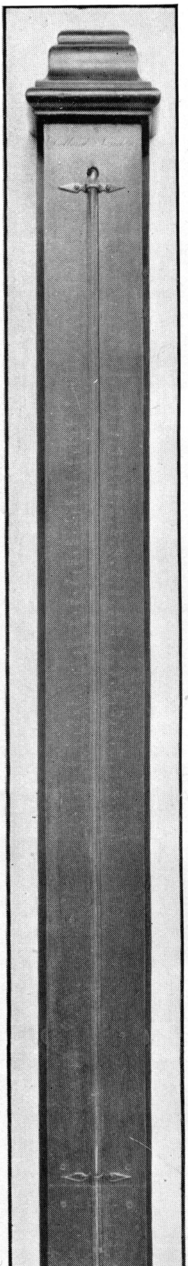
The thermometer is enclosed in its perforated metal case, when it is rapidly swung above the head about six times by means of a silk cord. The temperature indicated will then be found to be almost precisely that of a thermometer in a Stevenson screen. By this method more accurate results are obtainable than by exposure on stands of ordinary construction.

(*See* Q. J. R. Met. Soc. 1877.) Inv. 1893–154.

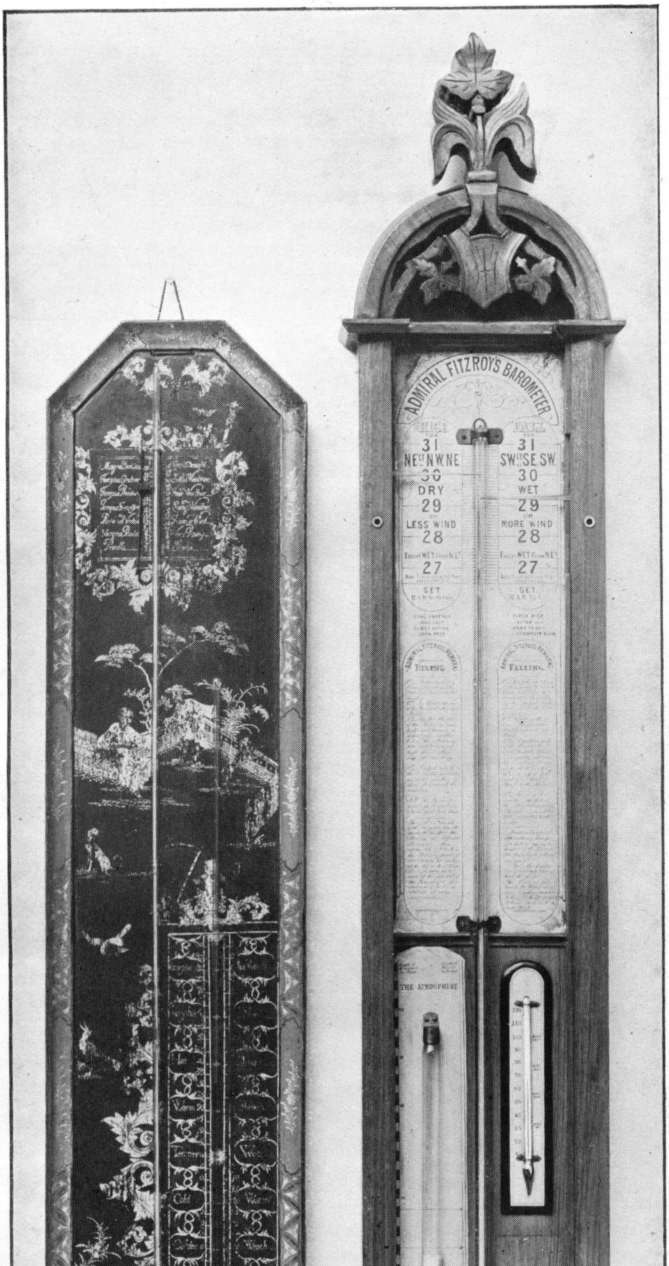
7. SPIRIT THERMOMETER. Made by Pastorelli. Lent by The Meteorological Office.

This instrument, which is graduated from −60° to +120° F., was used in Arctic expeditions on board H.M.S. "Resolute" (Captain Sir H. Austin, R.N.,

PLATE I.



Royal Society's
Standard Thermometer.



Early Siphon Barometer and Admiral Fitzroy's Barometer.

1850–51), and on board H.M.S. "Fox" (Captain, afterwards Admiral, Sir F. L. McClintock, R.N., 1857–59).

On the back is written :—

"This thermometer being nearly a mean of 11 others tried at temperatures varying between zero and $-46°$ was selected as a standard for the winter, and was placed accordingly on the fixed ice 15 yards from the ship. It is thus marked in order that comparative measures may hereafter be made with it as also any with reference to the journal kept by the officers of Resolute.

"This Ther. shewing on several occasions $-39°$, mercury began to consolidate, $-39.5°$ it was no longer in a fluid state, and at 40° it could have been propelled by powder. H.M. 'Resolute,' 7th October, 1851, Horatio Austin."

"Fox Yacht, 1857–9."

Inv. 1908–91.

8. SPIRIT THERMOMETER. Made by Newman. Lent by The Meteorological Office.

Graduated from $-90°$ to $+100°$ F. At the back it is inscribed :—"This thermometer was used on board the Arctic ship 'Assistance' during the winter of 1850–51 for registering the temperature of the air on deck. 9th August, 1851."

"Fox Yacht, 1857–9."

Inv. 1908–92.

9. SPIRIT THERMOMETER. Made by Hicks. Lent by The Meteorological Office.

The graduations range from $-70°$ to $+120°$ F.

It is marked at the back :—"Used by Sir Geo. Nares, 1883–4."

Inv. 1908–93.

10. SPIRIT THERMOMETER. Made by Pastorelli. Lent by The Meteorological Office.

This thermometer is graduated from $-70°$ to $+120°$ F. It is inscribed at the back :—"From Capt. Penny, October, 1851, for examination with a second thermometer and an aneroid barometer."

"Fox Yacht, 1857–9."

Inv. 1908–94.

11. FLUCTUATION THERMOMETER. Lent by Prof. Balfour Stewart, F.R.S.

This instrument was designed and used by Prof. Balfour Stewart in 1856 to measure the sum of the fluctuations of temperature.

Advantage is taken of the difference of capillary force and friction in two tubes of different capacity connected with the same bulb.

The thermometer, which consists of two tubes of different bores connected by a bulb in the centre, is set in a horizontal position, when an increase of temperature causes the mercury in the wider tube to move from the bulb towards the end, but with a decrease in temperature the mercury in the tube of narrower bore moves towards the bulb. Thus with all changes there is a movement of the mercury in the direction of the extremity of the wider tube, towards which the mercury steadily creeps. The instrument is fitted with a scale, divided into two parts, and graduated from 0 to 180, by means of which the amount of fluctuation during any interval of time can be ascertained. The thermometer is set for observation by standing it on end.

(*See* Proc. Roy. Soc., Vol. VIII, 1856–7, p. 195.)

Inv. 1876–77.

12. BALFOUR STEWART'S EXPERIMENTAL THERMOMETERS. Lent by The Meteorological Office.

These experimental mercury-in-glass thermometers are of unique design. Each instrument possesses a central bulb and two stems, which are differently disposed in the three cases.

In the longest instrument, a large bulb lies between the two portions of a capillary tube 19¾ in. long, while in the smallest one the bulb is situated at the lowest point of a U-tube, formed by two stems of different bore, one of them being enamelled behind the mercury column.

In the other thermometer, the bulb is situated at the lower extremity of one of the stems, the second stem joining the first one about ½ in. above the bulb, the two stems being parallel and about ¾ in. apart.

The stems of these thermometers are not graduated. Inv. 1915–153.

13. CHRONOTHERMOMETER. Made and presented by W. F. Stanley, Esq.

This instrument was designed by Mr. Stanley in 1876 for registering temperature cumulatively. An increase of temperature of 1° F. is found to accelerate the clock by 17·5 beats per day.

In the chronothermometer, the lower chamber or cistern is hermetically sealed over with a large air space above it, so that it is purely an air thermometer. The mercury is elevated through the central tube from the lower to the upper vacuum chamber by pressure from the expansion of the air contained therein due to increase of temperature, and the rate of the clock is increased in accordance with the decrease of the radius of the centre of oscillation.

The registration, during the day or for any period of time, of a high or low number of oscillations, would represent a high or low average for the height of the thermometer for that time.

(*See* Q. J. R. Met. Soc., Vol. III, 1877, p. 355, and Vol. XII, 1886, p. 15.)

Inv. 1886–77.

14. SYMONS'S EARTH THERMOMETER. Lent by L. Casella, Esq.

This arrangement was designed by G. J. Symons to obviate the difficulties encountered in obtaining ground temperature at different depths.

It consists of a heavy iron tube pointed at its lower end and driven into the ground to the depth at which the temperature is to be measured, while its upper end projects about 6 in. above the surface of the ground. A slow action thermometer protected by a boxwood casing is suspended by a chain within the iron tube, and remains there until a reading is taken, which is done by momentarily raising the thermometer. The scale is graduated in degrees from 25° to 95° F.

In this way the earth temperature at any convenient depth may be measured, the depths most frequently employed being 6 in., 1 ft., 2 ft., 3 ft., 4 ft., 6 ft., and 10 ft. Inv. 1893–155.

15. HOLLOW BULB THERMOMETER. Lent by The Meterological Office.

The bulb of this thermometer is of annular form, and encloses a cylindrical air space running almost the whole length of the bulb, thereby exposing a larger area, and accelerating the action of the thermometer.

A scale of graduations is etched on the front of the glass stem, but the values of these graduations are not indicated. Inv. 1915–154.

16. THERMOMETER WITH ENCLOSED LIMB. Made by J. G. H. Ronketti, London. Lent by The Meteorological Office.

This is a mercury-in-glass thermometer, with the stem and graduated scale enclosed in a glass tube.

The external tube is sealed to the thermometer bulb near its upper extremity, and encloses the stem and ivory scale, which are secured in position by a metal clip at the upper end. The scale is graduated to read from 23° F. to 116° F. in fifths of a degree. Inv. 1915–155.

17. WATER THERMOMETER. Made by Messrs. Negretti and Zambra. Lent by The Meteorological Office.

This thermometer is designed specially for measuring the temperature of water, and is of the type supplied to observers at sea.

It consists of an ordinary mercury-in-glass thermometer, graduated from 10° F. to 134° F., and mounted in a metal case with its bulb near the bottom of a deep trough. The bulb and the lower portion of the stem thus remain completely surrounded by the liquid when the instrument is lifted from the water. Inv. 1892–154.

18. BOILING POINT THERMOMETER. Made by Casella. Lent by The Admiralty.

This boiling point thermometer was used on the British ("Discovery") Antarctic Expedition of 1901, and is adapted for hypsometrical measurements.

It is a mercury-in-glass thermometer graduated to read from 180° F. to 215° F. in fifths of a degree. Immediately above the bulb is an enlargement of the bore. Inv. 1911–168.

19. BALLOON THERMOMETER. Lent by The Meteorological Office.

This very sensitive thermometer was constructed by Casella in order to obtain accurate indications of the temperature of the layers of air through which a balloon might be passing rapidly.

It is a mercury-in-glass thermometer, provided with a long bulb of narrow bore, and mounted fully exposed to the air, so as to reduce the lag to a minimum. Its delicacy of construction, however, renders it very fragile, and liable to damage from the bumping which frequently accompanies balloon descents.

It is graduated in degrees from −10° to 105° F. Inv. 1894–117.

20. AEROPLANE THERMOMETER. Made by Hicks. Lent by The Meteorological Office.

This thermometer was designed for use on aeroplanes, for indicating atmospheric temperature. It has now been replaced by an improved type.

The instrument consists of a large bulb filled with coloured liquid, which also partially fills the long column. The bulb is enclosed in a polished metal cover, which affords protection from sunshine, and is ventilated to allow free passage of the air. The thermometer, which is mounted on a strut of the aeroplane, some distance from the engine, is somewhat sluggish in action, and is unreliable when the machine is ascending or descending rapidly. It is graduated in degrees from 40° to 82° F. Inv. 1919–516.

SELF-REGISTERING THERMOMETERS.

21. PHILLIPS'S MAXIMUM THERMOMETER. Lent by L. Casella, Esq.

This type of thermometer, in which the temperature is registered by means of a separate portion of the column, was designed by Prof. Phillips in 1832.

It consists of a mercury-in-glass thermometer, the index of which is a portion of the mercurial column separated from the remainder by an air bubble. The instrument is mounted horizontally, so that with a rise of temperature the detached portion moves to the right, but remains in its extreme position on a subsequent fall of temperature.

The end of the index further from the bulb then indicates the maximum temperature attained. Inv. 1893–153.

22. STANDARD MAXIMUM THERMOMETER. Made and lent by Messrs. Negretti and Zambra.

The self-registering instrument was designed and patented by Messrs. Negretti and Zambra in 1852 to indicate the maximum temperature reached since the previous observation.

The thermometer stem is bent at right angles about an inch above the bulb, and near the bend is inserted a small piece of solid glass enamel which acts as a valve, allowing mercury to pass over it only on the application of heat. On subsequent cooling the column of mercury which has passed the valve cannot recede past the constriction, so that it remains in position and registers the maximum temperature.

After a reading has been taken the thermometer can be reset by gently shaking the mercury past the constriction, until the lower portion of the stem is completely filled.

The instrument is graduated in degrees from 10° F. to 146° F.

(*See* Pat. Specn., No. 14002 of 1852.) Inv. 1921–318.

23. RUTHERFORD'S MINIMUM THERMOMETER. Lent by L. Casella, Esq.

This type of minimum thermometer was designed by Dr. Rutherford in 1794 and is still in use.

It is a spirit thermometer, in the column of which is a glass index. It is mounted horizontally so that a decrease of temperature causes the spirit to recede to the left, carrying back the index to the lowest position, where it remains when the temperature subsequently rises. The minimum temperature is then registered by the end of the index remote from the bulb. The instrument is set by tilting until the index slides up to the meniscus.

A scale is etched on the thermometer stem and graduated in degrees from 0° to 135° F.

(*See* Trans. Roy. Soc., Edin., 1794.) Inv. 1893–158.

24. STANDARD MINIMUM THERMOMETER. Made and lent by Messrs. Negretti and Zambra.

This self-registering minimum thermometer is constructed on the principle proposed by Rutherford in 1794.

This alcohol thermometer is used horizontally and a small glass index floats in the spirit, its end furthest from the bulb being flattened. The instrument is set by inclining it with the bulb uppermost, until the index reaches the meniscus of the indicating column, after which it is again placed in the horizontal position. Any subsequent decrease of temperature causes the index to be drawn back to the lowest point to which the alcohol recedes, but an increase of temperature has no effect, so that the end of the index remote from the bulb registers the minimum temperature which has been attained. Inv. 1921–319.

25. MINIMUM ALCOHOL THERMOMETER. Lent by L. Casella, Esq.

This minimum alcohol-thermometer is constructed on Rutherford's principle, and is provided with a forked bulb which increases its sensitiveness.

The instrument is mounted on a block of ebonite, beyond which the bifurcated bulb projects. The large surface area of the bulb tends to reduce sluggishness, and to improve the sensitiveness of the instrument.

The stem is graduated in degrees from −20° to 118° F. Inv. 1893–152.

26. MERCURIAL MINIMUM THERMOMETER. Lent by G. J. Symons, F.R.S.

This instrument was designed and patented by Messrs. Negretti and Zambra in 1855, to indicate the minimum temperature attained since a prior observation was made.

The large bulb of the thermometer is connected to a fine capillary tube, above which and continuous with it is a tube of wider bore, provided with a graduated scale and terminating at its upper end in a small bulb. A steel index pointed at both ends is free to move along the wider tube, and when set for observation its upper point is brought to the mercury level.

With any contraction of the mercury column, the index falls by its own weight, but with increase of temperature the mercury expands and rises in the tube, passing the index and forcing it to the side of the tube, where it remains firmly fixed, and indicates the minimum temperature reached by the position of its upper point. A magnet serves to adjust the index, thereby setting the instrument for another observation.

The scale is graduated in degrees from −47° to 126° F.

(*See* Pat. Specn., No. 2306 of 1855.) Inv. 1893–129.

27. MERCURIAL MINIMUM THERMOMETER Made and lent by Messrs. C. F. Casella & Co., Ltd.

This instrument was designed and patented by Mr. L. M. Casella in 1861, to indicate the minimum temperature attained subsequent to the previous reading.

It is an ordinary mercury in glass thermometer, supported with its stem horizontal. About 1·5 in. from the bulb this horizontal stem is fitted with a lateral chamber, shouldered near its extremity, into which the mercury expands as the temperature rises, while the position of the mercury in the indicating stem remains stationary. Subsequent fall of temperature causes the mercury to recede in the stem, while that in the lateral chamber is unaffected. In this way the thermometer continually indicates the minimum temperature attained since it was last set.

(*See* Pat. Specn., No. 2100 of 1861.) Inv. 1921–314.

28. HICKS MERCURIAL MINIMUM THERMOMETER. Lent by The Royal Meteorological Society.

In this form of instrument, which was introduced in 1861, the temperature is ascertained by the measurement of a detached portion of the mercurial column.

In the bulb is a piece of platinum wire extending from a contraction at the neck to the bottom, and above the bulb is a small air bubble by which the column is divided.

During a fall of temperature, mercury passes below the air bubble (when it is in its lowest position at the neck of the bulb) into the bulb, thus shortening the column; on the temperature rising, the air bubble is raised and carries along with it the detached column unaltered in length.

To take a reading, the zero of the scale is brought into line with the upper part of the air bubble, when the number corresponding to the top of the upper column will give the minimum temperature.

(*See* Pat. Specn., 1861, No. 1244.) Inv. 1915–420.

29. MERCURIAL MINIMUM THERMOMETER. Made and lent by Messrs. Negretti and Zambra.

This self-registering instrument was designed and patented by Messrs. Negretti and Zambra in 1862, to indicate the minimum temperature reached since the previous observation.

Attached to the stem of the thermometer, and about an inch above the cylindrical bulb, is a supplementary tube, in which is inserted a small platinum plug. The thermometer is used horizontally, and if it is inclined the mercury flows along the supplementary tube until it reaches the plug.

On a decrease of temperature the mercury will fall in the indicating column until it attains its minimum temperature, and on a subsequent increase of temperature the mercury will rise in the supplementary tube, so that the indicating column will continue to register the minimum temperature.

To reset the instrument, the bulb end of the thermometer is raised until the mercury again comes in contact and is checked by the plug.

(*See* Pat. Specn., No. 1223 of 1862.) Inv. 1921–320.

30. MINIMUM THERMOMETER, WITH FLAT BULB. Presented by Dring and Fage.

This spirit minimum thermometer of the steel index type is specially designed and constructed to eliminate sluggishness, which is a disadvantage of spirit thermometers.

The bulb is made flat and shallow so as to expose as large a surface as possible to the atmosphere, while the glass is made as thin as is consistent with a non-barometric action.

The instrument is graduated in degrees from $-27°$ and $138°$ F.

Inv. 1876–857.

31. SIX'S THERMOMETER. Presented by Messrs. Dring and Fage.

This instrument, invented by James Six in 1782, is designed to furnish a continuous indication of both the maximum and minimum temperature experienced since the setting of the instrument.

The thermometer consists of a U tube, one arm of which is again bent downwards, while a bulb is provided at each extremity. The long cylindrical bulb is filled with alcohol or creosote, the other bulb being partially filled with the same liquid and also containing a bubble of air under pressure. Mercury is contained in the lower half of the V-tube, and as the temperature rises, the liquid in the filled bulb expands and pushes in front of it the column of mercury at either end of which is a steel index coated with glass, which is enabled to retain its position in the tube by means of an attached hair. The index on the right is thus pushed upwards and remains at the extreme point to which it is pushed, the maximum temperature being then indicated by the position of its lower extremity. A subsequent fall of temperature moves the mercury column to the left, pushing the left hand index upwards, thus indicating the minimum temperature.

The instrument is set for observation by adjusting the steel indexes to the ends of the mercury column by means of a magnet. Inv. 1876–856.

32. RUTHERFORD'S MAXIMUM AND MINIMUM THERMOMETERS. Lent by The Royal Meteorological Society.

The mercurial maximum and spirit minimum thermometers, which were originally designed by Dr. Rutherford in 1794, are shown together on the same frame.

The thermometers are mounted horizontally, the maximum one being uppermost, and consisting of a mercury in glass instrument, provided with a steel index which is pushed along by the mercury column as the temperature rises. The minimum instrument is a spirit thermometer, provided with a glass index, which recedes with the indicating column on a fall of temperature, but does not change its position when the temperature rises.

This form of maximum thermometer is not now in common use, but the minimum thermometer is frequently employed.

(*See* Trans. Roy. Soc., Edin., 1794.) Inv. 1915–421.

33. SIX'S THERMOMETER WITH FLAT BULB. Lent by S. G. Denton, Esq.

This instrument is a modification of the Six's thermometer of 1782, a thin flat bulb being fitted to increase its sensitiveness.

The thermometer is identical in principle to the Six's thermometer shown adjacent. The large bulb is specially designed, however, so as to present as large a surface to the air as possible, thereby increasing the sensitiveness of the instrument and reducing its lag. Inv. 1876–849.

34. DIMENUON THERMOMETER. Made and lent by C. F. Casella & Co., Ltd.

This instrument is similar in principle to Six's instrument, but is constructed to hang horizontally instead of vertically.

The tube is in the form of a U, having a bulb at each extremity, one being completely filled with spirit, and the other containing spirit and also a bubble of air under pressure. As the temperature rises, the liquid in the filled bulb expands and pushes in front of it a column of mercury, having an iron index at each end. As the temperature decreases the mercury is allowed to move back and pushes the lower index to the left. The indexes remain at the furthest point to which they are pushed by the mercury as it travels forwards or backwards, and thus indicate both maximum and minimum temperatures, the readings being taken from the ends of the indexes nearest the mercury. They are reset by tilting the instrument so that they fall by their own weight on to the mercury column. Inv. 1921–311.

THERMOGRAPHS.

35. METALLIC THERMOGRAPH. Lent by The Royal Meteorological Society.

This self-registering thermometer was invented and made by N. S. Heineken in 1837.

A compound bar is bent into the form of the letter C and opens out or closes with variations of temperature.

One end of the bar is secured to the base of the instrument, and the other is free to act upon a lever bearing a toothed arc. This arc, by means of a pinion and wheel, moves a rack carrying a pencil by which a record is made upon the paper of the drum. This drum is ruled for temperature and divided by twelve vertical lines for the hours. The whole is set on a mahogany stand.

Inv. 1915–419.

36. WHITEHOUSE'S EXPERIMENTAL THERMOGRAPH. Lent by The Royal Meteorological Society.

This consists of a Six's thermometer of which the part of the tube containing the mercury is bent into the form of a circle. This circular part is set in a vertical position, while the bulbs and connecting tube form a horizontal axis on which the whole instrument is free to turn.

The expansion or contraction of the alcohol in the thermometer through changes of temperature causes a movement of the mercury in contact with it, and a consequent change in the position of the centre of gravity of the apparatus, with the result that the glass circular tube turns. An index can be so arranged in connection with the tube as to mark on a paper the movement and thus record the rise and fall of temperature.

Inv. 1915–418.

37. THERMOGRAPH. Lent by The Meteorological Office.

This instrument, which is of the Meteorological Office pattern, is designed to furnish a continuous record of temperature at any place. For meteorological use it must be exposed out of doors, preferably in a screen.

It consists essentially of a bi-metallic spiral, one end of which is firmly secured, the motion of the other extremity being communicated by a shaft to a long lever arm carrying a pen. This pen bears lightly on a clock-drum carrying a daily or weekly chart. A device is provided for altering the position of the pen on the chart and so setting the pen for different seasons or climates.

Two ranges of charts are used in the British Isles; the Winter chart, which has a range from −10° F. to 65° F., and the Summer chart from 30° F. to 105° F., the proper date for changing from one set of charts to the other varying considerably with the locality. For London the changes should be made about the middle of April and of October respectively.

Inv. 1921–75.

THERMOMETER SCREENS.

38. STEVENSON THERMOMETER SCREEN. Lent by The Meteorological Office.

This thermometer screen of the Royal Meteorological Society's pattern, which is in general use in this country, is a modification of the screen originally devised about 1864 by Thomas Stevenson, C.E., F.R.S.E., Engineer to the Board of Northern Lights, and was improved in 1883 by a Committee of the Royal Meteorological Society.

It consists of a wooden box designed to protect thermometers from radiation, while at the same time providing adequate ventilation. It is fitted with a double roof and double louvred sides, the floor consisting of three narrow boards, the outer ones overlapping the inner one in such a way as to completely shut off radiation from below, but allowing free access of air. Enclosed in the screen are maximum, minimum, and wet and dry bulb thermometers, which are clamped in position, and so arranged that they may be read without the necessity for moving any of them, while the bulbs are as far removed from the walls of the screen as possible.

The screen should be freely exposed to sun and wind, and should stand on four legs above closely cut grass, the floor of the screen being at a height of about 3 ft. 6 in. above the ground, and so fixed that the opening side faces North or slightly to the East of North, to avoid radiation effects while observations are being made.

(*See* Q. J., Met. Soc., Vol. XXIII, 1897, p. 72.) Inv. 1892–153., S.M. 1442. L.S.

39. NORWEGIAN THERMOMETER SCREEN. Lent by Prof. H. Möhn, Christiania.

This screen was designed by Prof. H. Möhn about 1875 for use at stations under the control of the Norwegian Meteorological Institute, and is intended as a shelter for a minimum thermometer only.

It is made of sheet iron with double walls, and is supported outside a window on a horizontal rod which is designed to pass through the window frame, so that the screen and thermometer together may be tilted in order to set the instrument.

The double walls protect the minimum spirit thermometer, which is of the Rutherford type, from radiation. Inv. 1876–780.

40. NORWEGIAN THERMOMETER SCREEN. Lent by Prof. H. Möhn, Christiania.

This screen was designed by Prof. H. Mohn about 1875 for obtaining the air temperature, and was used at stations controlled by the Norwegian Meteorological Institute.

It is a single walled sheet-iron cylindrical shelter, to be mounted outside a window or on a wall, and kept in the shade. Adequate ventilation is provided by the absence of a floor and by large air vents immediately below the conical roof. A sensitive thermometer is supported axially in the screen by two radial arms, and can be read through a rectangular aperture in the side of the screen.

The thermometer is graduated in intervals of 2° from −40° C. to 35° C.

Inv. 1876–781.

41. NORWEGIAN THERMOMETER SCREEN. Lent by Prof. H. Möhn, Christiania.

This screen was designed about 1875 by Prof. H. Möhn for meteorological stations of the second order, controlled by the Norwegian Meteorological Institute.

It is a single walled sheet-iron shelter designed to be mounted outside a window and kept in the shade, while the back being louvred and the fact that no front or floor is provided, ensure adequate ventilation. The screen contains dry and wet bulb thermometers, a minimum thermometer of the Rutherford pattern, and a single-hair hygrometer of the type designed by Saussure.

Inv. 1876–782.

BAROMETERS.

Several general notions in regard to the weight and pressure of air seem to have been entertained in ancient times, but it was due to the celebrated experiment of Torricelli in 1643 that the barometer in its best form was at once created. After this some time elapsed before attention was directed to the variation of height of the mercury column or to the fact that this variation was related to weather changes.

Barometers really group themselves into two divisions, the cistern type and the siphon type, the former of which is principally used in England, and the latter on the continent.

The siphon form of barometer appears to have been contrived at an early date, and then abandoned, as it diminished the range of motion of the mercury, while efforts were chiefly centred on rendering the scale more open. Hooke, in 1665, described a wheel barometer, having one line and a single pulley, and the following year Boyle described a balance barometer, which was later modified by Morland, in which a hollow glass sphere was balanced against a metal counterweight, which could be fitted with a wheel and index.

The earliest proposal for increasing the scale is ascribed to Descartes, and was carried out by Huyghens, who employed a supplementary tube extending upwards above the mercury column containing water, the motion of the surface of which magnified the variations due to atmospheric pressure. However, it proved unsatisfactory, and in 1672 Huyghens proposed another arrangement known as the double barometer, which was modified by De la Hire in 1690.

This was followed by Morland's diagonal barometer, in which the upper portion of the tube was inclined considerably to the vertical, in order to increase the scale.

The first effort to indicate the height of the mercury column with accuracy was due to Derham, who in 1698 proposed to use a fine finger, a rack connected with which moved a hand traversing a graduated circular dial giving readings to 0·01 in., while in the same year Gray proposed to read off the height by using a double microscope furnished with a micrometer, an arrangement similar in principle to the cathetometer.

A further device for increasing the scale known as the rectangular barometer was proposed by Cassini, and later by Bernouilli in 1710, in which the upper closed end of the tube acted as the cistern, and the lower end was extended as a narrow horizontal tube, so that a variation in vertical height gave a greatly increased variation along the horizontal tube.

Dalencé in 1688 described a portable barometer having a closed wooden cistern, with no communication to the external atmosphere.

An ingenious conical barometer for use at sea was devised by Amontons in 1695, which consisted of a conical tube closed at the upper end and open below, and of diameter gradually increasing downwards. Variation of atmospheric pressure causes the mercury to rise and fall in the tube, thereby increasing or decreasing its vertical depth.

Towards the end of the seventeenth century Hooke introduced a combination of an air thermometer and a sealed thermometer, so that by comparison changes of pressure could be inferred. This instrument has been modified at various times and eventually reached the form of the sympiesometer.

The earliest mention of boiling the mercury was made in 1738 by Beighton, who stated that Orme in making diagonal barometers boiled the mercury in order to drive out air.

Quare in 1685 constructed a barometer in which, by means of a screw acting upon a leather below the cistern, the mercury could be forced up the tube and so render the instrument portable. Modifications were introduced by Sisson, Rowning in 1744, Bourbon in 1751, and a similar form was described by Desaguliers.

In order to ensure a definite level of the mercury, Brisson in 1755 provided a small hole in the cistern so that the superfluous liquid might overflow, a method which was adopted by Lavoisier in 1779, Austin 1790, Power 1877, and Negretti and Zambra in 1886.

About 1788 Ramsden constructed a barometer provided with a double index in front and behind the tube, which was adjusted so as to be tangential to the convex mercury surface. The index carried two verniers indicating English and French readings, while a thermometer was fitted giving the temperature on the Fahrenheit and Réaumur scales.

Another method of adjusting the level of the mercury was introduced by Gough in 1807, who employed an ivory piston in the lower widened branch of the siphon barometer, to adjust the mercury to an external mark on the glass ; a similar method was also employed by Newman. Fortin in 1810 suggested applying this to the cistern barometer, and adjusting the mercury by screw action from below so as just to touch a fixed ivory point representing the zero of the scale, while in 1837 Newman produced his standard barometer in which the rod carrying the scale terminated below in an ivory point for adjustment to the mercury surface.

Gay Lussac's siphon form of portable barometer was first described in 1816. In this instrument the lower part of the principle tube is contracted, and a small hole near the end of the short branch affords communication with the external air. This was modified in 1824 by Bunten, who placed within the lower part of the main tube a second tube tapering downwards and terminating in a small orifice, thereby preventing access of air to the vacuum.

In 1837 Baily described the well-known flint-crown glass standard of the Royal Society, consisting of two distinct tubes, one of flint and the other of crown glass, dipping both into one cistern, and provided with a common scale.

In order to increase the sensitivity of the barometer, Guthrie in 1877 connected the two branches of a siphon barometer by a horizontally-placed spiral of small internal diameter, having an included small air bubble to indicate barometric variation.

The Kew standard barometer was first described by Welsh in 1856, while of other standards may be mentioned the normal barometer and cathetometer of the Russian Central Physical Observatory.

Liquids other than mercury have been employed in the construction of barometers, the most important examples being linseed oil by Luke Howard in 1801, and water by Daniell in 1830 in the well known water barometer of the Royal Society, which was afterwards destroyed by fire at Crystal Palace. Glycerine was also employed by Jordan in 1873, and an example of this type of barometer is exhibited.

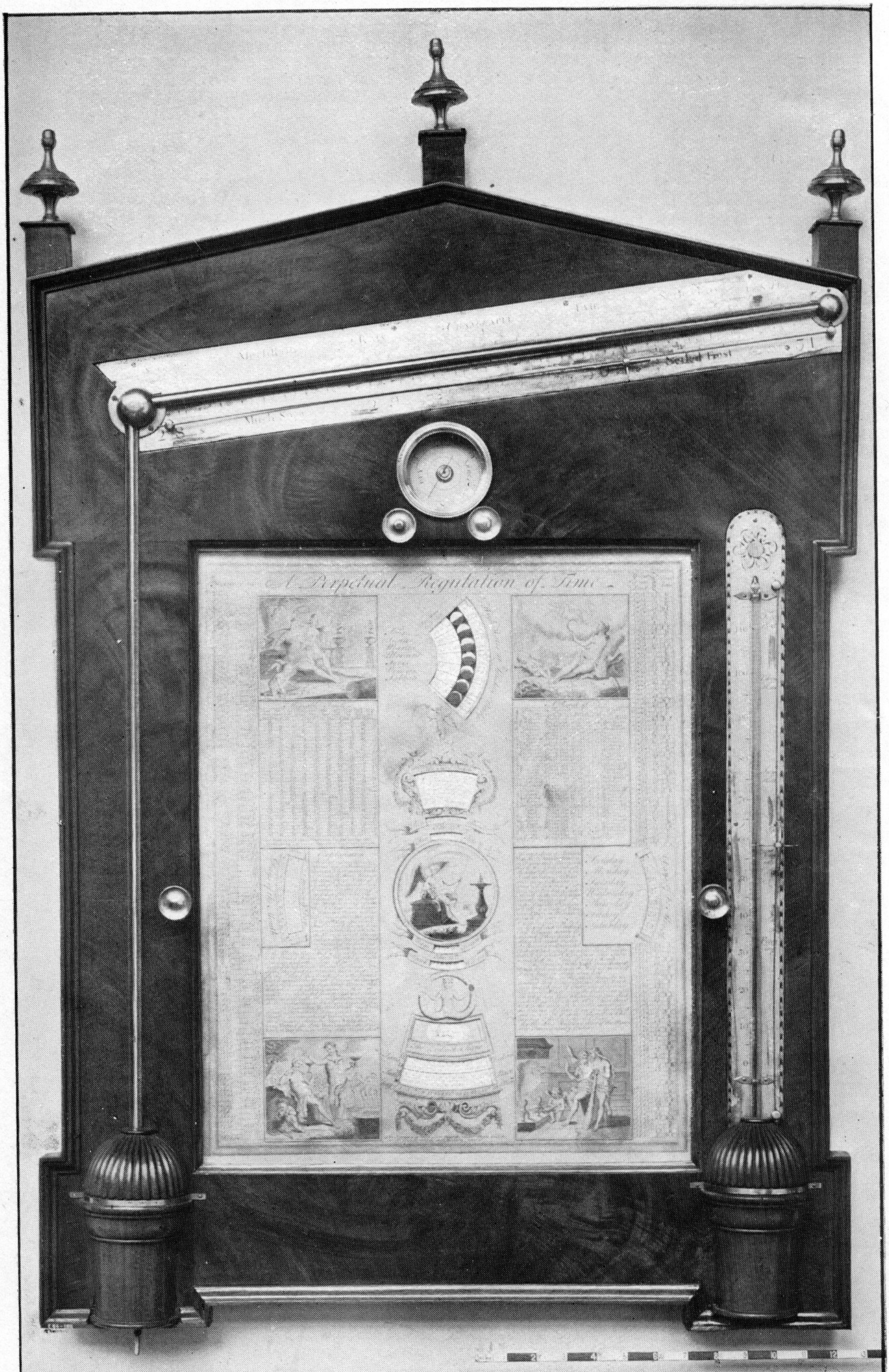
In 1880 Wallis designed his barometer adjunct, which consists of a small microscope for attachment to the cistern for facilitating the adjustment of the ivory point.

The practice of attaching to barometer scales words indicating the kind of weather to be expected with different heights of the mercury appears to be one of comparative antiquity. In 1688 Dalencé indicated nine different types of weather, together with the corresponding barometer readings, while Derham in 1698 also mentions weather plates.

Fitzgerald's wheel barometers of 1761 and 1770 give six different distinctive types of weather, while on Ramsden's portable barometer of the same period there are seven.

Changeux in 1780 proposed modifications having regard to different winds, while Fitzroy at a later date endeavoured to give weather indications that should better accord with actual fact.

PLATE II.



Diagonal Barometer.

A recording barometer was designed by Beaudoux in 1777, and consisted of a siphon barometer attached to a semi-circular balance beam carrying a pencil, which traced a continuous record on a travelling paper. This arrangement was modified in 1780 by Changeux, who arranged the recording pencil to be left free, and to be struck by a hammer at definite times, a method afterwards adopted by Kreil 1841, Brysson 1844, and others. The discovery of photography and the applications of electricity enabled Jordan in 1838 to apply photography to the registration of barometric and other variations, and he was followed in 1847 by Brooke and Ronalds working independently.

The balance barometer, after having been employed by Morland, was revived by King in 1853 for recording purposes, and again by Secchi four years later.

Regnard's barometrograph of 1857 provided a continuous record by differential action originating from a clock or from electric currents, controlled by the movement of the float in the lower branch of a siphon barometer, by which means motion is communicated to a screw or a line passing over a pulley, in either case carrying a recording pencil. This arrangement was modified by Redier in 1875, and again in 1886.

CISTERN BAROMETERS.

42. DIAGONAL BAROMETER. Made by Messrs. Watkins and Smith, London. Presented by The Admiralty.

This instrument, which dates from about 1750, is of the type designed by Sir Samuel Morland. In order to obtain an open scale, the upper portion of the tube is inclined considerably to the vertical, and any change in the barometric pressure is accompanied by a much greater motion of the mercury along the tube than in the case when the barometer tube is vertical.

It is a closed cistern barometer, provided with a leather base and an adjusting screw, operated from below. The barometer tube is bent at an angle of about 80° near the 28-in. graduation, and a graduated scale corresponding to a barometer variation of 3 in., but having a length of about 20 in., is fixed alongside the upper portion of the tube, enabling the barometer to be read to 0·01 in.

Mounted on the same board is an alcohol thermometer, graduated according to the Fahrenheit scale.

The intervening space is occupied by a calendar entitled: "A perpetual Regulation of Time," from which the days of the month, zodiacal signs, sun's right ascension, declination, and time of rising and setting, high water at London Bridge, and phases of the moon can be ascertained.

Inv. 1876–814, S.M. 987, L.S.

43. PORTABLE CISTERN BAROMETER. Made by F. Watkins, London.

This early instrument is of the closed cistern type, and represents the stage of development of the barometer about the middle of the eighteenth century.

It consists of a barometer tube entering at its lower extremity a cylindrical wooden cistern which is closed at its base by a covering of thin leather, and the whole is enclosed by a hemispherical cap of mahogany. Below this cistern a screw presses on the leather, and may be employed to force the mercury to the top of the tube for facility of transport. A scale graduated in inches and tenths is fixed near the upper end of the barometer tube, and carries a pointer which may be set at the barometer reading.

A series of nine weather indications are engraved opposite the appropriate graduations, enabling the instrument to be used as a weather glass.

Inv. 1920–54.

44. OPEN CISTERN BAROMETER. Made by Ramsden. Lent by The Royal Society.

This barometer was in use at the rooms of the Royal Society during the latter half of the eighteenth century, and is referred to by Cavendish in 1776 in his description of the Royal Society's instruments.

The cistern consists of a turned mahogany hemisphere, provided with a cover. The barometer tube is secured with its lower end below the surface of the mercury in this chamber, while at the upper end a movable index carries a vernier by means of which the barometric height may be read on the graduated scale. The internal diameter of the tube is approximately 0·25 in., and the depression of the mercury due to capillarity is 0·05 in., while the limit of the capacity error is about 0·01 in.

Seven weather indications are marked opposite the appropriate barometric readings.

(*See* Phil. Trans., Vol. LXVI, 1776, p. 375.) Inv. 1893–143.

45. STANDARD FORTIN BAROMETER. Made by Messrs. Elliott Bros.

This is a closed cistern barometer embodying the principle first suggested by Fortin about 1810, which consists in adjusting the mercury in the cistern until its surface is just in contact with a fixed ivory point.

The graduations of this instrument are made from the tip of the ivory pointer in the cistern which indicates the zero of the scale, and before a reading is taken the surface of the mercury is brought into contact with this tip by means of a screw at the bottom of the barometer, which, acting on an inner flexible leather base of the cistern, raises or lowers the contents. The readings obtained in this way give the actual height of the mercury column from the surface of the mercury in the cistern, and the capacity error is thus eliminated. A metal scale and vernier enable this height to be read to 0·002 in., and a Fahrenheit thermometer on the case of the instrument indicates the temperature.

A barometer tube is supported by a bracket and fitted with a ring and clamping sciews, so that it may be fixed readily in a vertical position, which is essential for accurate observations. Inv. 1885–116 & 117.

46. OPEN CISTERN BAROMETER. Made by Newman. Lent by The Royal Society.

This open cistern mercurial barometer, which dates from about 1820, was made for the Royal Society by Newman, under the direction of Dr. Daniell.

This cistern is turned in well-seasoned mahogany, and there is a small cavity in its base to receive the end of the barometer tube, while a groove communicates with a cavity to ensure the free passage of the mercury. An ivory float with marked stem indicates the change of level of the mercury in the cistern with the rise or fall of the barometer, and by means of which the level may be taken very accurately.

The tube has a large bore (0·53 in.), hence the error from capillarity is small, and the correction to be applied for the capacity of the cistern is 0·01 of the distance above or below the neutral point, which is given on the instrument as 30·576 in. A scale reading to 0·002 in. enables the barometric height to be read and reduced to the standard temperature of 32° F.

A small thermometer in front of the instrument dips into the mercury of the cistern, and is graduated with the Réaumur and Fahrenheit scales.

(*See* Meteorological Essays and Observations, by J. F. Daniell, F.R.S., 1823.) Inv. 1893–142.

47. OPEN CISTERN BAROMETER. Made by Newman. Lent by The Royal Society.

This barometer, which dates from 1824, was made for the Royal Society by Newman under the direction of Sir H. Davy.

It consists of an open cylindrical iron cistern into which dips the lower end of the barometer tube. Within the lower part of the main tube is enclosed a second tube tapering downwards and terminating in a small orifice as applied to the siphon barometer by Bunten in the same year, thereby preventing access of air to the vacuum.

Correction is made for capacity error by means of an iron plunger, which is of the same diameter as the interior of the barometer tube, and is made to dip into the mercury of the cistern. When the vernier is raised or lowered for taking readings, the plunger is moved simultaneously, but in a contrary direction, by the action of a pinion and a double rack. Thus any decrease or increase in the amount of mercury in the cistern, consequent on a rise or fall of the barometer, is compensated by the immersion of the plunger. A barometer is attached to the instrument, the bulb of which is placed in the cistern. A graduated scale and vernier are fitted, enabling the barometric height to be read to 0·002 in.

Inv. 1893–138.

48. LARGE CISTERN BAROMETER. Made by R. C. Woods. Lent by The Royal Meteorological Society.

This instrument was made in 1837 by R. C. Woods as a standard barometer for the Meteorological Society.

It consists of a large glass cistern, 7 in. in diameter, and capable of holding about 70 lb. of mercury. The sectional areas of the cistern and tube are in the proportion of 50 to 1, so that corrections for capacity error are thus rendered unnecessary.

Graduated scales are attached near the upper end of the tube, upon which the barometric height can be read in French or English units, the latter with an accuracy of 0·001 in. Inv. 1915–422.

49. RONALDS'S ORIGINAL PHOTO-BAROMETROGRAPH. Lent by The Meteorological Office.

This apparatus was designed and constructed by Sir Francis Ronalds in 1847, for registering photographically the changes in the height of the barometer upon a daguerrotype plate. It was afterwards erected and used at the Kew Observatory.

In this instrument the light from an argand lamp, after passing through a condensing lens, falls on a narrow slit cut in a metal plate attached to a barometer tube, the mercury in which, by rising or falling, varies the length of the slit illuminated. An achromatic combination of lenses, by Voigtlander, throws a magnified image of the bright slit upon an aperture in the case, past which a daguerrotype plate is moved slowly by clockwork, and so registers the changes in the height of the barometer.

The barometer itself, together with the cistern, which is of large area, is suspended from a system of levers and zinc rods, on the principle of the gridiron pendulum, in such a manner as to render the indications immune from the effects of temperature fluctuation.

An improved form of this instrument, in which the photographic image is received upon paper, was developed later, and employed in many observations.

(*See* Brit. Assoc. Report, 1851.) Inv. 1876–795.

50. GLYCERINE BAROMETER. Made by Jas. B. Jordan, Esq.

This instrument was designed in 1873 by J. B. Jordan with a view to producing a delicate "weather glass" indicating small changes of pressure by considerable variations in the height of the indicating column, and at the same time preserving the accuracy of the mercurial barometer.

The fluid employed in this barometer is pure glycerine, having a specific gravity of 1·26, or about one-tenth that of mercury. On account of its high boiling point this liquid possesses a low vapour tension at ordinary temperatures, so that a barometer of this construction is not subject to the errors of a water barometer.

The fluctuations of the column of glycerine are observed in a glass tube of 1 sq. in. sectional area, or one-hundredth that of the cistern, while the tube forming the body of the instrument is an ordinary composition gas pipe of ·625 in. diameter and 27 ft. long, placed in the well of the staircase between the upper and lower galleries. The exposed surface of the glycerine in the cistern is protected by a layer of paraffin oil, in order to prevent absorption of moisture from the atmosphere.

The divided scale on the right hand side is in inches, and that on the left shows the equivalent values reduced to a column of mercury.

(*See* Proc. Roy. Soc., Vol. XXX, 1873, p. 105.) Inv. 1876–760.

51. CHRONOBAROMETER. Made and presented by W. F. Stanley, Esq.

This instrument, which is similar in principle to those of Hall in 1851 and Rankine 1853, was designed by Mr. Stanley in 1876 in order to secure the mean of the atmospheric pressure for any given period, as hourly, daily, weekly, monthly or yearly, by simple observations.

In the chronobarometer, a barometer tube of modified construction is suspended as a pendulum, and driven as an ordinary time pendulum, by clockwork. The modification consists principally in making the vacuum chamber at the top and the cistern below of nearly equal diameters, so that increase of atmospheric pressure shall raise as great a weight as is necessary to shorten the radius of the centre of oscillation sufficiently for the clock to be accelerated considerably thereby. The clockwork is so constructed that the number of oscillations of the pendulums are continuously counted off on the dial, which reads decimally up to ten millions, and it is found that a rise of 1 in. of mercury in the barometer pendulum accelerates the clock about 949 beats per day.

To ascertain the mean atmospheric pressure over a given period by this instrument, the time of observation at which the period commences must be taken by an ordinary clock simultaneously with the reading of the dial, as also at the end of the given period. Temperature correction is made by means of the temperature clock or chronothermometer shown adjacent.

(*See* Q. J. R. Met. Soc., Vol. III, 1877, p. 352, and Vol. XII, 1886, p. 115.)

Inv. 1886–70.

52. BAROMETER ADJUNCT. Lent by L. Casella, Esq.

This apparatus was designed in 1880 by Wallis for use with the Fortin barometer in adjusting the level of the mercury in the cistern before taking a reading.

It consists of a small microscope for attachment to the cistern, to facilitate adjustment of the ivory point.

(*See* Q. J. R. Met. Soc., Vol. VI, p. 164.) Inv. 1893–156.

53. PORTABLE PEDIMENT BAROMETER. Made and lent by Messrs. Elliott Bros.

This portable mercurial barometer is of the closed cistern type, and may also be used as a weather glass.

The cylindrical wooden cistern is fitted with a flexible leather diaphragm, which is adjusted by means of a screw operated from below. Opal scales and a double index are provided behind the upper end of the tube, while rackwork verniers enable the reading to be made to 0·01 in. and compared with that of the previous day.

Barometer indications are given on one scale for a rising, and on the other for a falling, barometer, while a thermometer attached to the front of the instrument indicates temperatures in the Fahrenheit and Centigrade scales.

Inv. 1890–49.

54. PORTABLE PEDIMENT BAROMETER. Lent by Messrs. P. Harris & Co.

This instrument is of the closed cistern type, the cylindrical wooden cistern being fitted with a flexible leather base, adjusted by a screw operated from below.

Near the upper portion of the tube is a graduated scale fitted with two rackwork verniers, by means of which the height of the barometer can be read to 0·01 in. and compared with the reading of the previous day.

Four weather indications are also given opposite the appropriate graduations, enabling the instrument to be used as a weather glass. Inv. 1889–24.

55. FISHERY BAROMETER. Made by Messrs. Negretti and Zambra. Lent by The Meteorological Office.

This barometer is of the closed cistern pattern, and is of the type supplied to small ports and fishing stations.

The instrument has a wooden cylindrical cistern provided with a flexible leather base, which is adjusted by a screw operated from below. A graduated scale behind the upper portion of the barometer tube is fitted with a rackwork vernier by means of which the height can be read to 0·01 in. Weather indications are also given for a rising and falling barometer enabling the instrument to be used as a weather glass, while the temperature is indicated by a Fahrenheit thermometer on the front of the case, graduated from 5° F. to 148° F.

Inv. 1892–151.

56. STATION BAROMETER. Made by Calderara.

This Kew Pattern Station barometer is in general use in the British Isles at the present time, and is used at all land stations under the control of the Meteorological Office.

In this type of instrument the glass tube is considerably contracted for the greater portion of its length in order to prevent unsteadiness of the mercury column or "pumping," also to strengthen the tube and to lessen the weight of mercury. The tube is enclosed in a metal case, which is mounted on gimbals to ensure verticality, and the upper part of the instrument carries a scale, graduated in millibars and inches, while a vernier enables the height to be read to 0·01 millibars or 0·002 in. The instrument also carries a thermometer, which is graduated to read temperature on the Fahrenheit scale from 5° F. to 130° F., and on the absolute scale from 253*a* to 328*a*.

A small hole in the upper part of the cistern admits access to the superincumbent air in the cistern, and a washer of leather permits the atmosphere to exert pressure, but prevents the mercury escaping from the cistern.

To prevent air and moisture leaking into the vacuum above the mercury column, the tube is furnished with a small "air-trap," or funnel, as suggested by Bunten in 1824, which is inserted between the cistern and the top of the mercury column. By this means, any air entering the tube becomes imprisoned at the trap, and therefore cannot interfere with the efficiency of the instrument.

Inv. 1914–312.

57. MICRO-BAROGRAPH. Made by Messrs. Negretti and Zambra. Lent by The Meteorological Office.

This apparatus was designed in 1903 by Sir Napier Shaw, F.R.S., and Mr. W. H. Dines, to secure a magnified record of the minor fluctuations of atmospheric pressure, and, at the same time, to disentangle these fluctuations from the general barometric surges.

It consists of a closed metal cylinder, of about one-third of a cubic foot capacity, containing air at approximately atmospheric pressure, provided with a mechanical arrangement by which the variations of the difference of the pressures inside and out are recorded. In order that the temperature of this air may only change slowly, the cylinder is enclosed in a large wooden case, the intervening space being packed with feathers, or some other non-conducting material, while, in order that the pressure inside may not differ materially from that outside, a very small leak is allowed, through a fine capillary tube, which does not interfere with changes of short period, but prevents the pen from wandering from its mean position during a steady rise or fall of the barometer. A hollow cylindrical bell floats mouth downwards in a vessel containing mercury, and the interior of the bell communicates with the air chamber through a vertical pipe. Fairly rapid decrease of external pressure, or increase of internal pressure, causes the bell to rise, and the motion is magnified by a system of levers and communicated to the pen, which records on a chart rotated by clockwork.

(*See* Q. J. R. Met. Soc., 1905, p. 39.) Inv. 1921–74.

58. MICROBAROGRAM AND FLOAT BAROGRAM. Lent by The Meteorological Office.

A record obtained with the microbarograph at Kew on 17th–18th February, 1921, is here shown with one taken at the same time with the float barograph, for the purpose of comparison.

The degree to which minor fluctuations of atmospheric pressure are magnified can be seen by an examination of the records. Pressure variations which are too small to be seen in the float barogram are plainly discernible in the microbarogram, while changes of pressure which are sufficiently large to appear in the former record assume considerably greater proportions in the latter, enabling the wave-form to be investigated. Inv. 1922–10, 11.

59. MICROMETER-READING BAROMETER. Made and lent by Messrs. Negretti and Zambra.

This instrument was designed and patented by Mr. F. L. Halliwell in 1919 in order to incorporate in a station barometer the accuracy and ease of reading which are peculiar to the micrometer.

In this barometer the vernier is dispensed with, and the finer readings are made direct on a drum micrometer.

The barometer, which is of the Kew pattern, is suspended freely from an arm and may be clamped in position by the three screws at the lower end. The upper portion of the tube is surrounded by a metal cylindrical collar, carrying at its upper extremity a sighting piece bearing an arrow which moves along the scale. The motion of the collar is governed by the rotation of the micrometer head, by means of which its position may be adjusted.

When taking a reading, the sighting piece is brought level with the top of the mercury by revolving the micrometer head. The arrow mark on the sighting piece shows the reading to the nearest 0·1 in., while the micrometer drum indicates to 0·005 in., which can be subdivided easily by the eye to 0·001 in.

In the case of instruments fitted with the metric and C.G.S. scales, the barometric height can be determined similarly to 0·025 mm. and 0·025 millibars respectively.

(*See* Pat. Specn. No. 139029, 1919.) Inv. 1921–321.

MARINE BAROMETERS.

60. MARINE BAROMETER. Made by Thomas Jones. Lent by The Meteorological Office.

This instrument was made by Thomas Jones in the early part of the nineteenth century.

A metal case encloses the wooden cistern, which is provided at its lower end with a flexible leather cap, adjusted by a screw operated below. The bore of the barometer tube is contracted for the greater portion of its length to minimise "pumping," and is enclosed in a mahogany case provided with a brass scale and vernier near its upper extremity. It is graduated in tenths of an inch and reads by vernier to one-hundredth. A thermometer is attached to the instrument which reads from 0° to 134° F. Inv. 1908–83, S.M. 1437, L.S.

61. MARINE BAROMETER. Made by Newman. Lent by The Meteorological Office.

This instrument was designed by Newman in 1824, and embodies many interesting features.

In this metal-cased barometer an open iron cistern replaces the customary wooden one, and the instrument is rendered portable by screwing the lower portion of the case. A mercury thermometer is fitted with its bulb in the cistern so as to indicate the temperature of the mercury accurately. By means of a graduated scale and vernier the barometric height can be read off to 0·002 in.

It was in putting forward this barometer that Newman called attention to the inaccuracy of the ordinary system of marking off barometer scales from a presumed standard, without regarding the absolute height of the mercury, or the relative proportions of the diameters of the tubes and cisterns.

(*See* Quart. Jour. of Science, Vol. XVI, p. 277.) Inv. 1908–86.

62. MARINE BAROMETER. Made by Pastorelli. Lent by The Meteorological Office.

This instrument, which dates from the early nineteenth century, is of the closed cistern type, and is provided with a wooden cistern, the leather cap of which can be adjusted from below.

It is designed to be mounted on gimbals, and a metal scale and rackwork vernier enables the barometer height to be read to 0·002 in. No thermometer is fitted. Inv. 1908–82.

63. MARINE BAROMETER. Made by Bate. Lent by The Meteorological Office.

This barometer, which dates from the first half of the nineteenth century, is shown supported by a spring arm, designed to reduce oscillations.

In design, the instrument is almost identical with that by Dennis, shown adjacent. As in other marine barometers, the bore of the tube is contracted in the central portion in order to eliminate "pumping," which is still further damped by the spring arm. The scale is graduated in tenths of an inch, and a vernier enables the height to be read to one-hundredth of an inch.

A thermometer is fitted, graduated according to the Fahrenheit and Réaumur scales. Inv. 1894–118.

64. MARINE BAROMETER. Made by J. C. Dennis. Lent by The Meteorological Office.

This instrument was used during the Arctic expedition of 1853 to 1855 on board H.M.S. "Rattlesnake."

It is a closed cistern barometer, similar to the others shown adjacent. The lower portion of the metal case has been removed in order that the wooden cistern may be seen. The graduations are in tenths of an inch, and readings to hundredths are obtainable by vernier. The thermometer is graduated for both the Fahrenheit and Réaumur scales. Inv. 1908–85.

65. MARINE BAROMETER. Made by T. C. Sargent. Lent by The Meteorological Office.

This barometer, which also carries a sympiesometer, was used on board H.M.S. "Repulse," under Admiral Cochrane, in 1877.

It is of the closed cistern type, provided with a wooden case, and fitted with a gimbal support. The scale is graduated in tenths of an inch, and the two rackwork verniers enable the barometer reading to be taken to 0·01 of an inch and compared with that of the previous day.

The sympiesometer is of the pattern designed by Adie in 1818, and described in an adjacent label. Inv. 1908–84.

SIPHON BAROMETERS.

66. EARLY SIPHON BAROMETER. Made by Robelou, London.

This barometer, which is of the early siphon form, is mounted with an alcohol thermometer on an ornamental wood panel, which bears the inscription :—

"Isaac Robelou, fecit, Londini, 1719."

The short arm of the siphon is in the form of a conically shaped cistern, while the upper portion of the main tube is graduated in eighths of an inch from 0 to 36, and the corresponding weather indications are given in Latin and English, between the extremes of "storm" and "great drought."

The thermometer, which is 2 ft. long, has a large globular bulb and contains coloured alcohol. It is graduated from 0° to 90° in each direction from the zero, which indicates "temperate weather," the limits being marked "excessive cold" and "excessive hot weather." This is an early form of graduation in use before the introduction of the Fahrenheit and other well-known scales of temperature. Inv. 1909–134, S.M. 989, L.S.

67. BAROMETER. Presented by T. H. Court, Esq.

This portable siphon barometer was made by I. Miller, of Edinburgh, about 1770, and represents the stage of development at that period.

The lower end of the barometer tube terminates in a leather bag below which is a screw, by means of which the mercury may be forced to the top of the tube for transport. It is provided with a brass scale, graduated to 0·05 in., while a vernier enables the barometric height to be read with an accuracy of 0·002 in.

A thermometer is also fitted, reading from −10° F. to 150° F., thereby enabling the observed reading to be corrected for the effect of temperature.

The whole instrument is mounted in a wooden case to facilitate transport.

Inv. 1921–565.

68. BAROMETER. Made by Manticha, London.

This instrument, which probably dates from about 1800, is an ordinary siphon form barometer.

The bulb is enclosed in a box at the lower end, and a vertical thick-walled capillary tube serves to contain the column of mercury. A scale of inches is provided behind the upper end of the instrument, upon which weather indications are also marked.

Inv. 1918–191.

69. KREIL'S BAROMETROGRAPH. Made by Dressler, Prague. Lent by The Meteorological Office.

This instrument, which was designed in 1841, was employed at the Kew Observatory in 1845 for the purpose of registering automatically the height of the barometer.

It anticipated the principle of Changeux, who, in 1870, introduced mechanism by which the recording pencil, instead of acting continuously, was left free, and struck by a hammer at definite times. The apparatus consists of a siphon barometer having a float resting upon the surface of the mercury in the open end of the tube, and attached to a cord, which passes round a sector of the short arm of a balance lever, to which it is secured. The other end of the lever carries an ordinary pencil, which is struck at five minute intervals by a clock regulated hammer, and makes a point on a rectangular chart drawn along in a horizontal direction by clockwork.

(*See* Magnetische und Meteorologische Beobachtungen zu Prag, 1841–1842.)

Inv. 1876–793.

70. MILNE'S BAROGRAPH. Made by West. Lent by The Meteorological Office.

This barograph, of the type designed by Milne in 1857, resembles in general principles that of Kreil shown adjacent.

It is a balance form of siphon barometer, in which the record is obtained by a float placed on the mercury of the short arm, and connected with one arm of a horizontal lever the other arm of which carries a pricker. A small hammer, actuated by the clock train, drives this pricker every hour against a rectangular chart which travels along horizontally to receive the record, and the series of indentations thus made shows the fluctuations in barometric pressure. The paper is ruled in tenths of an inch, and estimations of smaller amounts can be made readily owing to the long range afforded by giving the greater length to the recording arm of the lever.

Graduated scales fitted with vernier are attached to the longer and shorter arms of the siphon tube, and enable the barometric height to be read to 0·01 in.

(*See* Milne: "Treatise on Meteorological Instruments," 1864.)

Inv. 1894–119.

71. ADMIRAL FITZROY'S BAROMETER.

This barometer, which is of the siphon form, is said to have been the property of Admiral Robert Fitzroy, and probably dates from about 1860.

The cistern which forms the short arm of the siphon has a large sectional area compared with that of the main tube, and in consequence the capacity error is small. A graduated scale enables the height of the barometer to be read to 0·1 in., and two pointers are provided so that the reading may be compared with that of the previous day.

A mercury thermometer is fitted, and directions are given for forecasting weather from observations of the barometer, thermometer, and anemometer, while there are also tables indicating heights above sea level, with corresponding atmospheric pressures.

The instrument also embodies a storm glass, which is a hermetically sealed cylindrical phial, containing crystals of potassium nitrate and ammonium chloride in an alcoholic solution of camphor to which a small amount of distilled water has been added, the upper portion of the phial being filled with air. In fine weather, the crystals are said to remain at the bottom of the tube, leaving the liquid clear, but in stormy weather they are said to rise, when the liquid becomes turbid. These changes, according to Admiral Fitzroy, are due to variation of the mixture with the direction of the wind, when the glass is exposed in the outer air or in the ordinary light of a well-ventilated room, but according to Tomlinson they are due entirely to variations of light and heat. By others, the instrument is considered to be simply a chemical thermoscope, the changes arising solely from temperature variation. Inv. 1906–38, S.M. 989, L.S.

72. ILLUMINATED WHEEL BAROMETER. Presented by W. Hinton, Esq.

This pediment barometer is of the siphon type, and is so designed that it can be read by night as well as by day.

The small arm of the siphon tube contains a metal plunger, which floats on the mercury and rises and falls with the liquid. It is connected with a balancing weight by a fine cord passing over a pulley at the centre of the dial, which it causes to revolve, and which, by its rotary motion, moves the pointer over the circular scale.

It is fitted with a translucent face, which can be illuminated from behind by artificial light, as patented by Mr. Hinton in 1862, so that the barometer and thermometer scales can be observed. Inv. 1862–101.

73. REDIER BAROGRAPH. Made by Redier, Paris.

This instrument was designed by Redier in 1875 to produce mechanically a continuous record of the barometric height without the application of photography or electricity. As the motive force of the mercury is not sufficient to overcome the friction of a pencil on paper, a powerful clockwork movement is employed to do the work, and the barometer only directs the action of the clockwork.

In this siphon barometer, a small ivory float rests on the mercury in the short arm, and carries a light, vertical needle, on the top of which rests a very light arm, which has a small ratchet at its end. At the side of the apparatus are two clock movements, working in opposite directions, and a differential train unites this double cistern with a pulley, to the axis of which a cog-wheel is attached. The chronometer escapement tends to draw the pulley and the pencil, and to raise the barometer upwards; the light arm pushed by the ivory float, follows the movement, when the ratchet releases a fly, and allows it to revolve, which brings the barometer down again.

These small successive movements are followed by the pencil, and thus a straight line is produced if the barometer is stationary, and one varying right or left according as the column rises or falls.

On the other side of the barometer are two other movements, one driving the paper-covered cylinder and the other driving a small tapping apparatus to overcome any capillarity in the barometer.

(*See* Q. J. R. Met. Soc., 1875, Vol. II, p. 412.) Inv. 1876–773.

74. SENSITIVE SIPHON BAROMETER. Lent by Prof. F. Guthrie, F.R.S.

This form of siphon barometer was designed and made by Prof. Guthrie in 1877 with a view to increasing the range of motion and obtaining an extremely sensitive instrument.

It consists of a siphon barometer in which a horizontal spiral of small internal diameter containing an air bubble forms the connection between the two vertical tubes of larger diameter. Any variation of atmospheric pressure causes the height of the column of mercury in the longer arm to rise or fall by one-half of this amount, and in consequence the bubble moves along the spiral, through a distance determined by the relative sectional areas of the vertical and spiral tubes.

(*See* Phil. Mag., Vol. III, 1877, p. 139.) Inv. 1885–19.

75. MERCURY AND GLYCERINE BAROMETER. Made by Negretti and Zambra.

This instrument is a modification of the ordinary mercurial barometer, in which a more extended scale is obtained, and the sensitiveness is increased.

It consists of a barometrical tube of the siphon form, about 36 in. long, one side of which is closed at the upper end and filled with mercury, thus creating a vacuum as in an ordinary barometer. To the open end is joined a second tube, having a much smaller internal diameter, so as to form a U-tube of which both arms are parallel. The smaller tube, which is open at the upper end and partly filled with glycerine, is provided with glycerine traps near its lower end, which serve to receive the glycerine when the instrument is tilted, and thus prevent it from mixing with the mercury.

Any alteration in the height of the mercury column in the larger tube is accompanied by a much greater movement in the smaller tube, due to the unequal capacity of the two tubes, and the difference in the specific gravities of mercury and glycerine. In this way a more extended scale is obtained, about 9 in. of which correspond to 1 in. of the ordinary mercurial barometer, while 0·01 in. of the mercury barometer can be read without the use of a vernier, and the slightest variation is plainly visible. Inv. 1906–39.

76. DINES SELF-RECORDING BAROMETER. Lent by J. J. Hicks.

This instrument was designed by W. H. Dines, Esq., F.R.S., to give a trace from which the height at any time may be determined to 0·005 in.

The pen is actuated by a float in the lower cistern of the siphon barometer, the motion being multiplied by a lever so that a length of 1·5 in. on the paper may correspond to a change of 1 in. in atmospheric pressure. The float is in the form of a hollow cylinder, sealed at the top and floating inverted in the mercury.

A rise of temperature lowers the level of the mercury in the lower cistern, but at the same time it expands the air in the float, and makes it swim higher in the mercury. The volume of air is so adjusted that there may be a complete compensation. There is an additional pen fixed to the frame, which draws a line of reference on each chart while it is on the clock drum, and for accurate measurement this line is taken as the zero line, since by this means the error that might be caused by placing the chart unequally on the drum, or by an incorrect printing of the charts, is avoided. Inv. 1922–125.

ANEROID BAROMETERS.

The precursor of the aneroid may be said to be Zaiher's arrangement for use at sea, which dates from 1758. It consisted of a hollow cylinder void of air and of which the ends were moveable, but kept apart by an internal spring, so that the ends would approach or separate with pressure variation.

Vidi is said to have produced an aneroid in 1843, but it was not for several years that his instrument became generally known. Improvements successively made have been the application of a temperature compensation bar, and the substitution of a laminated steel spring for the original spiral spring.

Rush in 1851 added an altitude scale, and Loseby in 1860 and Goldschmidt in 1870 dispensed with the ordinary gearing, the motion being multiplied by a fine micrometer screw which operated an index hand, while Field in 1873, by an ingenious shift of the altitude scale, accommodated the instrument to different temperatures for altitude work.

Richard Breguet, in 1867, and many others, have adapted the aneroid, using one or more vacuum chambers to register its indications on a revolving cylinder.

The Bourdon form of metallic barometer devised in 1851 consists of a thin elastic metal tube of elliptic section, in shape a portion of a circle, closed at its ends and exhausted of air.

Increase or decrease of atmospheric pressure causes the ends to approach or recede, which motion by gearing work is communicated to an external index.

Kohlrausch in 1874 caused a Bourdon ring to act on a small suspended mirror, and by others the Bourdon ring has been made to work a pencil and furnish a continuous record.

77. BOURDON METALLIC BAROMETERS. Made and presented by E. Bourdon, Esq., Paris.

These instruments, the movements of which are visible, are of the type designed and introduced by Mr. Bourdon in 1850 as a modification of the ordinary form of aneroid.

In this case the movement consists of a thin circular-shaped elastic metal tube of elliptic section, closed at its ends, and exhausted of air. On increase of atmospheric pressure, the ends approach each other, and on decrease of pressure, recede. This motion is communicated by gearing to a central shaft carrying an index hand, which traverses a dial plate. The graduations are in tenths of an inch from 28 to 31 in., and weather indications are also given, whilst a movable pointer indicates any rise or fall in the barometer since the last reading.

(*See* Report of Jury on Phil. Insts., 1851 Exhibition.)

Inv. 1876–741 & 742, S.M. 1430, L.S.

78. EIGHT-INCH ANEROID. Made by R. Deutschbein, Hamburg.

This aneroid is so arranged that the mechanism can be readily seen and its method of operation examined.

It consists of a thin, partially exhausted, metallic vessel, the surface of which is corrugated in concentric circles to render it more sensitive to pressure variation. To the centre of the upper corrugated surface is attached a vertical rod, the other end of which is secured to a horizontal brass arm, pivotally mounted on a horizontal shaft. Pressure variation causes movement of the corrugated cover of the aneroid chamber, and the horizontal arm is rocked about its axis. By means of a system of levers and a silk cord, this motion is transmitted to a vertical shaft which is caused to revolve, carrying with it an index which travels over the graduated circular scale. The scale is graduated in tenths of an inch, and is also marked as a weather glass. Inv. 1876–759.

79. ANEROID. Lent by Messrs. F. Darton & Co.

This instrument shows the stage of development the aneroid had reached in the middle of the latter half of the nineteenth century.

It is provided with a dial, 4·5 in. diameter, marked as a weather glass, and graduated to fiftieths of an inch from 25 to 31 in. Inv. 1875–23.

80. LARGE ANEROID BAROMETER.

This aneroid, having a dial of 1·50 metres diameter, was designed and made by M. Redier, of Paris, about 1875, for use at public buildings.

The index of the dial is actuated by a small aneroid connected through a lever with a clock having two trains which work in reverse directions. When the air pressure is constant the fans of the two trains are held fast by a cross-piece of the levers, but with a rise or fall of the pressure one or other of the fans is released, and its train thus freed to turn the index round the dial.

Inv. 1876–774.

81. COMPENSATED ANEROID. Made by A. Kruss, Hamburg. Presented by The Deutsche Seewarte, Hamburg.

This instrument is of the 8 in. type which was at one time supplied by the Deutsche Seewarte for use in connection with their system of conveying weather intelligence and storm warnings.

The effect of pressure variation on the aneroid chamber is converted into a rotary motion of the central spindle, which carries a pointer moving over a circular scale, which is graduated in inch and millimetre scales. A centigrade thermometer is fitted and reads from 15° C. to 60° C., and the instrument is compensated for temperature. Adjustment of the hand of the aneroid is effected by a screw in the base of the instrument. Inv. 1884–56

82. ALTIGRAPH. Made by Richard, Paris. Lent by The Meteorological Office.

This pocket instrument is designed to give a continuous record of altitude, and for this purpose is used in meteorological work.

It consists essentially of an aneroid box, the expansion of which is regulated by the atmospheric pressure, and is communicated by levers to a pointer carrying a pen which moves over the chart. This chart is mounted on two cylinders, which are rotated by clockwork, so that a record is produced from which the altitude at any given time can be determined.

The altitude scale of the record indicates heights up to 20,000 ft., and at right angles to this is set the time scale. Inv. 1919–517.

83. ANEROID BAROMETER (MARK I). Made by Hicks. Lent by The Meteorological Office.

This represents the modern type of compensated aneroid, designed for the use of the Admiralty.

It consists of a vacuum chamber composed of two discs of corrugated nickel silver firmly soldered together, forming a box, from which the air is exhausted, and to each side of which is attached a brass centre, one having a hole drilled across it to receive a knife-edge, which suspends the vacuum chamber from a powerful spring. A circular iron base plate carries the vacuum chamber, across which is fixed a strong carriage supporting the mainspring, and to which is attached a compound iron and brass main lever in order to compensate for temperature changes. A small steel rod connects the end of this arm to the regulator, which is furnished at its centre with a vertical arm of brass, by which it communicates with the movement. A length of fine chain, as used in the works of watches, is attached to and works round the arbor on the rise or fall of the lever, and a fine hair-spring of coiled steel keeps the hand in its proper position. The hand is carried by the arbor and moves over a silvered brass scale the graduations of which are engraved in inches and millibars. Inv. 1921–72.

84. ANEROID BAROMETER (MARK II). Made by Messrs. Wilson, Warden & Co. Lent by The Meteorological Office.

This instrument, in general construction, resembles the Mark I type, shown adjacent, of which it is a cheap modification, designed for use on coastal motor-boats during the war (1914–18).

It is compensated in a manner similar to the adjacent model, but is fitted with a porcelain dial, which is graduated only in inches and tenths.
Inv. 1921–73.

85. HYPSOMETRIC ANEROID. Made and lent by J. H. Steward, Esq.

This instrument is designed to enable a close reading of altitude to be obtained without the application of a vernier scale or the customary calculations.

The movement of the aneroid is compensated, and closely resembles that of the adjacent instrument. It is furnished with two scales, the inner fixed scale being known as the "pressure scale," and graduated in fiftieths of an inch from 25 to 31 in., and the outer and movable one as the "altitude scale." This revolving altitude scale consists of three concentric circles, each division on the outer circle representing 100 ft., each division on the inner circle 20 ft., and these are sub-divided to 10 ft. by means of the middle circle of divisions. These divisions are so arranged that in connection with the index hand the altitude can be read to 5 ft. or less.

Half the altitude scale, known as the "ascent" scale, is divided to the left and coloured black, and the other half, known as the "descent" scale, to the right and coloured red. The altitude scale is calculated by taking 30 on the pressure scale as zero, at a mean temperature of air 50° F., and as the movement of the aneroid is designed to give an equally divided altitude scale in a closed circle, no error is introduced when the zero is shifted.

A small pointer is carried on a bezel ring which can be revolved independently of the altitude scale, while a reading lens is provided to eliminate paralactic error. For the purpose of ascertaining the air temperature a swing thermometer is supplied, which is graduated from 20° F. to 160° F. Inv. 1921–146.

86. LARGE PATTERN BAROGRAPH. Made by Short and Mason.

This is a self-recording aneroid barometer designed to give automatically a continuous record of atmospheric pressure, and to indicate at a glance any change in the value of that pressure.

The instrument consists of a specially-constructed movement, in which thirteen aneroid chambers are employed. The effect of atmospheric pressure on these chambers is communicated by means of levers to a long arm carrying a pen at its extremity. This pen is adjusted so as to touch the paper chart, carried upon a metal drum, which is revolved by clockwork, one revolution being completed in seven days. As the drum revolves, the pen marks the chart paper, tracing a continuous record of the barometric pressure, which may be read off in millibars on the vertical scale of the chart. Inv. 1914–403.

HYPSOMETERS.

87. HYPSOMETER. Made by Casella. Presented by The Admiralty.

This instrument was used in the British ("Discovery") Antarctic Expedition of 1901.

The water is carried in a vertical cylindrical chamber and heated by means of a spirit lamp from below. The thermometer is carried in a tube passing through the middle of the water chamber, the upper portion being enclosed in a telescopic tube, so that the thermometer stem is surrounded by steam. The thermometer is graduated to read from 180° F. to 215° F. The whole instrument is enclosed in the iron cylinder for protection. Inv. 1911–164.

88. HYPSOMETER, HORIZONTAL TYPE. Made by Elliott Bros. Lent by the Meteorological Office.

This instrument was designed for the determination of altitude, by observing the boiling point of water.

The instrument consists of a cylindrical brass chamber which carries the bulb of a horizontal mercury thermometer. The chamber is partially filled with water, which is boiled by means of a spirit lamp beneath the chamber, and the temperature at which this occurs is accurately read on the scale. Owing to the diminution of pressure with altitude, the boiling point has a lower value as the height above sea level increases, and a knowledge of the boiling point enables the observer to calculate the altitude readily. Inv. 1917–31.

SYMPIESOMETERS.

89. SYMPIESOMETER. Lent by L. Casella, Esq.

This instrument is identical in principle with Hooke's marine barometer, which was produced towards the end of the seventeenth century, and was re-discovered and patented by Adie in 1818.

It consists of a capillary tube of siphon form, provided with a bulb at each end, while near the bottom of the longer limb is a fine constriction, to lessen the oscillations of the liquid in stormy weather. The bulb at the upper end is sealed and contains hydrogen, while that at the lower end is open to the atmosphere, and partially filled with oil or other dark fluid, in this case sulphuric acid, which also rises in the longer arm. A mercury thermometer is also provided, graduated from 0° F. to 120° F. A reversed temperature scale is fitted on the right of the instrument over which slides a shifting barometer scale bearing weather indications and carrying a pointer.

In using the instrument, this shifting scale is adjusted until the pointer is opposite the same scale reading as is registered by the thermometer, the height at which the coloured liquid then stands is read off on the sliding scale, and indicates the height of the barometer. In this way readings may be obtained to 0·05 in., and set on the revolving scale at the bottom of the instrument.

(*See* Pat. Specn. 1818, No. 4323.) Inv. 1893–157.

90. SYMPIESOMETER. Made by Mrs. Janet Taylor. Lent by The Meteorological Office.

The sympiesometer is particularly useful for observations at sea, as it is not liable to damage by the motion of the ship during stormy weather.

This instrument is almost identical in form with the one shown adjacent. Air has access to the lower tube, and by the aid of its pressure on the surface of the liquid, both the weight of the column of liquid and the pressure of the gas in the longer branch are balanced. With a change of barometric pressure equilibrium is disturbed, and a variation in the heights of the liquid in the two branches takes place.

Correction for temperature having been made, the barometric height can be found from the height of the column in the longer branch. This temperature correction is made mechanically by a sliding scale to represent inches, which is moved along the temperature scale until its index is in line with the number which corresponds with the thermometer, when the graduation on the sliding scale in line with the top of the liquid column will indicate the height of the barometer, and can be read to 0·02 in. Inv. 1908–81.

91. SYMPIESOMETER. Made by Messrs. Adie & Son, Edinburgh. Presented by F. L. Lucas, Esq.

The sympiesometer is now used chiefly in conjunction with the mercurial and aneroid barometers, for purposes of comparison. Its indications result partly from the pressure and partly from the temperature of the atmosphere; it would, therefore, be more correctly named a thermo-barometer.

It consists of a capillary tube of syphon form, provided with a bulb at each end, while near the bottom of the longer limb is a fine constriction. The upper end of the tube is sealed while the lower end is open, and the bulb at this end is partially filled with coloured liquid which also rises in the longer arm. A mercury thermometer is also provided, graduated in half degrees from 30° F. to 110° F.

In using the instrument, the temperature of the thermometer is first noted, after which the metal pointer of the pressure scale is adjusted to the same reading as is indicated on the thermometer. The height at which the coloured liquid then stands shows, on the sliding scale, the atmospheric pressure to the nearest fiftieth of an inch on the barometer scale. Inv. 1918–14.

92. PIESMIC BAROMETER. Made by Darton.

This instrument, designed by Mr. A. S. Davis, M.A., with the view of portability and cheapness, combined with accuracy, depends for its action on the variation that the volume of air contained in the tube undergoes due to changes in atmospheric pressure.

It consists of a U-tube, the longer arm of which is a capillary tube terminating in a small cast iron cistern containing mercury, the air in this cistern, though not in actual communication with the external air, is kept at atmospheric pressure by being in communication with a long purse-shaped case of thin paraffined paper, which will yield to any slight pressure variation.

When the tube is horizontal, the mercury lies on one side of the cistern, leaving the open end of the tube exposed to the air, but when the tube is brought into a vertical position the mercury flows over and closes the mouth of the tube, flowing down the tube to a greater or lesser depth dependent upon the atmospheric pressure at the time. The capacity of the whole tube is designed so as to be 35 times that of a single inch of the capillary tubing, so that if the barometer is standing at 30 in. the mercury will descend 5 in., and if at 29 in. it will descend 6 in. A scale of inches being placed behind the tube, the reading of the end of the mercury column against this scale indicates the height of the barometer. To read the barometer, the tube is brought into the vertical position, and moved to and fro until the mercury has settled, when the reading should be taken at once to avoid temperature errors. Inv. 1905–74.

HYGROMETERS.

Hygrometric effects have been noticed and regarded as weather signs from the earliest times, and Pliny has been cited as the earliest observer of the dew-point, but it was not until the middle of the seventeenth century that the first scientific instrument was produced for this purpose.

The earliest name for this form of instrument was "Notiometer," but this was superseded by "Hygrometer," which has now been in use for over 250 years, having been first suggested by the celebrated mathematician, Lambert, while the name "Psychrometer," first employed by August early in the nineteenth century, is also used extensively.

Hygrometric instruments may be divided into four classes, according to their method of operation :—

1. Hygrometers of condensation, *i.e.*, dew-point instruments.
2. ,, absorption.
3. ,, evaporation, *i.e.*, wet and dry bulb thermometers.
4. Chemical hygrometers for determining the amount of vapour by analysis.

The earliest condensation or dew-point hygrometer dates from about 1660 and was made at the Accademia del Cimento for measuring the amount of condensation on the outside of a glass vessel, while in 1696 Fontana determined the increase of weight of a glass of cold water due to condensation of vapour on the outside. Variations of the method were introduced by Le Roy 1751, Dalton 1802, and Berzelius 1808, but Soldner in 1809 was the first observer to note both the temperature at which dew was formed and at which it disappeared. Prof. Daniell's well-known instrument was introduced in 1819, in which one bulb was blackened and the other covered with muslin. Dobereiner in 1822 anticipated the hygrometers of Connell and Regnault in producing a thimble-shaped polished metal tube on which dew was deposited by cooling produced in passing a current of air through ether. Twenty-three years later, Regnault modified and improved this instrument, replacing Dobereiner's syringe by an aspirator, while further modifications were introduced by Ronalds in 1851 in an instrument which was employed for many years at Kew. Dines's dew-point hygrometer appeared in 1871, having its glass plate horizontal, and was re-designed by him eight years later, when the plate was placed in a vertical position, and a breathing tube provided enabling ether to be used.

Absorption hygrometers form by far the largest class, and date from 1664, when Folli da Poppi made a hygrometer perfected by the Accademia del Cimento, and having a band of paper as the hygroscopic body. During the same year Hooke described an oat-beard hygrometer, while six years later Cardinal Cusano observed the absorption of moisture by dried cotton or silk, and measured the resulting increase in weight, and Coniers utilized the lateral expansion of wood by moisture as an indication of atmospheric humidity. Catgut was first employed in 1682 by Gould, while other materials made use of were whipcord by Molyneux, 1685, sponge by Desaguliers and Pickering, 1744, ivory by De Luc in 1773, paper by Laurian, 1782, and by Coventry eight years later.

De Luc's hygrometer consisted of an ivory cylinder filled with mercury, and used as the bulb of a thermometer, an arrangement which was modified the following year by Buissart, who substituted a goose quill for the ivory cylinder, while in 1781 De Luc employed a strip of whalebone cut transversely to the fibre. Saussure in 1780 first used as a hygrometric indicator human hair, thoroughly freed from grease, which Chiminella replaced two years later by a strip of gold beater's skin. Further modifications were introduced by Monnier in 1800, rendering the instrument both small and portable, while Landrianus, twenty years later, adapted it to record the extreme variations during the observer's absence.

Hygrometers of this type lend themselves conveniently to the production of continuous records, and many types of hair hygrograph are in existence, in which the hygrometric state of the atmosphere is recorded on a revolving drum.

The first evaporation hygrometer was due to Cullen, who, in 1777, ascribed the cooling of a wetted thermometer to evaporation, and Hutton used a moistened bulb thermometer in order to ascertain the humidity of the air in 1792. Leslie in 1799 applied his differential thermometer to measure humidity, by making one of the bulbs of blue glass and covering the other with wet muslin. This instrument was used in 1802 by Boeckmann and compared with his wet and dry bulb thermometer, the wet bulb of which was surrounded by gold beater's skin dipped in water. Another wet and dry bulb thermometer was introduced in 1817 by Gordon, having its wet bulb covered with silk leading to an adjacent vessel of water. It was not until 1836 that Mason produced his wet and dry bulb thermometer, which in its essential features were identical with those of Boeckmann and Gordon.

In order to ensure an accurate record of the temperature of both thermometers being obtained at any time during the absence of the observer, Negretti and Zambra in 1874 applied the principle of their maximum thermometer to both thermometers of the wet and dry bulb hygrometer.

Assmann at a later date introduced his ventilated psychrometer in which air is drawn at a definite speed by means of a fan, past the two thermometer bulbs, enabling a flow of air to be established, which ensures the wet and dry bulb temperatures being trustworthy under all conditions.

The chemical hygrometer was first introduced by Brunner in 1830 for the quantitative measurement of the amount of water vapour contained in a given volume of air. A known volume of air was drawn through a weighed tube containing dried asbestos and sulphuric acid, and the increase in weight determined. Eighteen years later the apparatus was improved by Haeghens, who employed a larger aspirator, and placed his absorbing medium, pumice stone and concentrated sulphuric acid, in a U tube. Andrews, however, in 1851, discountenanced these drying agents, and proposed dried calcined sulphate of lime, while he also attached a small gasometer to a Dutch clock in order to ensure regular aspiration. Another form of chemical hygrometer was produced by Buys-Ballot in 1876, in which air was drawn by an aspirator over calcium chloride contained in a tube suspended on a balance arm, while Schwackhofer, two years later, proposed a method of directly determining the amount of aqueous vapour in a given quantity of air by volumetric analysis.

CONDENSATION OR DEW-POINT HYGROMETERS.

93. DANIELL'S HYGROMETER. Made by J. Newman, London. Presented by The Admiralty.

This hygrometer is of the type designed by Daniell in 1819, and consists of two bulbs, connected by a glass tube bent twice at right angles. One of these bulbs is blackened and the other is covered with fine muslin.

In the limb terminating in the blackened bulb is fixed a sensitive thermometer, and a similar thermometer is attached to the pillar supporting the instrument. The blackened bulb contains a small quantity of pure ether, whilst the tube and the other bulb are filled with ether vapour, all the air having been carefully removed.

To use this instrument, it should be turned so that all the ether flows into the blackened bulb. A little ether is then dropped on the muslin until a ring of dew is deposited on the black bulb. Both thermometers should then be read instantly, and again at the moment of disappearance of the dew. The mean of the readings of each thermometer gives respectively the temperature of the air and the dew-point. Inv. 1911–169.

94. DANIELL'S HYGROMETER. Made by W. Ladd.

This hygrometer is of the form designed by Daniell in 1819.

It is an instrument for determining the "dew-point" or the temperature at which the aqueous vapour contained in the air begins to be condensed, and consists of a glass siphon connecting two bulbs. One of the bulbs is blackened and contains ether, into which dips a small thermometer for the determination of the temperature of the liquid. The instrument is mounted on a stand bearing another thermometer to indicate the external air temperature. The empty bulb is covered with muslin which is tied round it, and upon which a little ether is poured. Cold produced by rapid evaporation of the ether condenses the ether vapour inside the empty bulb as fast as it is formed in the blackened bulb, and by this action the temperature in the blackened bulb is lowered. As soon as the dew-point is reached, aqueous vapour from the air condenses as dew on the black bulb, and at that instant the readings of the two thermometers must be observed. Inv. 1872–47.

95. DANIELL'S HYGROMETER. Lent by Messrs. J. J. Griffin & Sons.

This instrument is a form of Daniell's hygrometer as modified by Greiner in 1822.

The essential feature of this modification is a thick band of gilding which covers the bulb on which the dew is deposited, thereby enabling the dew-point to be determined very readily. Inv. 1880–85.

96. JONES'S HYGROMETER. Lent by the Royal Society.

This hygrometer which has its bulb at an acute angle is of a type designed and made by Jones in 1826, and resembles closely that of Koerner in 1822.

It consists of a mercurial thermometer which can be used to obtain both the temperature of the air and the dew-point. For the latter purpose the bulb has a black enlarged and convex top on which the deposition of moisture is observed. The other portion of the bulb is covered with silk, and over this ether is poured to lower the temperature of the mercury, as in Daniell's and other condensation instruments. The thermometer which is about 4·5 in. long is supported by a brass wire attached to the case, and can be set at any desired angle.

(*See* Phil. Trans., 1826, p. 53.) Inv. 1893–135, S.M. 1450, L.S.

97. REGNAULT'S HYGROMETER. Made by Messrs. Elliott Bros.

This hygrometer is of the type designed and introduced by Regnault in 1845.

It consists of two very delicate thermometers, the bulbs of which pass through collars and almost reach the bottom of two thin and highly-polished silver cylinders. From near the bottom of these cylinders, two tubes, which subsequently unite, pass into an aspirator. One of the silver cylinders is supplied with sufficient ether to completely immerse the bulb of the thermometer. The aspirator being filled with water and the tap at its base turned, air is drawn past the thermometer bulbs and through the two cylinders; in passing through the one containing ether, rapid evaporation is produced, the temperature falls, and when the cylinder is dimmed by the deposition of dew, the thermometer carried by this cylinder indicates the dew-point temperature, and the other one the temperature of the atmosphere.

It is claimed that this instrument has a greater degree of accuracy than Daniell's, for the whole of the ether being maintained at one temperature by the agitation produced by the air, the indications of the dew-point thermometer are more reliable. The error in the readings arising from the proximity of the observer may be avoided by the use of a telescope.

(*See* Ann. de Chimie, Vol. XV, p. 129.) Inv. 1893–34.

98. GEISSLER'S HYGROMETER. Made by Geissler, Bonn.

This instrument, which was introduced about 1876, is a modification of Daniell's hygrometer, in which the dew-point and the temperature of the surrounding air are obtained from two separate thermometers mounted on one stand.

The dew-point thermometer has a double cylindrical bulb in the interstitial space of which, is the mercury which forms the bulb of the thermometer. The cylinders are welded into one about half-way up, and thus the thermometer bulb is closed; then the cylinder is contracted to a tube which terminates in a hollow spherical bulb. Before closing this bulb a little ether is poured through it and the tube of the inner cylinder, while the terminal bulb after sealing is covered with muslin.

The action of the instrument is as follows: Ether when dropped on the muslin evaporates and cools the bulb, the ether in the thermometer bulb cylinder evaporates and also cools, thereby reducing the temperature of the double cylindrical bulb until dew is deposited on its surface, when the temperature can be read off at once. Both thermometers are graduated to read to 0·2° C.

Inv. 1876–762.

99. PSYCHROMETER SCALE.

This scale was designed by Prof. Prestel of Emden, for determining without calculation the relative and absolute moisture of the air, as well as the dew-point. Inv. 1876–755.

100. DINES'S HYGROMETER. Made and lent by L. Casella, Esq.

This represents the original type of dew-point hygrometer as designed by Mr. G. Dines in 1871.

It is a condensation instrument in which the dew-point is determined by noting the temperature at which dew is deposited on a horizontal sheet of glass. Ice and water, or cold water only, are put into the small upright cistern, whence the water flows under a thermometer to a small chamber in which rests the bulb of the thermometer. The bulb and chamber are covered with a thin black glass plate. As the water flows out of the pipe at the further extremity of the hygrometer the temperature of the black glass plate is lowered to the dew-point and a film of moisture is deposited upon the plate. The temperature at which this deposition of dew takes place can be noted from the thermometer, and the dew-point temperature thus ascertained. The temperature of the surrounding air is then read, when the hygrometric state of the atmosphere can be calculated by the usual methods.

(*See* Symons, Meteorological Magazine, Vol. VI, 1871, p. 146.)

Inv. 1893–160.

101. DINES'S HYGROMETER. Made and lent by Casella.

This instrument, which is a modification of the adjacent form, was designed by Mr. G. Dines in 1879.

The essential feature of this hygrometer is that the glass is mounted in a vertical position, while ether may be employed instead of water, a receptacle for its storage being supplied. Ether is poured in at the spout, to which is connected a breathing tube, and cooling is produced by forcing air through the ether, when moisture is deposited on the black glass plate as in the horizontal instrument.

(*See* Q. J. Met. Soc., Vol. VI, p. 39.) Inv. 1893–164.

ABSORPTION HYGROMETERS.

102. OAT-BEARD HYGROMETER. Presented by F. C. Bayard, Esq.

In this instrument, which resembles in principle Hooke's first oat-beard hygrometer of 1664, the twining and untwining of the beard of the wild oat is employed to turn an index round a graduated dial.

One end of a short length of the beard is attached to a plate at the bottom of the hygrometer case, and the other is secured to the index. As the humidity of the atmosphere increases, the beard untwines, and the index is turned round the dial in a clockwise direction, while with increasing dryness the movement is reversed. The brass case is perforated to allow the air to act freely on the beard, and is furnished at the back with a knob by which the index can be set.

(*See* Hooke—"Micrographia," 1667.) Inv. 1893–116.

103. WOOD HYGROMETER. Lent by H. L. P. Lowe, Esq.

This hygrometer, which dates from the eighteenth century, carries a paper label attached to the screen, which describes the instrument as "Invented by and belonging to Dr. Benjamin Franklin, the patriot and philosopher." Wood hygrometers, however, had been in use for many years, and three instruments of this class are described in Phil. Trans. 1676.

In this form of instrument the change in dimensions of a thin board under the influence of damp or dry weather is made to indicate on a scale variations in the humidity of the atmosphere.

In the instrument here exhibited, a thin board, about 14 in. long and 1⅝ in. wide, is arranged on its edge, with the fibres running transversely to the length. Near one end of the board a lever is fixed in such a way that the longitudinal expansion of the wood actuates the shorter end of the lever, and causes the long arm to give a magnified indication on a paper scale of the expansion of the board. When dryness causes the board to shrink, a counterpoise brings the index back to its original position.

This type of hygrometer was considered by some to be a more reliable instrument than the oat-beard hygrometer which preceded it.

Inv. 1902–84, S.M. 1449, L.S.

104. DE LUC'S WHALEBONE HYGROMETER. Made by Hausmann. Lent by G. J. Symons, Esq., F.R.S.

This type of hygrometer was originally designed by De Luc in 1781, and depends for its action on the variation in length of a strip of whalebone caused by changes in atmospheric humidity.

A narrow strip of whalebone, cut transversely to the fibre, is connected at one end to the frame of the instrument, and at the other with the larger of two pulleys, co-axial with each other and with the index of the graduated circle. Attached to the smaller pulley is a spring which serves to keep the whalebone taut, and on the lengthening of the strip by increased moisture, the spring carries the index round. Contraction of the whalebone strip due to dryness, causes the index to be moved in the contrary direction.

De Luc claimed that the action of this instrument was more uniform than that of the Saussure hair hygrometer.

(*See* Phil. Trans., Vol. LXXXI., p. 389.) Inv. 1893–125.

105. SAUSSURE'S SINGLE-HAIR HYGROMETER. Lent by Messrs. J. J. Griffin & Sons.

Saussure in 1780, designed his single-hair hygrometer, in which the hygrometric state of the atmosphere was indicated by the length of a suitably prepared human hair.

In this instrument one end of a human hair thoroughly freed from grease is secured to the top of the frame, the other end being passed round a pulley and kept taut by a small weight. Shortening of the hair due to dryness revolves the pulley and causes the index to rise, while with increased humidity the index descends, a silvered scale being provided to indicate the reading.

(*See* Saussure's "Essais sur l'Hygrométrie," 1783.)

Inv. 1880–86, S.M. 1439, L.S.

106. SAUSSURE'S EIGHT-HAIR HYGROMETER. Lent by The Meteorological Office.

Richeus in 1789, first proposed a modification of Saussure's hygrometer, using eight hairs instead of one, and this instrument, which is of that type, was formerly the property of Mr. Francis Ronalds, and was used by him at Kew in 1843.

In this instrument, all the eight hairs are attached to one bar, and it would seem that the indication must always be that of the shortest individual hair, the others remaining slack. From the lower bar to which the hairs are attached, a cord passes round one of two pulleys coaxial with each other and with the index, while a small weight supported by a cord passing over the other pulley serves to move the index when the hairs expand due to increased humidity.

(*See* Rozier—Observations sur la Physique, Vol. 34, p. 58.) Inv. 1876–794.

107. NICOLLE'S "AQUEOUS METER." Lent by B. C. Wainwright, Esq.

This wood hygrometer is a modification of Conier's first wood thermometer of 1670, and Arderon's of 1746.

In this instrument a thin slab of wood is cut across the grain and fitted in a frame furnished with a graduated arc and an index. The axis of the index is attached to the wood so that the expansion or contraction of the slab by increase or diminution of humidity of the air causes a motion of the index along the scale. The graduations range from 0° to 100°, the limit at one end being "Dessication" and at the other "Immersion." Inv. 1893–114, S.M. 1447, L.S.

108. WHALEBONE HYGROMETER. Made by Devrine, Paris. Presented by T. H. Court, Esq.

In this instrument, the hygrometric state of the atmosphere is directly recorded on the dial of the instrument.

The effect on a strip of whalebone, of the moisture present in the air, is transferred into rotary motion of a pivoted quadrant, which actuates a small gear wheel. This in turn directly operates the pointer, which moves to the left or right in accordance with the dryness or dampness of the atmosphere.

Inv. 1911–205.

109. KATER'S HYGROMETER. Made by Robinson. Lent by The Royal Society.

In this instrument which was devised by Capt. Kater in 1809, the active agent is a twisted filament of the Indian grass *Andropogon contortum*, which twines and untwines with increased dryness or dampness of the atmosphere.

The grass is fastened to the cleft end of the axis of the index of the larger dial and is continued in a line to the back of the case, where it is secured to a pin which can be adjusted to give the necessary tautness. The larger dial is graduated in 100 parts, and the smaller dial serves to indicate the number of revolutions of the index of the larger. The case is perforated to allow of free access of air and to provide efficient ventilation.

(*See* Asiatic Researches, Vol. IX., pp. 24 & 395.) Inv. 1893–140.

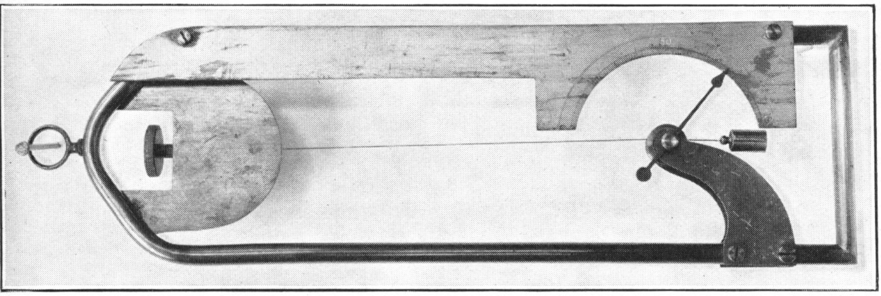
110. BIFILAR HYGROMETER.

This instrument, which was designed by Prof. Ernst Friedrich Klinkerfues of Göttingen about 1870, is a hair hygrometer actuated by the stiffness of the hair and not by its variation in length.

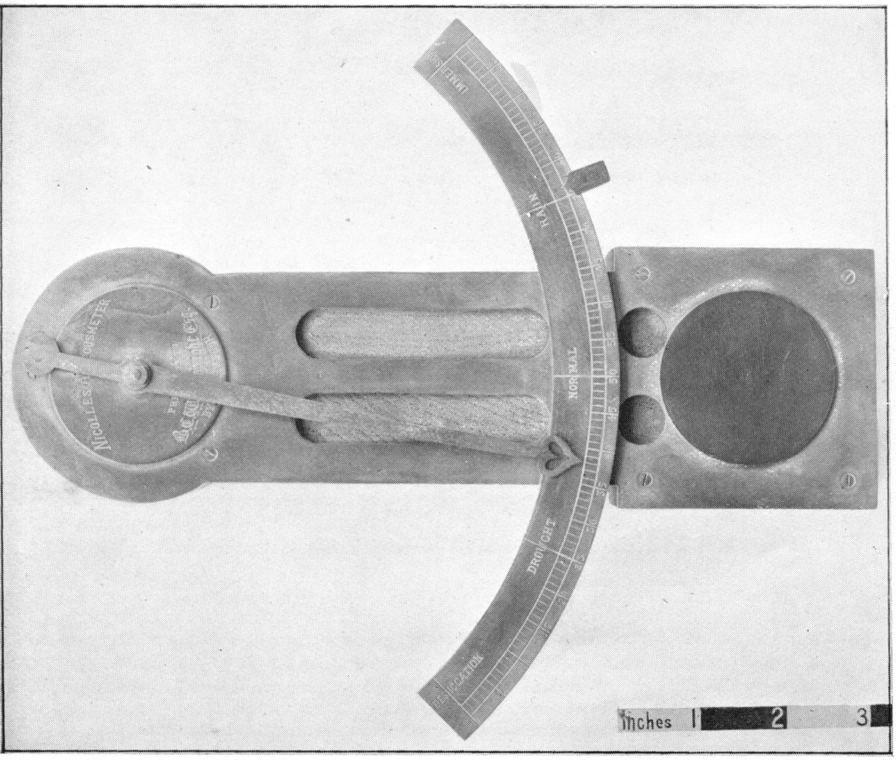
A wisp of hairs is passed through holes at each end of a small cross-bar of the spindle which carries the index, and the ends of the wisp are made fast to a plate near the top of the instrument. A second and shorter wisp is also passed, but in a contrary direction to the first, through the same holes, crossed, and the ends secured to a bar near the bottom. In this way a twist is given to the hairs acting on the spindle, and the index made to take up a position dependent upon the balance of the torsions of the upper and lower wisps. With a change in the humidity the balance is disturbed, and the change made apparent by the movement of the index towards one or other of the extremes of the scale. A thermometer and reduction disc are supplied by which air temperature can be obtained and the dew-point calculated.

(*See* Klinkerfues, "Theorie des Bifilar-Hygrometers mit gleichtheiliger Prozent-Scala.") Inv. 1876–756.

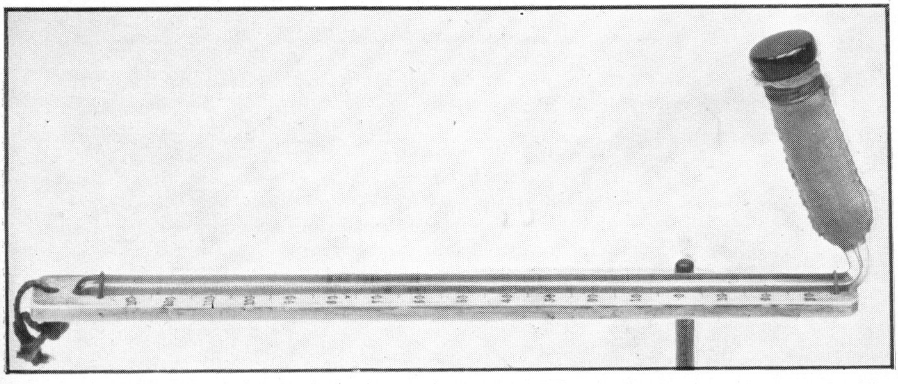
PLATE III.



Saussure's Hygrometer.



Nicolle's Aqueousmeter.



Jones's Hygrometer.

111. KLINKERFUES HAIR HYGROMETER. Lent by The Meteorological Office.

This instrument, which was designed and patented in 1882 by F. H. F. Engel and W. Klinkerfues, is similar in principle to the hair hygrograph shown adjacent.

It consists of a wisp of about five or six hairs, 4 cm. long and fixed at each end. Midway between the ends is attached a string which passes over a pulley on the index axis and is kept in tension by a spring. Variations in the length of the hair due to changes of the atmospheric conditions are thus transmitted to the index finger which indicates the relative humidity.

(*See* Pat. Specn. No. 6161 of 1882.) Inv. 1922–8.

112. RUSSELVEDT HAIR HYGROMETER. Lent by The Meteorological Office.

This hair hygrometer which is of the type used in Norway, has for its hygroscopic element two lengths of horse-hair arranged to resemble a bifilar system.

The indicating arm is mounted upon a pair of twisted threads under tension, so that the arm always tends to move towards the saturated end of the scale. Its exact position is determined by the lengths of the horse-hair, and consequently that position is a measure of the relative humidity. Inv. 1922–9.

113. HYGROGRAPH. Lent by The Meteorological Office.

This instrument is designed to furnish a continuous record of the humidity of the atmosphere.

It consists essentially of a wisp of hairs securely clamped at both ends and passing over a hook mid-way between the ends. Contraction of the hairs due to decrease of atmospheric humidity causes the hook to be moved outwards to the right, while a spring controls the hook in the reverse direction as the humidity increases. The motion of the hook is communicated by a series of levers to the pen, which traces the record on a chart carried by the revolving drum. The chart is graduated from 0 to 100 indicating respectively absolute dryness and complete saturation. Inv. 1921–77.

EVAPORATION HYGROMETERS
or
WET AND DRY BULB THERMOMETERS.

114. PSYCHROMETER. Made and lent by Messrs. Pastorelli & Co.

This is a wet and dry bulb hygrometer of a type originally designed by Boeckmann in 1802, and later employed by Gordon, 1817, and Mason, 1836, in which two thermometers are mounted side by side a few inches apart.

The bulb of one thermometer is freely exposed to the air, and indicates the air temperature, while the bulb of the other is enclosed in muslin kept constantly moist by water conducted by a cotton wick immersed in water contained in a brass vessel. The latter thermometer indicates the temperature of evaporation. From the data furnished by each of these instruments and Glaisher's Tables of the elastic forces of vapour at different temperatures, the humidity of the air can be deduced. Inv. 1860–34.

115. APPOLD'S AUTOMATIC HYGROMETER. Lent by The Royal Society.

This instrument was designed by John George Appold, F.R.S., about the middle of the nineteenth century for the registration and regulation of the atmospheric moisture in the rooms of his house.

By the use of this instrument the flow of a small stream of water over a warm stove is regulated, and by this means a uniform humidity is ensured throughout the building.

The hygrometer essentially consists of two bulbs at the extremities of a glass tube, which is connected to a brass rod, the whole turning on a knife edge after the manner of a balance. Mercury fills the tube, and, in part, the bulbs, while in the latter also is a small quantity of ether. One of the bulbs and half of the tube are covered with a paper which is kept constantly moist by water supplied through a pipe above. The knife edge is placed immediately above the covered bulb, beyond which is an arm carrying an adjustable counterpoise, with which the tube is balanced and adjusted, a helical spring serving to regulate the range.

In a dry atmosphere, evaporation occurs from the moist paper, producing a decrease of the temperature and causing a contraction of the ether in the covered bulb, which is accompanied by a transference of mercury from the uncovered to the covered bulb, under the influence of the pressure of the ether vapour in the former. The uncovered bulb, being lighter, now rises, and in so doing actuates a lever, opening a valve which allows water to pass through a tube to some heated pipes covered with bibulous paper. By evaporation from these pipes, the amount of moisture in the air is increased until the desired humidity is attained, when the action ceases.

A pencil attached to one of the levers can be made to record on a chart the motion of the mercury tube, and this record can be checked by readings of the Mason's hygrometer.

(*See* Proc. Roy. Soc., Vol. XV, 1886, p.144.) Inv. 1893–141.

116. WET AND DRY BULB HYGROMETER. Made by Braham, Bristol. Presented by T. H. Court, Esq.

This is a convenient and portable form of hygrometer, made by Braham, of Bristol, about 1860.

The two thermometers are fixed side by side on an ivory mounting, which is supported on a box in which it may be enclosed after use. The bulb of the wet bulb thermometer is covered with muslin, which conducts water from the glass container fixed vertically between the tubes. Inv. 1917–103.

117. MILL HYGROPHANT. Presented by Messrs. J. Casartelli & Son, Manchester.

This instrument is designed specially to enable the hygrometric state of the atmosphere to be ascertained directly by inspection and is particularly suitable for use in weaving and spinning mills.

It consists of a dry and a wet bulb thermometer, between which is placed a case containing a scale to represent dry bulb readings, and a revolving cylinder graduated with percentages of moisture for each degree of difference of the two thermometers from 1° to 21°. This difference being ascertained, the corresponding column of percentages as indicated by the number at the top, is turned to the front, when, in line with the number representing the dry bulb reading, will be found the percentage of moisture in the atmosphere at the time of observation. Saturation is represented by 100. Inv. 1897–16.

118. PSYCHROMETER. Designed and made by Geissler, Bonn.

This is an improved type of wet and dry bulb hygrometer produced by Dr. H. Geissler, of Bonn, in 1876.

The thermometers of this instrument are graduated in tenths from −28° to 46° C. Inv. 1876–761.

119. PSYCHROMETER. Made by Messrs. Warmbrunn, Quilitz & Co., Berlin.

This is a wet and dry bulb hygrometer known on the continent as August's hygrometer; it is similar to but larger than the adjacent instruments.

The thermometers are graduated in tenths from −20° to 50° C.

Inv. 1876–745.

120. PSYCHROMETER. Lent by S. G. Denton, Esq.

This combination includes a Six's thermometer with a mercurial wet bulb thermometer attached to the same stand, thereby combining four instruments, namely, maximum, minimum, and true temperature thermometers, and hygrometer. Inv. 1876–848.

121. REDUCTION DISC FOR PSYCHROMETERS.

This arrangement was designed by Prof. Ernst F. Klinkerfues, of Göttingen, about 1870, for finding the dew-point temperature mechanically from the readings of the dry and wet bulb thermometers.

It consists of a circular scale giving the dew-point temperature, above which is mounted a cardboard disc graduated for dry bulb indications. If the numbers on the scale and disc which correspond to the wet bulb reading be brought into coincidence, the dew-point temperature will be shown on the scale in line with that number on the disc which represents the dry bulb reading.

The coloured part of the scale is for use when the air temperature is below freezing point. Inv. 1876–758.

122. GALTON'S TRACE COMPUTER. Lent by The Meteorological Office.

This instrument was designed in 1870 by Sir Francis Galton, F.R.S., for deducing a curve of vapour tension from the corresponding curves of the dry bulb and wet bulb temperatures, and was employed at the Meteorological Office for deducing curves of vapour tension from reduced copies of thermograms for publication in the Quarterly Weather Report.

The instrument consists essentially of three portions :—

First.—A carriage for holding the two traces from which the third is to be deduced. This carriage is moved from side to side of the instrument by means of a rack and pinion controlled by the operator's right hand, the line of movement being governed by bevelled wheels running in grooves. To the front of the carriage there is fixed a frame, the upper part of which carries a plate intended to receive the deduced curve. The movement of this plate is therefore similar to that of the two curves to be operated upon.

Second.—The second part of the instrument consists of another carriage, having a movement along a track at right angles to that of the first, and carrying a templet with a specially curved surface, corresponding to the required function of the two variables, which in this particular case is the value of the vapour tension for a given temperature of the dry bulb and depression of the wet bulb.

Motion is given to this carriage by a milled head and screw controlled by the operator's left hand, but an independent movement can be given to the templet from side to side of the carriage by means of another screw at the end of an arm which carries a pair of microscopes arranged to follow the wet and dry bulb traces respectively.

Third.—The third section of the instrument is placed immediately above the templet, and consists of a partially counterpoised frame which can move up and down in a set of vertical grooves. The frame terminates in a style which rests lightly upon the templet, whilst at the top it carries a horizontal tube in which slides a pricker, held back in the tube by a spring.

When the microscopes have been set so that their cross wires intersect respectively the dry and wet bulb traces, the pricker is struck by a hammer moved by the operator's foot, and a dot is made on the plate. The distance of this dot below a zero, previously ruled upon the plate, corresponds to the height upon the templet at which the style rests at the moment when the blow is delivered and to the tabular values of the vapour tension for the temperature of the dry bulb and depression of the wet bulb indicated by the two traces.

The succession of dots made at half-hour intervals was connected by a graver, so as to form a continuous curve, which was transferred to a copper plate by means of a pantagraph.

(*See* Report of the Meteorological Committee of the Royal Society, 1870 and 1871.) Inv. 1906–100.

123. ASSMANN'S PSYCHROMETER. Lent by The Meteorological Office.

This ventilated and portable psychrometer was designed in 1887 by Prof. Assmann, of Berlin, in order to obtain trustworthy wet bulb readings during balloon ascents when a relative calm is produced by the balloon travelling with the wind.

It consists of two mercurial thermometers, of which the bulbs are kept respectively dry and wet, together with an arrangement for drawing air over the bulbs at a certain speed by means of a fan driven by clockwork. The bulbs of the thermometers are protected from external radiation by two highly polished cylindrical tubes, thereby enabling the instrument to be placed in strong sunshine, or employed on aircraft at great heights, without fear of solar radiation affecting the readings. The dry bulb thermometer gives the true temperature of the air, and the wet bulb the temperature due to the effect of evaporation, the depression of the wet bulb increasing, as the relative humidity decreases. Inv. 1921–80.

124. COMIN PSYCHROMETER. Lent by The Meteorological Office.

This electrically ventilated psychrometer is designed to ensure that the temperatures indicated by the instrument are accurately those of the wet and dry bulb thermometers.

As in the Assmann instrument, air is drawn past the dry and wet bulb thermometers through the agency of a small fan driven electrically by means of a small motor enclosed in the lower portion of the apparatus. An inverted glass tube containing distilled water enables the muslin to be kept uniformly wet however the current of air may be varied. Inv. 1922–6.

125. LLOYD'S HYGRODEIK. Lent by The Meteorological Office.

This instrument was designed by Messrs. A. J. Lloyd & Co. in 1902 to give a direct indication of the relative humidity, dew-point, and the absolute humidity.

It consists of wet and dry bulb thermometers provided with a specially-designed chart, over which an indicating arm can be moved. In using the instrument, this arm is moved to the scale on the left near the wet bulb, and the sliding pointer is set to the temperature indicated by the wet bulb thermometer. The arm is then moved to the right until the pointer is on the curved red line corresponding with the reading of the dry bulb thermometer. The relative humidity is then indicated on the graduated arc at the bottom of the chart, while the dew-point is given on the printed dry bulb scale by the intersection of the thick curved black lines. The absolute humidity is indicated by the numbers at the upper end of these lines, which give the amount of water in grains per cubic foot of air. Inv. 1922–3.

126. AEROPLANE PSYCHROMETER. Lent by The Meteorological Office.

The instrument here exhibited is designed for use on an aeroplane, where it is mounted in an exposed position and is read from a distance.

It consists of wet and dry bulb thermometers mounted on a frame, which can be attached to an interplane strut of the machine several feet away from the observer, where they are unaffected by the heat of the engine. Lenses are provided to facilitate the reading of the thermometers and can be adjusted by the observer by means of the cord. Inv. 1922–5.

127. MODEL OF WHIRLED PSYCHROMETER. Lent by The Meteorological Office.

This apparatus is designed for whirling thermometers through the air, thereby enabling the wet and dry bulb temperatures to be obtained with accuracy and rapidity.

It is provided with two arms, which are rotated rapidly by operating the small wheel and handle. To these arms are attached two thermometers, the bulb of one being covered with wet muslin. The thermometers are then whirled and the readings taken.

(*See* "U.S. Dept. of Agriculture Weather Bureau, Psychrometric Tables, Part I, Washington, 1918.") Inv. 1922–4.

128. HYGROGRAPH. Made by Pastorelli and Rapkin.

This instrument is designed to give a continuous indication of the wet and dry bulb temperatures, thereby enabling the humidity to be determined at any time during the absence of the observer.

It consists of two similar bi-metallic strips, each pivoted at one end and bent into a wave-like form, while to the other end is connected a series of levers by means of which the motion is communicated to an arm carrying a pen, which records on the rotating drum.

One of these bi-metallic strips is covered with muslin and by means of a series of wicks is supplied with moisture from a cylindrical metallic reservoir containing water.

Adjusting screws are provided near the pivoted end, which enable the position of the pens to be adjusted.

The range of the instrument is from 100° F. to 200° F. Inv. 1922–47.

SUNSHINE RECORDERS.

The first instrument for recording sunlight dates from 1838, but it was not until fifteen years later that an instrument was produced for furnishing a continuous record of sunshine.

In general, sunshine recorders fall into two main classes, according to their method of operation, and whether the record is produced photographically or by burning, the intensity of the solar radiation being investigated by other forms of instrument known as actinometers and solar radiation thermometers.

Instruments of the burning type date from 1853, when John Campbell, of Islay, produced his sunshine recorder, which took the form of a mahogany bowl containing a hollow glass sphere filled with acidulated water, which he replaced in 1857 by a solid spherical lens of crown glass. Campbell modified his arrangement in 1878, introducing a gypsum bowl containing a strip of cardboard, and the following year Sir G. G. Stokes added the zodiacal frame, when the instrument became known as the Campbell-Stokes sunshine recorder. In 1880 Stokes devised a new form of card holder, while in 1901 Curtis introduced further modifications.

Another method of supporting the lens was adopted in the Whipple-Casella instrument, which is provided with divided latitude and diurnal circles, enabling it to be set for any latitude and any day of the year.

The idea of recording sunlight photographically dates from 1838, when T. B. Jordan invented his daylight and sunlight recorder, but the first instrument to be used with success was Sir H. Roscoe's chemical photometer, which was produced in 1863, and subsequently modified by him. The most successful sunshine recorder of the photographic type was due to J. B. Jordan, who, in 1884, produced his single-cylinder recorder, which he improved four years later, adding a second chamber. About the same time, McLeod designed an instrument having a glass sphere silvered inside and placed before the lens of a camera, and Maurer, in Switzerland, produced a heliograph similar in principle to Jordan's single-cylinder recorder. In the Dawson-Lander instrument, which consists of a hollow cylinder of copper, and in the side of which is cut a narrow slit to allow the sunlight to impinge on a strip of sensitive paper wound round a drum, the copper cylinder is made to revolve with the sun and moves in an axial direction, enabling a continuous record to be obtained for any required period. Richard has also designed an instrument in which the aperture is made to move over a sheet of sensitive paper in conjunction with the sun.

The earliest mode of measuring the temperature of the sun was by attempting to measure the heat of radiation, and the unsuitability of ordinary thermometers for this purpose led to the contrivance of the instrument known as the actinometer. The first actinometer was produced in 1825 by Herschel, who made the first satisfactory measures of direct solar radiation in 1836. His instrument consists of a large glass cylinder filled with a solution of ammoniacal sulphate of copper, which acts as the bulb of a large thermometer. Pouillet, about 1854, proposed his pyrheliometer, of which there are two forms, in one of which the solar radiation is received direct, while in the second it is focussed by a lens on to a vessel containing liquid. In 1866, Hodgkinson designed an actinometer for his researches in Switzerland, and the following year another instrument was introduced by Balfour Stewart. The next step was made by Secchi, who designed an instrument consisting of two co-axial cylinders with a thermometer bulb in the middle, on which the sun's rays were allowed to fall, the annular space between the cylinders being filled with liquid at a known temperature. In 1885 Stanley produced his copper pyrheliometer, which, however, was found to give readings lower than the solar radiation thermometer, while the following year Ångström introduced his compensated pyrheliometer, which was adopted as the International Conference in 1905.

The development of the solar radiation thermometer from the ordinary thermometer, commenced by making the bulb of black glass, in order to diminish reflection. In order to overcome the effects of wind, Herschel, in 1849, suggested enclosing the thermometer in an exhausted glass envelope, and later it was found desirable to coat the bulb with lamp black so that all heat falling upon it might be absorbed, while finally, owing to the influence of the lower temperature of the unblackened thermometer tube, a small portion of it adjacent to the bulb was similarly coated.

A recording instrument has been devised by Richard, consisting of two thermometers contained respectively in polished and blackened bulbs, the record being produced by two pens working on the same chart.

INSTRUMENTS PRODUCING A RECORD BY BURNING.

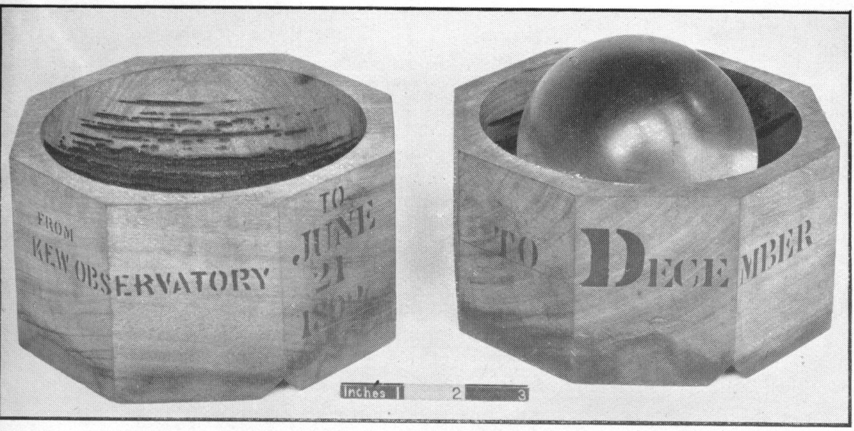
129. FIRST SPHERICAL LENS MADE FOR SUNSHINE-RECORDING. Lent by The Meteorological Office.

A label upon the lens states :—

"This lens was made in 1857, probably in Manchester, for Mr. Campbell, of Islay, and at the close of that year it was substituted for the original fluid lens which had been in use at the Office of the Board of Health, Whitehall, since Christmas, 1853, when continuous sunshine records were first begun. It is the first glass lens employed to record sunshine, and was transferred from Whitehall to Kew in 1875, and used there. The second lens employed was made by Chance in 1875, and was used at Greenwich Observatory. Inv. 1908–88.

130. CAMPBELL'S SUNSHINE-RECORDER BOWLS. Lent by The Meteorological Office.

These bowls were used at the Kew Observatory from the 21st December, 1891, to 21st June, 1892, and from June, 1892, to December, 1892. They furnish a record of the sunshine for that period.



Campbell's Sunshine Recorder Bowls.

McLeod's Original Sunshine Recorder (1886).

The hemispherical bowls are made of mahogany of uniform grain, and in the middle is placed a spherical water or glass lens, whose centre coincides with the centre of the cavity in which it rests and which is of such a radius that the focus falls on its inner surface. The sun's rays are focussed by the lens and as the direction of the sun changes, a record of its course is burnt into the wood, the position of the record rising or falling in the bowl according to the sun's declination. A measurement of the depth of the burnt record during different periods gives the relative heating powers during these periods.

The bowls exhibited indicate the difference in the sun's heat for the two halves of the year falling between the solstices. Inv. 1894–120, S.M. 1444, L.S.

131. CAMPBELL STOKES SUNSHINE-RECORDER. Made by Messrs. Short and Mason.

This instrument was developed by Stokes from Campbell's recorder of 1853, in which wooden bowls were used in conjunction with a water or glass lens. In 1876 the wooden bowl was replaced by one of metal containing a strip of cardboard, and in 1879 Stokes added the zodiacal frame. In the following year he devised an improved card holder, and other improvements were introduced by Curtis in 1901.

A spherical lens is mounted in a metal bowl which is fixed upon a slate base and grooved on its inner surface to hold the strips of card used as records. For observations, the bowl is placed in the meridian and its axis inclined in accordance with the latitude. The lens being carefully focussed, the charring of the card by the sun's heat indicates the duration and intensity of the sunshine.

Other forms of burning recorders, such as those with stone and metal bowls coated with some substance that melts under strong heat, have been employed from time to time, but these have now been entirely superseded by the Campbell-Stokes instrument.

(*See* Q. J. Met. Soc., 1880, Vol. VI., p. 83, and Vol. XXVII., p. 117.)
Inv. 1909–132, S.M. 1443, L.S.

132. WHIPPLE-CASELLA SUNSHINE RECORDER. Lent by Casella.

This instrument, which is of the burning type, was designed by G. M. Whipple in 1884 for use in any locality and at any time of the year.

It consists of an optically worked crown glass sphere, four inches in diameter, weighing approximately three pounds, and having a focal length of from 2·96 in. to 2·99 in. This lens is suitably mounted, and the instrument is furnished with divided latitude and declination circles, so that it may be used at any time and in any latitude. An adjustable metal rim in the form of a circular arc, serves to hold the strip of sensitized paper which forms the record. Inv. 1921–693.

PHOTOGRAPHIC INSTRUMENTS.

133. JORDAN'S SUNSHINE RECORDER. Made by Messrs. Negretti and Zambra.

This sunshine recorder was designed by Mr. J. B. Jordan in 1884, for photographically recording the duration of sunshine.

It consists of a single dark cylindrical brass chamber, on the inner circumference of which is placed a sheet of sensitized paper. A ray of sunlight being admitted into this chamber through a small rectangular aperture in the side, is received on the paper, and travels around it by virtue of the earth's rotation, leaving a distinct record of chemical action, thereby registering its duration and the degree of its intensity. The cylinder is mounted on a bronzed stand, with means of adjustment for the different seasons, and for use in any latitude.

The records are divided into hours and sixths, the cyanotype process being used in sensitizing them, while they are rendered permanent by simply washing for a few minutes in cold water and afterwards drying.

(*See* Q. J. R. Met. Soc., Vol. XII., 1866.) Inv. 1886–76, S.M. 1432, L.S.

134. JORDAN'S TWIN-CYLINDER SUNSHINE RECORDER. Lent by J. B. Jordan, Esq.

This instrument which is an improvement on the single cylinder type shown adjacent, was introduced by Jordan in 1888.

It consists of two semi-cylindrical dark chambers of brass, one to contain the morning and the other the afternoon record. The chambers are placed with their diametral planes outwards and at an angle of 60°, while they are hinged to a stand having a latitude arc. An aperture for admitting the beam of sunlight is placed in the centre of the rectangular side of each box, so that the length of the beam within the chamber is the radius of the cylindrical surface on which it is projected. Its path therefore at all seasons follows a straight line on the record.

The apertures for the admission of the sun's rays are so placed as to receive the early and late sunshine, and as there is only one aperture in each chamber, the amount of diffused light admitted is much less than in the single cylinder instrument, while the fact that the morning and afternoon charts are placed in separate cylinders offers improved facilities for changing the charts.

(*See* Q. J. Met. Soc., 1888, Vol. XIV., p. 212.) Inv. 1893–144, S.M. 1431, L.S.

135. McLEOD'S SUNSHINE RECORDER. Lent by Prof. H. McLeod, F.R.S.

This original sunshine recorder was designed by Prof. McLeod about 1886, and was subsequently modified and produced commercially.

It consists of a glass sphere silvered inside and placed before the lens of a camera, the axis of the instrument being adjusted parallel to the polar axis of the earth. The light from the sun is reflected from the globe and some of it passing through the double-convex lens forms an image on a piece of prepared paper within the camera. In consequence of the rotation of the earth, the image describes the arc of a circle on the paper and when the sun is obscured this arc is necessarily discontinuous. The image is not on a point, but a line, and in certain relative positions of the sphere, lens, and paper, the line is radial and very thin, so that the obscuration of the sun for only one minute is indicated by a weakening of the image.

The record is divided into hourly intervals, when the position of the meridian has been determined, by drawing radial lines at angles of 15°. Ferro-prussiate paper is used for the records, which are fixed by washing them in water for a few minutes.

Examples of the traces, divided for the hours, are exhibited with the apparatus.

(*See* Jour. Phys. Soc., Vol. VI., p. 216.) Inv. 1885–112, S.M. 1453, L.S.

136. MAURER'S SUNSHINE RECORDER. Made and lent by Th. Usteri-Reinacher, Zurich.

This photographic sunshine recorder which was designed by Dr. J. Maurer about 1886, is similar in principle to that of Jordan.

It consists of a cylindrical dark chamber of brass having its top oblique to the axis and pierced with a small rectangular hole. The bottom of the cylinder is removable to allow the sensitized papers which are accommodated inside to be adjusted. A small latitude arc is fitted below the instrument, and the whole is supported on an iron stand. If the cylinder be fixed with its axis adjusted for latitude, and its North South line in the meridian, the sun's rays passing through the hole at the top, leave a record of their course on the sensitized paper, and as this record is approximately a straight line at right angles to the hour lines engraved on the paper, the duration of sunshine for any particular period can be readily ascertained.

The record should be washed in water, after removal from the cylinder, in order to fix it. Inv. 1893–145.

SOLAR RADIATION THERMOMETERS.

137. HERSCHEL'S ACTINOMETER. Presented by Sir J. Hooker, F.R.S.

This actinometer which is of the type devised by Sir J. Herschel in 1825, was used by Sir J. Hooker in his investigations when travelling in the Himalayas.

It consists of a glass cylinder filled with a solution of ammoniacal sulphate of copper, to one end of which is connected a tube with an arbitrary scale of equal parts, while to the other end a screw is fitted which may be used to adjust the liquid in the tube, the whole forming a delicate thermometer. The temperature of the liquid is ascertained by a thermometer having its bulb in the liquid, and its stem passing through the screw. By noting on the arbitrary scale the height of the liquid immediately before and after the instrument has been exposed to the sun's rays for a definite time, and also making similar observations when it is set in the shade, a measure of the heating effect of the sun's rays can be ascertained. This can be corrected for the unequal expansion of the liquid with the aid of readings given by the alcohol thermometer. Herschel suggested that not less than three sun observations, and two intermediate shade observations should be taken, the calculations to be made from the means of the readings in each position.

The unit of solar radiation adopted in the ultimate reduction of the observation was the " Actine." By this is understood, " that intensity of solar radiation which, at a vertical incidence, and supposing it wholly absorbed, would suffice to melt one millionth part of a metre in thickness from the surface of a sheet of ice horizontally exposed to its action per minute of mean solar time."

(*See* Admiralty Manual of Scientific Enquiry. Article on Meteorology by Sir J. Herschel.) Inv. 1890–54.

138. HERSCHEL'S ACTINOMETER. Made by Robinson. Lent by The Meteorological Office.

This instrument, which is of the form devised by Sir J. Herschel in 1825, was used during the Antarctic Expedition of 1840–3 under the command of Sir James Ross, R.N.

In construction and design it is similar to the instrument shown adjacent.
Inv. 1908–96.

139. SOLAR RADIATION THERMOMETERS. Made by J. Hicks. Presented by The Admiralty.

Sir John Herschel in 1849 suggested enclosing the black bulb of an ordinary radiation thermometer in a vacuum tube, so as to prevent loss of heat due to radiation from the black bulb.

The two examples shown are made in this manner and were used on the British (" Discovery ") Antarctic Expedition of 1901. The indications are 20° F. to 30° F. higher than those of a similar instrument with exposed bulb. The larger example is graduated in degrees from 3° F. to 203° F. and the smaller from 10° F. to 207° F. Inv. 1911–116–7.

140. SOLAR RADIATION THERMOMETER. Lent by Townson and Mercer.

This form of thermometer is constructed with the view of measuring the intensity of radiation derived directly from the sun. To effect this, the bulb and part of the stem are blackened, and the whole thermometer enclosed in a glass shield as nearly as possible exhausted of air, so that results may be unaffected by passing air currents or by the presence of moisture in the surrounding atmosphere.

These thermometers are supported on specially constructed stands, to prevent their receiving heat from objects in their vicinity. They are occasionally made with mercurial vacuum gauges and other appliances for indicating the state of exhaustion of the air enclosed in the shield.

Sir John Herschel, in the " Admiralty Manual " of 1849, suggested this design of instrument, and many have been constructed since, which give favourable results as compared with other forms of apparatus for measuring the intensity of solar radiation. Inv. 1905–73.

141. POUILLET'S PYRHELIOMETER. Made by Casella. Lent by The Rev. F. W. Stow, M.A.

Pouillet about 1854 proposed his pyrheliometer of which there were two forms, known as the "pryheliometer direct" and the "pyrheliometer à lentille." The instrument exhibited is a modification of the former, introduced by the Rev. F. W. Stow.

It consists of a thermometer the bulb of which is immersed in the mercury contained in a small blackened cylinder of known capacity and base area. When in use, the base of the cylinder is turned for a definite period of time alternately towards and from the sun, and the mean of the thermometer readings in each position is taken. From these means can be determined the rise in temperature of the mercury contained in the cylinder due to the sun's radiation acting on a known area for a fixed time.

The base should be set so that the sun's rays fall perpendicularly on it and a paper disc is supplied to show by the position of the shadow of the cylinder, when this adjustment has been made.

The improvement due to the Rev. F. W. Stow is the addition of the outer cylindrical case to protect the thermometer tube from wind, and rays other than direct.

(*See* Tyndall—"Heat as a Mode of Motion.") Inv. 1893–113, S.M. 1438, L.S.

142. SECCHI'S SOLAR INTENSITY APPARATUS. Lent by Casella.

This apparatus was devised by Padre Secchi for measuring the comparative intensity of the heat of the sun's rays.

It is a metal vessel in the form of a hollow cylinder, ten inches in length and of three inches diameter, filled with a liquid at any desired temperature. In three tubes are inserted thermometers, the bulbs of two of which are immersed in the liquid, the bulb of the third being passed through the vessel into the hollow centre of the cylinder. For observation, the apparatus is placed on a stand, and adjusted so that the sun's rays fall on the exposed bulb.

Experiments showed that the increase in the thermometer reading was independent of the temperature of the surrounding liquid. Inv. 1893–146.

143. SOUTHALL'S HELIO-PYROMETER. Lent by L. Casella, Esq.

This instrument was devised by Southall to obviate the lowering of the readings of solar radiation thermometers due to air currents and the cooling resulting from evaporation from the soil.

It consists of a box lined with black cloth cushions, containing a maximum thermometer with blackened bulb, and closed by a glass lid. If set so that the sun's rays fall perpendicularly on this lid, the difference of the readings of the thermometer and those obtained from a thermometer reposed in the ordinary way in the shade, will give a measure of the heating power of the sun, allowance being made for loss of heat by reflection from the surfaces of the glass. Southall suggested 11.30 a.m. to 12.30 p.m. as the most suitable time for making observations, as no change in the position of the box is then necessary.

With this apparatus, a small vessel in which water is boiled by the sun's rays, has been used. Inv. 1893–161.

144. STANLEY'S COPPER PYRHELIOMETER. Lent by W. F. Stanley, Esq.

This instrument was designed by Mr. Stanley in 1885 to overcome the difficulties experienced in the use of solar radiation thermometers enclosed in a vacuum.

It consists of a thermometer the bulb of which is enclosed in a copper ball 1·4 in. diam., whose surface has been oxidised by heating. When in use, it is supported on a black polished slate slab, at a distance of about two inches from the surface, the slab being inclined at an angle of 45°. Readings obtained with this instrument were found to be lower than those obtained with the ordinary solar radiation thermometer, but results obtained with similarly constructed instruments were uniform.

(*See* Q. J. Met. Soc., 1885, Vol. XI., p. 124.) Inv. 1893–118.

145. ÅNGSTRÖM'S COMPENSATED PYRHELIOMETER. Made by The Cambridge Scientific Instrument Co.

This instrument, which was invented in 1886 by Knut Ångström for the absolute determination of heat radiation, provides a method of measuring solar radiation, and is also suitable for experimental work in the laboratory. It was adopted as the international standard instrument by the Innsbrück meeting of the International Conference in 1905.

The instrument consists essentially of two similar strips of thin blackened manganin foil, arranged side by side on a small circular ebonite frame, and connected to two constantan copper thermo-junctions, so that no current will flow if the two strips are at the same temperature. The strips are mounted in a tube provided with three diaphragms, on the front end of which a double walled reversible screen is arranged, which may be used to protect one or other of the strips from external radiations. An ebonite stopper closes the other end of the tube and carries terminals for the thermo-element and the strip. A commutator enables the current to be sent through either strip as required, and a thermometer is fitted to the tube, which may be sighted in any direction.

The auxiliary apparatus necessarily consists of a sensitive galvanometer and adjustable resistance, a milliamperemeter and an accumulator, the last three being connected in series with the strip. If now we know the width, resistance, and coefficient of absorption of the strips, we can calculate the absolute value of the radiation, when a balance is obtained, by equating the electrical power absorbed in the screened strip to the radiated power absorbed by the exposed strip, thus:—

If B = width of strip in cm.,
a = the power of absorption (0·985),
q = radiation in C.G.S. units,
r = resistance of unit length of the strips,
i = strength of electric compensation current:

then baq = radiated energy, and this is equal to

$\frac{ri^2}{4\cdot 18}$ = electrical energy;

whence $q=\frac{ri^2}{4\cdot 18ba}$ gram calories per second per sq. cm.

or $q=\frac{ri^2}{4\cdot 18ba}\times 60$ calories per second per sq. cm.

Adjustments are provided on the pyrheliometer, by means of which the instrument may be correctly sighted to the sun, this being obtained when the ray of light passing through the pin-hole on the top of the instrument is focussed on the cross-wires. One strip should now be exposed, and the current directed through the other strip and adjusted until no deflection is obtained. The test should then be repeated with the other strip exposed, and the current passing through the one which was previously exposed. Owing to slight lack of symmetry between the strips, the readings may disagree slightly, and a mean should be taken for the final result.

(*See* Astrophysical Journal, Vol. IX., 1899, pp. 332–346.)

Inv. 1914–726, S.M. 1434, L.S.

146. CALLENDAR'S SUNSHINE RECEIVER. Made by The Cambridge Scientific Instrument Co.

This instrument was designed by Prof. H. L. Callendar to indicate the total quantity of heat received by the earth's surface.

It is essentially a differential platinum thermometer, consisting of two equal resistance coils, one of which is blackened and the other left bright. These are set side by side in a horizontal plane, and protected by a suitable cover; the leads being well insulated are led to the bottom of the instrument, where they are connected to a 4-wire cable leading to a Callendar recorder. The difference of temperature between the two coils, which is indicated by the recorder, is proportional to the intensity of the vertical component of the radiation.

The instrument is calibrated and a factor obtained, by means of which the total amount of heat actually received by the instrument can be calculated.

Inv. 1914–725.

ANEMOMETERS.

The characteristics of the wind from the four points of the compass were noticed as early as 1000 B.C., and 500 years later the Grecians added four additional intermediate directions. This number was gradually increased to twenty-four, but twelve points were in more common use until the time of Charlemagne, when the intermediate directions were compounded from the four cardinal points similarly to the present nomenclature.

The earliest known device for locating wind direction was the octagonal Tower of the Winds at Athens, which was built about 100 B.C., while the first weathercock was fitted to a church in the Tyrol in the year 820 A.D., and the first wind vanes of modern form were those of Dante at Bologna and Florence in the middle of the sixteenth century, but the regular observation of wind vanes for meteorological purposes was not commenced until about 1650.

It is probable that the earliest attempts at gauging wind force were made by sailors, who, almost from the dawn of navigation, estimated the force as well as the direction of the wind, and who at the present time use the Beaufort scale for a similar purpose.

With a view to obtaining an accurate indication of wind force or velocity, anemometers have been designed, which fall naturally into three general classes, according as to whether they measure pressure, velocity or suction. The pressure anemometer is usually made according to one of two forms; either a metal plate of small dimensions, and pendulously suspended from its upper edge, is allowed to swing with the wind, and its departure from the vertical is noted, or a larger plate is exposed facing the wind, and its pressure is received on springs, the movement of which permits the force to be noted.

The earliest mention of an anemometer was in a Royal Society publication of 1667, in which was described a pressure plate anemometer of the pendulum type, which had been in use for some time. It was re-invented by Pickering in 1744 and fitted with a spring catch in order to register the maximum force of the wind, while an index indicated the direction. A more complicated instrument of similar type was produced by Dalberg in 1780, while Schmidt, of Giessen, in 1828 designed a very simple registering instrument. Wild's well-known instrument was produced in 1861, and although closely resembling the primitive type described in 1667 it was recognised as a "standard" for some time. A somewhat different modification was devised by Howlett in 1868, in which the pressure plate was replaced by a sphere, thereby enabling the wind to be measured in any direction.

Related to these "pendulum" anemometers are the "bridled" anemometers, in which the swinging of the plate is prevented by an interposed resistance. The earliest of this type is probably that of Wolf or Wolfius in 1708, in which a set of small windmill sails on a horizontal axis communicates the motion, by means of an endless screw, to a toothed wheel, on the axis of which is fixed a rod carrying a leaden weight, the angular rotation of the wheel being a measure of the wind force. Leopold in 1724 and Leutmann the following year published almost identical descriptions of a bridled anemometer in which the sails were curved and set in the form of a paddle wheel. Leopold also invented other anemometers, one of which was exactly reproduced by Martin in 1771, and modified by Beaufoy fifty years later. Ronalds original anemometer of 1844 consisted of a light wooden cross in a vertical plane, the upper extremity of which carried a plane facing the wind, while the other arms carried a scale pan and counterpoises. The instrument was subsequently modified so as to turn to the wind by the action of a vane. Galton in 1879 designed a "torsion" anemometer, and two years later Stokes produced his "bridled" anemometer.

The earliest pressure anemometer which was not of the pendulum type was designed by Bouguer in 1746, and consisted of a pressure plate anemometer in which a sheet of cardboard was pressed backwards by the wind against a spring, an arrangement which was modified by Demenge ten years later, while in 1836 Osler produced his instrument in which the pressure plate acted on a wire passing down the hollow spindle of the vane. Attempts were made by Jelinek, 1850, and Cator 1864, to eliminate the suction behind the plate by fitting a fairing.

Lind's well-known anemometer was produced in 1775, and consisted of a U tube mounted and swinging freely on a vertical spindle, so as to form a direction vane. This apparatus was modified by Forbes some seventy years later, so as to give a measure of extreme gusts. A more important modification was Wollaston's "differential barometer," in which the U tube contained both oil and water, thereby giving a magnified scale, while Ramsbottom proposed a similar instrument in 1866. In a kindred instrument suggested by Brewster in 1830, air was collected in a funnel and forced back an index in the stem of a horizontal thermometer tube, thereby compressing the contained air. A more practical form, however, was due to Adie, who in 1836 invented an instrument in which the bell-mouthed tube was in communication with the interior of an inverted cylinder floating on water. This type of instrument was considerably improved by Dines in 1891, when he produced his pressure plate anemometer in which the pressure on a plate is made to raise or lower a suitably-shaped block floating in water. In a subsequent modification the block is replaced by an inverted float, the interior and exterior of which are connected to a pressure and suction tube respectively, causing the float to rise or fall with variation of wind pressure, the motion being recorded by a pen on a revolving drum.

An estimation of wind velocity was made by Mariotte before 1680 by observing the time taken for pieces of down to pass over a measured distance, a method which was repeated in 1708 by Derham, and systematized by Bouvet in 1733. A similar method was adopted for a standard measurement of velocity by Snow Harris in 1840, employing feathers mounted on thin discs of cork.

The earliest recorded instrument for measuring wind velocity was devised by Dinglinger about 1720, and closely followed if not imitated by d'Ons-en-Bray in 1734, both instruments having clockwork registering apparatus. In the latter, a vane on one side indicates the wind direction, and a wheel on the other side gives the velocity. Following this, Lomonoscow in 1751 proposed an anemometer in which an indication of the velocity is obtained from a paddle-wheel, and mechanical gearing contained in the hollow direction vane. The next attempt to measure wind velocity was due to Woltmann, who, in 1790, obtained a continuous motion from a set of windmill sails, a principle adopted by Whewell in 1837. Seven years later, Foster introduced a modified form in which the wind was received on four vertical plates, at the ends of the arms of a horizontal cross. It was fitted to turn only in one direction and was considered a decided improvement on its predecessor, but it was immediately overshadowed by Robinson's adaptation of the hemispherical cups in 1846, the origin of which he attributed to Edgeworth. Robinson's arrangement was subsequently modified and improved by Beckley in 1856, Osler, 1858 and 1865, Woodward, 1867, Hall, 1870-2, and many others, but in principle the instrument itself remains very much as Robinson originally designed it.

Attempts have also been made to estimate the velocity of wind by its physical effects, the first of which was described by Leslie in 1804. He enunciated the principle that the refrigerant power of a stream of air is exactly proportional to its velocity, and employed it to determine the wind velocity from the rate of cooling of a thermometer bulb. Brewster in 1892 obtained a measure of the velocity by observing the rate of evaporation from a wetted sponge or flannel, and during the period 1846-9 the methods of both Leslie and Brewster were re-invented by Phillips.

Allied to these methods are those based on the friction of masses of fluid in motion and their consequent power of suction. The principle was first illustrated by Bernouilli about 1738, but it was not until towards the end of the century that Venturi studied it carefully, and Overduyn in 1854 applied this method for estimating the speed of a ship, suggesting at the same time that air currents might be measured in a similar manner. The same principle but without Venturi's tube was applied by Fletcher in 1867 to a modification of Lind's instrument, thereby anticipating Hagemann's anemometers, which were produced in 1876.

Another type of instrument is the musical anemometer, which measures the wind by the musical sound which it is able to produce. From the first idea of measuring wind, attempts were made to establish a relation between the force of the wind and the sound it could produce, and Hooke himself suggested some such method. Kircher, about the same time, constructed several instruments which remitted musical sounds when the wind blew upon them, and were similar to the Aeolian harp. Leopold invented an instrument by means of which the wind was measured by its piping, and Delamanon in 1782 produced an organ in which the pipes were fitted with valves so constructed that the wind was only able to raise one at a time, enabling the force and direction of the wind to be indicated by the resulting sound.

PRESSURE TYPE ANEMOMETERS.

147. LIND'S ANEMOMETER. Lent by Messrs. F. Darton & Co.

This instrument is of the type designed by Lind in 1775 for indicating the pressure of the wind.

It consists of a U tube containing water and adjusted with the mouth of the longer arm facing in an upwind direction. For observations the tube is filled with water until its level reaches the zero mark on the scale. If it then be brought into position with the mouth of the longer branch facing the wind, the water will rise in the shorter branch to an extent which will vary with the wind's force. From the difference of levels, with the aid of scales prepared for each instrument, the pressure and also the velocity of the wind can be ascertained.

The wind vane serves to turn the mouth of the tube to the wind, and also indicates the direction. Oscillations owing to rapid changes of pressure are lessened by narrowing the tube connecting the two branches.

(*See* Phil. Trans., Vol. LXV, p. 353.) Inv. 1876-850.

148. RONALDS BALANCE ANEMOMETER. Presented by The Meteorological Office.

This pressure plate anemometer was designed and constructed by Mr. Francis Ronalds at the Kew Observatory in 1843, for the purpose of measuring the force of the wind.

It consists of a light board, 1 ft. sq., fixed transversely to a cross of wood, suspended by a brass axis passing through its centre, and turning in glass tubes in such a way that the system can partially rotate in a vertical plane. The lower end of the bar carrying the board is counterpoised, so as to keep the surface of the board vertical, and a scale pan, hung to one end of the horizontal bar of the cross, serves to receive the weights which are necessary to counterbalance the force of the wind pressing on the board opposed to it, at any time. A small box, covering the scale pan, serves to shield it from the action of the wind. The instrument was, at the time of observation, placed so that the surface of the pressure-plate should stand at right angles with the direction of the wind, as indicated by a vane.

Inv. 1876–799.

149. LIND'S ANEMOMETER AS MODIFIED BY SNOW HARRIS. Made by Messrs. J. Lilley & Son. Lent by The Meteorological Office.

This apparatus, which indicates both the force and direction of the wind, was designed by Sir W. Snow Harris, F.R.S., in 1858.

It consists of a large bulb open to the atmosphere at the upper end, and terminating at the lower end in a long glass tube, the upper portion of which is L-shaped and supplied with a graduated scale. Coloured liquid is inserted in the bulb until it reaches the zero graduation on the horizontal scale. The instrument is levelled and then turned so that the wind vane and the glass tube are in the same vertical plane, when the elbow attached to the upper end of the bulb is facing in an up-wind direction. The direction of the wind can then be read off by means of the compass in the base of the instrument, while the position of the liquid column on the graduated scale indicates the pressure and velocity of the wind.

A table is also provided in which the gauge reading pressure, and velocity are tabulated.

(*See* Symons Monthly Magazine, Vol. ii., p. 52.) Inv. 1917–30.

150. MODIFIED LIND'S ANEMOMETER.

This instrument, which is a modification of Lind's anemometer due to Sir W. Snow Harris, is similar in general principle to the one shown adjacent.

In this anemometer the mouth of the tube receiving the wind is provided with a movable cap, which enables the tube to be closed instantly, and a record of the wind pressure gust obtained.

(*See* Symons Monthly Magazine, Vol. ii., p. 52.) Inv. 1894–115.

151. WILD'S PRESSURE PLATE ANEMOMETER. Presented by The Meteorological Office.

This pressure plate instrument, which is of the pendulum type, was designed by Wild in 1861, and is a modification of the anemometer originally described by Hooke in 1667. It was for many years the standard type of anemometer in Russia.

It consists of a freely hanging metal plate suspended on a horizontal axis from above. The wind blowing against this plate causes it to swing out of the normal vertical position, the angle of displacement varying with the force of the wind, the velocity of which is indicated by a series of small rods carried on an arc and forming a scale.

The direction of the wind is indicated by a vane mounted on the same vertical shaft, and situated below the pressure plate.

(*See* Mittheilungen der naturforschenden Gesellschaft in Bern für 1862, p. 221.) Inv. 1921–378.

152. HOWLETT'S ANEMOGRAPH. Lent by Messrs. Elliott, Bros.

This instrument was designed by Howlett in 1868 for registering the direction and force of the wind, and is of the pressure-plate pendulum form in which the plate has been replaced by a sphere.

This sphere is connected by a brass rod, which acts as a lever having as fulcrum the gimbal support at the top of the case of the recording slate. The sphere is raised or lowered on the rod according as light or heavy pressures have to be measured, and its position, along with that of the weight on the recording end of the rod, serve together with the trace in determining the force of the wind in pounds per square foot.

The instrument is so constructed, that when the sphere is in its lowest position, pressures from 0 to 20 lb. can be shown, when at it highest 0 to 5 lb. and with the small weight at the top 0 to 2·5 lb. The scale of the recording slate is graduated from 0° to 360° in 5° intervals, and the direction and pressure of the wind are ascertained from the position and length of the pencil trace.

Inv. 1893–47.

153. DYNAMIC ANEMOMETER. Lent by The Council of the Royal Aeronautical Society.

This apparatus was designed about 1870 for obtaining the horizontal and vertical components of the pressure of air in motion upon inclined surfaces of different forms and angles.

The instrument is intended simultaneously to determine the component pressures of a current of air when directed against planes of different areas, and of different forms, and angles from 15° to 90°.

(*See* Report of the Aeronautical Society, 1871.) Inv. 1876–1216.

154. BRIDLED ANEMOMETER. Lent by The Meteorological Office.

This instrument, which was in use at Holyhead for many years, was designed in 1880 by Sir G. G. Stokes, Bart., F.R.S., to give a measure of the strength of the wind during gusts, the maximum pressure of which is not always registered by a pressure tube anemometer. It was not designed to register light winds, and therefore it is unaffected by any wind of lower velocity than 20 miles per hour.

The portion of the instrument which is acted upon by the wind consists of five hemispherical copper cups, each of which is fixed by a short strong arm to a vertical spindle, around which they were originally placed equidistantly, and in the same horizontal plane. In 1890, however, the cups were re-arranged spirally to prevent any possibility of one cup sheltering another.

An indication of the wind force is obtained by attaching to the spindle two weights, which are raised by the rotation of the spindle under the action of the wind, the weights being sufficient to prevent the spindle from making one complete rotation, even in the strongest wind. The weights are suspended by flexible cords, which pass over pulleys and attach to the root of two snails carried on the spindle, the cord being wound upon the periphery of the snails as the cups turn. Below the spindle, and coaxial with it, is a cylinder which carries the record and also forms the driving weight of the clock, by which its descent is regulated.

The pen is carried on an arm of the spindle, each motion of which causes the pen to sweep round the cylinder and trace a record of the corresponding wind speed. In this way, the horizontal ordinates give a measure of the force of the wind, and the abscissæ of the trace become the time-scale.

(*See* "Report of the Meteorological Council," 1898, p. 28.)

Inv. 1912–195, S.M. 1451, L.S.

155. PRESSURE DISTRIBUTION APPARATUS. Designed and lent by R. H. Curtis, Esq.

This apparatus was designed by Curtis in 1881 for determining the distribution of wind pressure upon flat surfaces exposed perpendicularly to the wind.

The plates used for the purpose were pierced with holes half an inch in diameter, and situated at known distances from the centre, where there was a similar hole called the "standard." In making an observation all the holes except the "standard" and the hole to be compared therewith were closed by means of plugs, inserted from the back, and fitting flush with the front surface of the board, so as to make it continuous. Into the two open holes brass nozzles were then inserted from the back; and these were connected by india-rubber tubes with two graduated glass tubes standing vertically in a glass jar containing water. The face of the board being presented to a current of air a depression of the water was caused in the glass tubes; and the observation was made by noting the amount of this depression in the two tubes at the same moment. Experiments were made with square surface of 1, 1·2, 6·25 and 16·0 sq. ft. area respectively, and with a circular surface of 2 sq. ft. area. From the mean results obtained, the distribution of pressure over the surface was determined; and shown graphically by means of lines drawn upon diagrams representing the surface experimented upon.

(*See* Q. J. R. Met. Soc., Vols. VIII. & IX.) Inv. 1893–120.

156. DYNAMIC ANEMOMETER. Lent by W. H. Dines, Esq., F.R.S.

This apparatus was designed and constructed by Mr. Dines about 1890 for determining the pressure of the wind on an inclined surface, and is intended to be revolved by some form of whirling machine.

When carried round by the machine, the pressure of the air is balanced by the centrifugal forces upon the two horizontal bars. Of these the larger is adjusted by hand and clamped, but the final adjustment is effected by the automatic action of the smaller bar. The pressure board is inclinable, and the lever which carries it can be set at any angle with the help of the graduated arc, to which, when used for observations, it is clamped. This arc is connected by an arm and stud with the pivoted frame carrying the two horizontal bars in such a way that the movement in a vertical plane of the lever produces a movement in a horizontal plane of the bars. This allows a pulley to act through a crown wheel, pinion and rack on the smaller bar, which is carried along until equilibrium is established between the wind pressure and the centrifugal force. The pressure is then determined from the positions of the bars, as shown by their graduations.

(*See* Proc. Roy. Soc., 1891, p. 233.) Inv. 1898–32.

157. SHOT WIND-PRESSURE GAUGE. Lent by W. H. Dines, Esq., F.R.S.

This instrument is specially designed to measure the maximum wind pressure. The upper receptacle is filled with shot, which falls through the hole at the bottom, until the weight of the shot in the lower vessel is equal to the pressure of the wind on the plate.

As soon as this occurs, the plate moves forward, and at the same time closes the opening. On the occurrence of a stronger gust of wind, the plate is forced back, the hole is opened, and shot falls through until equilibrium is again obtained.

To read the instrument, the plate is fastened in its forward position by the catch on the upper receptacle, and the shot is then withdrawn from the lower receptacle and weighed, or, preferably, measured in a glass which has been tabulated once for all. The weight of shot gives the maximum pressure which has occurred since the instrument was last set. Inv. 1893–162.

158. PORTABLE PRESSURE-TUBE ANEMOMETER. Lent by L. Casella, Esq.

This instrument was designed by W. H. Dines during the last decade of the nineteenth century, and is particularly suitable for use at sea.

In making observations, the tube is drawn from its case, and using the latter as a handle, held in a vertical position with the nozzle facing the wind. The height to which the liquid rises in the tube then indicates on the scales the velocity of the wind in miles per hour, and its pressure in pounds per square foot. The instrument is very compact, and is calibrated to read accurately the velocity and force of the wind. Inv. 1896–65.

VELOCITY TYPE ANEMOMETERS.

159. D'ONS EN BRAY'S ANEMOMETER. Lent by R. B. Prosser, Esq.

This instrument, which was designed by D'Ons en Bray in 1734, is the earliest registering anemometer with clockwork gearing of which we have any distinct account, and to some extent resembles Dinglinger's apparatus of 1720.

The instrument consists essentially of four portions, a clock movement, a dial for indicating direction, and apparatus for recording direction and velocity respectively. A vane on one side of the instrument is connected by simple gearing to the indicating dial, and so registers the wind direction. The motion of the vane is communicated to a recording apparatus, and the appropriate one of a series of thirty-two pencils, corresponding to the points of the compass, is caused to record the direction on a travelling strip of paper.

The velocity of the wind is obtained from the rotational speed of a drum fitted with vanes and driving the recording apparatus through intermediary gearing.

(*See* Histoire de l'Acad. Roy. des Sci., 1734, p. 123.) Inv. 1892–139.

160. CACCIATORE'S ANEMOMETER. Presented by Prof. G. Cacciatore.

This instrument was designed by Niccolo Cacciatore in 1832, for indicating the velocity and inclination of the wind.

(*See* Annuario della Societa Meteorologica Italiana, Vol. 1, p. 121.)

Inv. 1876–730.

161. WHEWELL'S SELF-REGISTERING ANEMOMETER. Lent by The Admiralty.

This instrument was designed by Whewell in 1834, and was in use at the Greenwich Observatory from 1843 until 1862, when it was superseded by Robinson's cup anemometer.

At the top of a case containing an upright cylinder marked for the points of the compass, is placed a horizontal circular plate, to which is attached a wind vane and a fly of eight fans. Connected to this plate, but contained in the case, is a vertical screw of some 15 in. long, which is set parallel to the cylinder and carries a nut to which is fastened a pencil. As the horizontal circular plate, by the action of the vane, turns with the wind, the pencil is carried round the cylinder, and the direction of the wind shown from the position of the pencil trace with regard to the compass points.

In addition to being carried round, the pencil descends, for the fly being revolved by the wind, turns the vertical screw through the action of the intervening wheelwork, and the pencil carrier is lowered. The time being known during which the wind has been blowing in any particular direction, the velocity of the wind can be ascertained from the length of the trace made by the pencil in its descent.

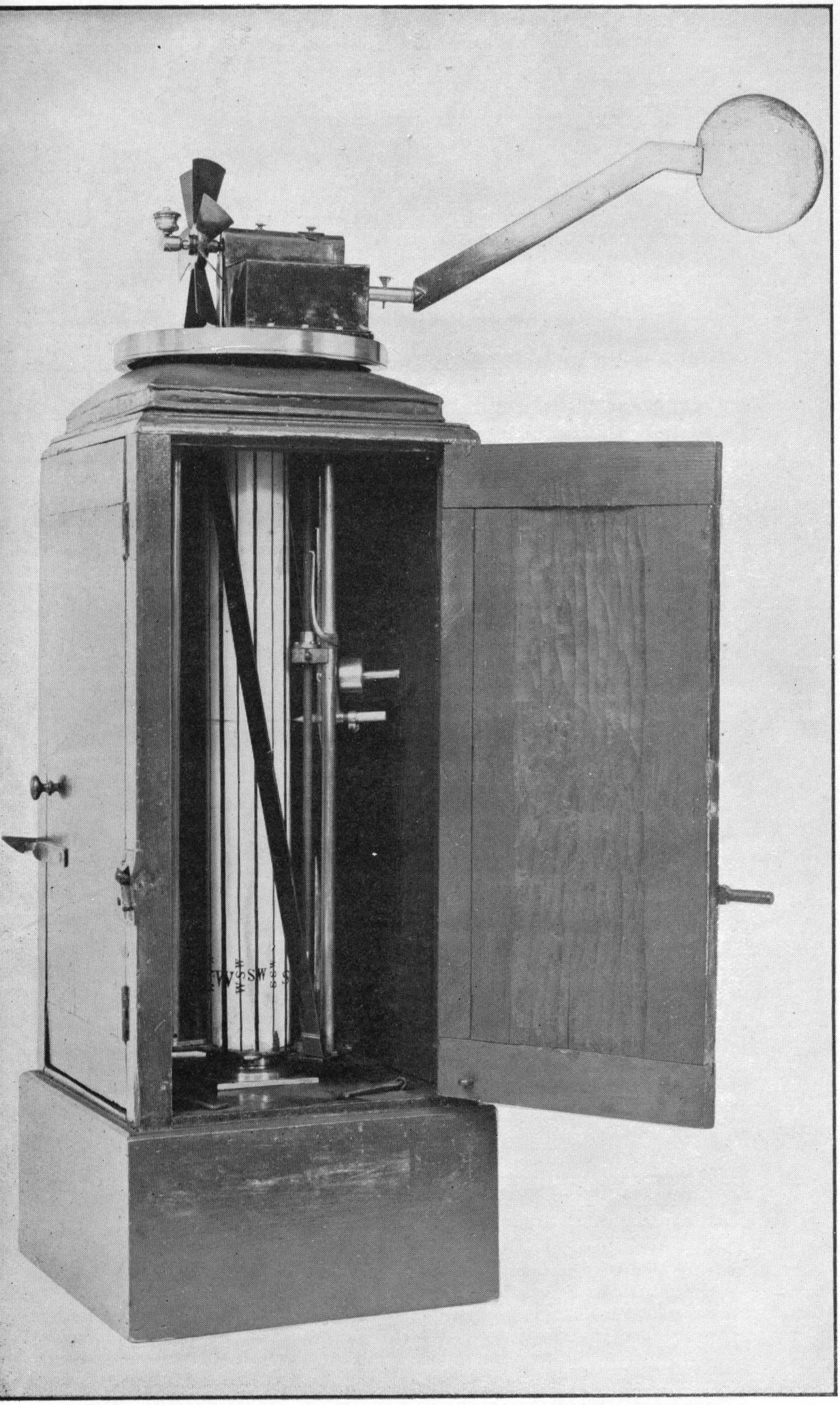
(*See* Brit. Ass. Rept., 1837, Vol. 2, p. 32, and Knight's English Cyclopaedia, 1840, Vol. 1, p. 158.) Inv. 1893–166, S.M. 1452, L.S.

162. ROBINSON'S CUP ANEMOMETER. Lent by Messrs. F. Darton & Co.

This instrument, embodying the hemispherical cups first used by Robinson in 1846, is designed for registering the wind, and is graduated in miles and tenths to 500 miles.

The rotation imparted to the cups by the wind is transmitted by a vertical rod to a hozirontal spindle furnished with an endless screw which gears with two worm wheels set together behind the dial. With the front wheel, the dial revolves, and with the hind wheel, the long index hand turns. The dial is graduated on its inner circle from 1 to 5 miles, and a reading is taken by the short stationary pointer above it. The outer circle has 100 divisions to represent each 5 miles to 500, the long hand serving as index. This latter indication results from the different rates of revolution of the two wheels. On each complete revolution of the dial wheel the index wheel falls one tooth behind, consequently the hand which moves with it falls one space behind on the dial and thus is apparently advanced one graduation. In this way the 5 miles shown by a complete revolution of the dial are recorded. Inv. 1876–850.

PLATE V.



Whewell's Self-Registering Anemometer.

163. ANEMOMETER. Lent by Messrs. F. Darton & Co.

This instrument, which is of the form first made by Biram in 1843, was designed specially for determining the velocity of air currents in mines.

It consists of a series of inclined vanes fitted with a registering apparatus, and mounted in a circular brass ring of 6 in. diameter. Inv. 1876–850.

164. ANEMOMETER. Lent by Messrs. Pastorelli & Co.

This anemometer of the Biram form is used in regulating the ventilation of mines.

It is similar in design to the adjacent instrument, but is smaller, having a diameter of 2·5 in. Inv. 1875–32.

165. ROBINSON-BECKLEY ANEMOGRAPH. Presented by The Meteorological Office.

This instrument is of the type designed by Mr. R. Beckley at the Kew Observatory in 1856, for indicating simultaneously on two sections of the same chart the velocity and the direction of the wind.

In this anemograph, Robinson's method of measuring the velocity of the wind by the rotation of a system of hemispherical cups is employed, while the wind direction is indicated by Osler's type of double wheel fan, which acts as a directing vane. A stout tubular support carries the whole of the external part of the apparatus, while a ball-bearing head reduces the friction to a minimum. As the cups are rotated by the wind, motion is given to a tubular shaft passing vertically downwards through the body of the apparatus to an endless screw which operates a worm-wheel, whence it is communicated to a brass spiral which forms the velocity recording device. Any change in the direction of the wind produces a movement of the fans, which is similarly communicated through the body of the instrument to the thin-threaded screw which records direction.

The chart, which is revolved by clockwork, is divided into two sections, upon one of which is recorded the motion of the wind and upon the other its direction.

(*See* Brit. Assoc. Report, 1856, II, p. 38, and 1858, i, p. 306.)
Inv. 1921–377.

166. LOWNE'S AIR METER. Made by Casella.

This portable magnetic instrument, designed by Mr. P. M. Lowne in 1874, is a modification of the anemometer which was devised and patented in 1842 by Mr. B. Biram.

It consists of a fan, the wheel of which is 2·5 in. diameter, and has eight aluminium vanes. The axle is connected directly to the counter, which is carried horizontally by the stand on which the fan and its guard are supported. The connection with the counter has the usual disengaging motion.

(*See* Q. J. R. Met. Soc., Vol. 2, 1874, p. 285.) Inv. 1914–920.

167. FAN ANEMOMETER. Lent by The Meteorological Office.

This fan anemometer, which is a development of Richard's model, is designed for use on kite balloons, and is arranged to give electrical contacts similar to those of the electric cup anemometer.

It consists of a light eight-vaned fan, mounted on a horizontal shaft, which drives a vertical shaft by means of bevel gearing. The upper end of this shaft rotates another parallel shaft carrying a cam, which actuates one end of a pivoted lever, causing a platinum point at the other end to make and break contact, so completing or breaking the electric circuit.

A table is provided by means of which the wind speed can be determined from the number of contacts per minute, the contacts being indicated by a telephone which may be situated either in the kite balloon or on the ground.
Inv. 1919–514.

168. SELF-TIMING ANEMOMETER. Lent by Messrs. Davis & Son, Derby.

This instrument is designed to enable the velocity of an air current to be ascertained without the use of a watch.

In taking observations the anemometer is exposed for a few seconds facing in a down-wind direction and the spring plunger pushed in. The position then taken up by the index indicates the velocity of the air current in feet per second. When more than one complete revolution of the index has been made the inner scale of graduations must be read.

To release the plunger, and to bring the index back to zero, the screw with milled head is employed. Inv. 1893–122.

169. SELF-RECORDING WIND COMPONENTS INTEGRATOR Lent by W. Spottiswoode, Esq., F.R.S., and Warren de la Rue, Esq., F.R.S.

This modification of the Robinson cup anemometer was designed in 1876 for indicating the mean velocity of the wind from the various points of the compass, by Dr. Arthur von Oettinger, Professor at the Imperial University of Dorpat, Russia.

In this apparatus the wind moves a system of hemispherical cups, acting on a circular plate, the velocity of which is ordinarily proportional to the velocity of the wind. Four systems of sliding rollers rest on this plate, whose bearings can be moved round a vertical axis, the principal planes of which follow the variations of a wind vane. Each sliding roller can revolve about a horizontal axis, but only in one direction, and after a half rotation an electrical contact is made the contact being limited to a fraction of a second. When the contact is made, one of four wheels, with number-types, is moved, and every half hour the position of these four wheels is shown by printed numbers on a strip of paper. The differences of these readings represent the mean velocity of the wind from the N., E., S. and W., and are converted into absolute values by means of a table. Different mechanism adjusts the position of each sliding roller.

(*See* Repertorium für Meteorologie, Vol. V.) Inv. 1876–838.

170. INTEGRATING ANEMOMETER. Presented by The Royal Society.

This instrument which was designed by Walter Bailey, F.R.S., in 1884, is somewhat similar to the integrating anemometer of Dr. A. von Oettingen, the records being obtained from wheels revolved by the friction of a plate turned by the wind.

There are two spindles, one to support the Robinson cups, and transmit their movement to the circular plate on which the recording wheels rest, the other for the vane to change the position on the plate of the two recording wheels in accordance with the direction of the wind. That this change may be readily effected, the wheels are connected to small carriages which run between tramlines on a plate placed parallel to, and above that which revolves.

By the method of connection with the direction spindle, one wheel turns when the wind is at either of the four chief points of the compass, in intermediate directions, as N.E., S.S.W., both are turned. As the speed of the revolving plate is ordinarily proportional to that of the wind, a measure can be obtained of the velocity of the latter from the number of revolutions of the wheels. The recording is effected by an electrical contact made at each turn of the wheels, which allows a current to actuate a set of counters. These counters are contained in a box, and are connected with the instrument by wires to the binding screws which represent the N., S., E., and W. points.

The value of the records can be determined either by measurement of the instrument or by direct experiment.

(*See* Phil. Mag., June, 1884.) Inv. 1889–64.

171. ANEMOGRAPH WITH RAIN GAUGE. Photograph presented by Prof. Palmieri. Naples.

This is a modification of the Robinson cup anemometer and was designed by Prof. Palmieri in 1886. Inv. 1877–436.

172. GALTON'S HAND ANEMOMETER. Lent by The Meteorological Office.

This instrument was designed by Mr. Francis Galton for determining wind velocity at sea, in order that the records of the force of the wind kept in log books might be obtained by a uniform method of observation.

It is a small portable arrangement of Robinson's cups with a dial which reads to 45 miles per hour. Attached to the frame of the instrument is a sand glass which empties in two minutes. The sand glass is connected at the back of this frame with the dial, so that, on its being turned to allow the sand to run out, the dial is put in gear with the screw of the spindle of the cups, but on reversal of the glass is thrown out of gear. In this way the velocity of the wind as indicated by a short period of exposure is registered. Inv. 1894–116.

173. ANEMOMETER. Lent by G. T. Kingston, Esq.

This instrument was devised to reconcile adequate exposure of the hemispherical cups with accessibility of the dial of the Robinson cup anemometer. It was specially designed and constructed for stations of the second and third order connected with the Meteorological Office of the Dominion of Canada.

The anemometer is fitted with a shaft, the length of which can be adjusted to suit different stations and with a dial reading to 10,000 miles. It consists of a short spindle bearing a small set of Robinson's cups and connected with a horizontal cogged wheel resting on friction rollers, also with a long shaft suspended from its centre, as in the anemographs of the British observatories. It is contrived so that the shaft may make 101 complete turns for 200 miles of wind. The mode of recording the miles is as follows:—At the lower end of the shaft is an endless screw which acts on the circumferences of two toothed wheels of equal diameter, turning in vertical planes about a common axis, and having 100 and 101 teeth respectively. From the centre of the back wheel (that of 100 teeth) projects forwards a short hollow pin which encloses and works on a solid pin fixed to a support behind the back wheel. The front wheel (that of 101 teeth) which turns on the above-named hollow pin, and slides closely on the face of the back wheel, has a graduated ring on its face, containing 100 divisions. The outer ends of the lines of graduation indicate miles, while the inner ends of the same lines, reckoned in the reverse order, indicate hundreds. The endless screw, at every turn, causes both wheels to advance two teeth, so that for 100 miles the front wheel makes one complete turn, or 100 divisions, while the back wheel makes one complete turn and one tooth, and thus advances one division with respect to the front wheel. The miles up to 100 are shown by a fixed pointer, and the hundreds by a pointer attached to the end of the hollow pin. For fractions of a mile there is a contrivance which needs adjustment at each observation. A correction of 1 per cent. nearly, should be subtracted from the fractional parts.

If the anemometer be too distant from the observer's office to allow the dial to be read conveniently with the required frequency, it may be connected electrically with a dial or with a self-recording apparatus, but in such a case the master dial should be read periodically as a check on the electrical dial.

Inv. 1876–784.

174. RUSSELL'S HAND ANEMOMETER. Presented by Capt. Sir D. Wilson-Barker, R.N.

This instrument is a Robinson cup type of anemometer modified for portability about 1891 by Russell, of Sydney, N.S.W. It is designed for use in the hand so that the force of the wind may be measured at any time.

It consists of a series of hemispherical cups mounted on a vertical shaft which is geared to a disc. A sand glass is provided, the period of which is two minutes, and the number of revolutions of the disc during this period is noted. One revolution of the dial indicates one-tenth of a mile of wind, and the subdivisions hundredths.

(*See* Qt. Jr. Met. Soc., Vol. IX, 1883, p. 241.) Inv. 1921–149.

175. HIGHEST RECORDED WIND VELOCITY. Lent by The Meteorological Office.

This record, which is a reproduction of one made at Fleetwood on Dec. 21st and 22nd, 1894, shows the highest wind velocity record obtained with the Robinson Anemometer for surface winds.

The upper curve shows the direction of the wind, which changed from W. through S.W. to S. and back again to W., with a sudden change between 2 and 3 a.m. on the 22nd from S. to W.S.W. The lower curve shows the space actually travelled by the cups of the anemometer. Thus between 11 a.m. and 3 p.m. on the 21st the distance travelled was about 60 miles, giving an average velocity of 15 miles per hour during this period. The increasing steepness of the lines indicates the increasing velocity of the wind. The average velocity between 4 a.m. and 11a.m. on the 22nd was about 94 miles per hour, while at certain times during the period the velocity was well over 100 miles per hour. Inv. 1915–359.

PRESSURE AND SUCTION ANEMOMETERS.

176. WINDMILL VANE. Lent by G. T. Kingston, Esq., *M.A.*

This instrument was designed by Mr. Kingston about 1876, to determine wind direction only, and to meet the case when a vane, if suitable exposed, is too distant to admit of being connected by a shaft with a dial in an inaccessible position. It was devised and constructed for stations of the second and third orders in connection with the Meteorological Office of the Dominion of Canada.

The instrument consists of a flat brass ring surrounding the step of the vane and attached to the bottom of a box. This ring is divided by radial lines into four equal parts corresponding to, but not necessarily in the direction of, the four cardinal points, and separated by small equal intervals. The direction arcs (as they may be termed) are insulated except as regards connexion with their screw cups. Clamped to the spindle, and capable of adjustment in azimuth, is a circuit maker, which consists of an arm bearing a brass arc, which is made to press on the flat brass ring. The length of this arc is 45° + interval between the fixed arcs. The step of the vane is connected by wire with one pole of a battery, and the direction arcs with four screw cups in near proximity to a brass plate fastened to the wall of the office, and so contrived that, by aid of a plug, metallic connexion may be made at will between the brass plate and any one of the four wires. Finally, two wires from the poles of a small telegraph sounder are attached to the brass plate and to the other pole of the battery, and the apparatus is complete. To ascertain the direction of the wind, notice by the sounder which direction arcs or pairs of arcs is placed in circuit as the brass plate is connected by the plug with the four wires in succession. If, for instance, N. only sounds, the direction is nearer to N. than either to N.W. or N.E., unless it be N.N.W. or N.N.E. exactly, but if N. and E. both sound, the direction is nearer to N.E. than either to N. or E. unless it be N.N.E. or E.N.E. exactly. The azimuth of the vane box need be governed only by appearance and the position of the door. To adjust the vane, unclamp the circuit maker, and insert a pin provided for the purpose, through the holes at the middle point of the circuit maker and the arc at the left of the box, which arc may represent any one of the four cardinal points. Turn the vane to that point, clamp the circuit maker, and remove the pin, when the adjustment will be complete. The apparatus works well with a single gravity cell, when the vane is 60 ft. or more from the battery and sounder. With a stronger battery it works well at the distance of a mile or more. Inv. 1876–785.

177. HAGEMANN ANEMOMETER. Lent by The Meteorological Office.

This is a differential pressure anemometer in which the effects of pressure and suction, caused by air passing two differently disposed orifices, are added to produce an increased movement of a column of liquid.

The instrument consists of a U tube containing liquid with the two branches lying parallel and close together. The upper end of one of the tubes terminates in a brass nozzle having a small hole at its extremity. The other tube carries a brass elbow, the end of which is slightly conical. The anemometer is placed with the horizontal arm of the elbow facing in an upwind direction, so that the pressure of the air in the elbow and attached tube is increased.

The effect of the wind on the orifice of the vertical tube is to create a suction in this tube. The two effects augment each other, and the liquid column rises in the suction tube and falls in the pressure tube. The difference in the vertical height of the liquid in the two branches which is due to the effect of the wind is measured by a moveable scale, from which the velocity of the wind can be read, as well as the corresponding Beaufort number. Inv. 1917–29.

178. HAGEMANN'S HAND ANEMOMETER. Presented by Capt. Sir D. Wilson-Barker, R.N.

This anemometer is a modification of Hagemann's original instrument and was introduced about 1881 by Mr. R. T. L. Ellery, F.R.S., Government Astronomer at Melbourne, for use at sea.

The instrument which was used for several years by the donor, consists of a U-tube mounted before a graduated scale on a wooden frame. It is held with the mouth of the shorter tube in an upwind direction, when the difference of level of the liquids in the two tubes was observed.

The readings obtained with this instrument were smaller than those obtained with a cup anemometer.

(*See* Q. J. Met. Soc., Vol. IX, 1883, p. 241.) Inv. 1921–148.

179. AIR-SPEED INDICATOR. Lent by The Meteorological Office.

This type of air-speed indicator, designed by Col. Alec Ogilvie, is used on kite balloons for determining wind speed.

It comprises an "Ogilvie" head, consisting of a pressure and static tube and an indicator connected thereto. The head of the instrument is placed in an upwind direction, so that air in the inner tube becomes compressed by the pressure of the wind, while that in the outer tube is reduced in pressure by the rush of air past the annular ring of holes.

The pointer of the indicator moves over a graduated scale, and is actuated by the motion of a diaphragm separating two chambers connected respectively with the two tubes of the head.

(*See* also "Air Speed Indicators" in Aeronautics Section.) Inv. 1919–513.

180. DINES'S PRESSURE TUBE ANEMOMETER. Presented by The Admiralty.

This instrument, which was designed by Mr. W. H. Dines for recording the velocity of the wind, is the outcome of a long series of experimental investigations into the relations between the velocity and pressure of the wind, carried out at Horsham in Surrey during the years 1887 to 1894.

The anemometer consists of two independent parts: the head, which is the part exposed to the wind, and the recording apparatus, which may be set up in any convenient place indoors, the two portions being connected together by flexible metal tubes.

The head consists of a vane formed of a horizontal tube open at one end, and pivoted upon the top of a vertical tube into which it leads. The vane is kept in position with its open end facing the wind, and every increase in wind pressure causes a corresponding increase of the pressure in the vertical or pressure tube. Just below the vane this vertical tube is surrounded by another one of much larger diameter, the exterior of which is perforated by four rings of holes placed close together around its circumference. As the wind passes across these perforations, the air in the tube is sucked out, so that a diminution of pressure results in this tube, which is called the suction tube. The recorder consists of a float, which is a specially-shaped cylindrical copper vessel, closed at one end and inverted in a vessel partially filled with water, and sealed from the air in the room. The interior of the float is in connection with the pressure tube, while the suction tube is connected with the top of the closed vessel containing the float. The two forces thus act together, but in opposite ways, to raise the float in the water.

To the top of the float is fixed a rod which carries a pen, the point of which rests against a sheet of paper attached to a drum which is rotated by clockwork. With every upward or downward movement of the float, corresponding to an increase or decrease of wind force, the pen leaves a trace upon the paper, and thus the magnitude of every variation of the strength of the wind is graphically registered, together with the time of its occurrence. Inv. 1911–163.

181. DINES'S PRESSURE-TUBE ANEMOMETER WITH DIRECTION RECORDER. Made by R. W. Munro. Lent by The Meteorological Office.

This instrument, of which the head, new type of vane, and recorder are shown, was designed by Mr. W. H. Dines for recording simultaneously the direction and velocity of the wind.

The vane, which is exhibited above the case, is mounted on the head of the instrument, and is arranged to operate the direction recorder. The connections to the pressure and suction tubes are located on opposite sides of the head, so that they may be separated in order to avoid trouble with snow.

The direction recorder, which is of the Meteorological Office pattern, consists of two recording pens actuated by a helix mounted on a vertical shaft, and giving a record on the same chart as the Pressure Tube Anemometer. Whenever the wind changes in direction from N.W. to N.E., the roller on the arm of the upper pen moves on from the helix and the pen is put out of action, while the lower pen is similarly put out of action when the wind changes from N.E. to N.W.

Inv. 1919–.

182. DRAWING OF DINES'S PRESSURE-TUBE ANEMOMETER. Prepared in The Museum.

This drawing indicates the general arrangement of the instrument, showing the internal construction and the method of operation. Inv. 1921–258.

183. RECORD FROM THE DINES'S PRESSURE-TUBE ANEMOMETER. Lent by The Meteorological Office.

This is a reproduction of the record made at Pendennis Observatory on 14th and 15th March, 1905.

It will be noticed that very high velocities were reached during the hours before midnight on the 14th, the highest being 103 miles per hour at 11.30 p.m.

Inv. 1915–360.

184. ROTCH'S WIND INSTRUMENT. Lent by Messrs. C. F. Casella & Co., Ltd.

This instrument was devised by Mr. A. Lawrence Rotch for determining the true direction and velocity of the wind at sea.

It consists of two brass discs of 3 in. diameter, marked with the cardinal points of the compass, each quadrant being divided into 90°, beginning at north and proceeding in a right and left-handed direction to east and west respectively. One of these discs is pivoted near the end of a boxwood rule, 10 in. long, having 30 divisions, and stamped "ship moving," with an arrow pointing away from the pivot. On this pivot there is also mounted, near one end, a similar rule, about 17 in. long, containing 60 of the above divisions, and marked "true wind," with an arrow directed away from the pivot. A brass slide upon the short rule carries the other movable disc, and also another pivoted boxwood rule, likewise divided into 60 parts, and marked "resultant wind," with an arrow head away from its pivot. Sights are attached to the pivots and to the outer ends of the long rules, and a handle screws into the back of the fixed disc.

In using the instrument the discs are rotated until they indicate the true course of the vessel on the "ship moving" rule, and the slide is placed on the graduation representing the speed of the ship. This "ship moving" rule is then sighted along the fore and aft direction of the ship, and the "true wind" rule turned until its sights are normal to the advancing wave crests, when the short end of this rule will indicate on its graduated disc the direction from which the wind comes. The "resultant wind" rule is now sighted to coincide with the direction of the receding line of smoke, when the velocities of the true wind and the wind experienced on board may be read off on the two long rules.

Inv. 1921–312.

RAIN GAUGES.

The earliest mention of an instrument for the measurement of rainfall dates from 1442, when, according to the ancient records of Korea, bronze instruments were constructed for this purpose.

In this country the earliest scientific instrument for indicating the rainfall was devised by Sir Christopher Wren about 1662, and was fitted with a tipping bucket, which served as a record.

Previously, no special instrument for the local measurement of rainfall had been produced, and the only available evidence was dependent on direct inference, such for example as the flood marks of valleys.

The first records of rainfall were made in Paris by Perrault in 1668, and the first in this country by Townley nine years later. Townley's gauge consisted of a funnel of 12 in. diameter, soldered to a leaden pipe through which the water flowed into convenient vessels, and was weighed. Great care was taken to ensure that the funnel was firmly fixed, and that no rain could trickle down the outside of the funnel into the receiver.

The next gauge of which details are available was designed by Hooke and used at Gresham College in 1695. It consisted of a glass funnel, of 11·4 in. diameter, mounted on a wooden frame, and leading into a large flask capable of holding about 2 gallons, and being provided with a long and narrow neck to minimise evaporation.

With this apparatus also the collected water was weighed, but this method is now resorted to only when extreme accuracy is required. Two years later Derham, at Upminster, employed a gauge which was similar in principle to Townley's, and similarly mounted.

As early as 1722 a close approach was made to the modern principle by Horsley in Northumberland, who used a large funnel, 30 in. in diameter, and collected the water in a cylindrical measure of 3 in. diameter and 10 in. deep, while a similar apparatus was employed by Abbot Didacus de Revillas at Rome in 1742.

Garnet in 1724 used a funnel bottle and jar, and attached a shield to prevent rain on the outside of the funnel running down into the bottle and being measured. Dalton also, in 1788, used a 10 in. diameter circular funnel leading into a glass bottle, the volume of the water collected being measured by a jar.

According to Leopold, a number of rain gauges were employed from about 1717 having a sharp edged glass funnel of about 4 in. diameter and graduated to indicate not the depth but the weight of water collected. Leopold, in 1726, also described a gauge of his own invention, which may be said to anticipate to some extent Crosley's instrument. He provided under the funnel a small bucket on one end of a balanced lever, which when full tipped and emptied, and in doing so moved a hand one division on a dial.

In 1744 Pickering proposed a gauge in which the funnel had an area of only 1 sq. in., and led into a glass tube of ½ in. diameter and about 2 ft. long.

Gauges of various dimensions have been proposed from time to time, the largest being more than 2,000 times the size of the smallest, but even in these extreme instances the indications did not differ by as much as 5 per cent. With gauges less than 3 in. in diameter, however, great care is necessary in measuring, while with those exceeding 10 in. in diameter the volume of water to be measured becomes inconveniently large and heavy.

It was found at an early date that a rim round the funnel of a rain gauge was an improvement, and among the gauges used in the eighteenth century, especially on the continent, there were several in which the funnel was surrounded with a vertical rim 6 in. high, but in England, until the introduction of the Snowdon pattern in 1864, the funnel usually reached almost to the top of the gauge. About the middle of the nineteenth century, Howard introduced a turned brass rim to form the top of the gauge, which by its solidity serves to preserve the shape of the funnel and prevent warping, while it also serves to define accurately the area within which rain drops are to be collected, and to cut any rain drop which falls upon it so that the correct proportion of the drop shall enter the gauge.

A float was first used to indicate the fall of rain in 1787 by Kite in a very complicated gauge which he used at Gravesend. This arrangement was soon adopted by others, and quickly came into general use, modifications of it being in use at the present time.

As already mentioned, the first rain gauge in which the collected rain-water was utilized to register its amount was designed by Wren about 1662. It was a wedge-shaped bucket, which, when filled to a certain height, tipped and emptied itself.

In 1724, a similar arrangement was described by Leutmann, and about one hundred years later, in 1827, Taylor made a gauge in which the water was led over a kind of water wheel with helical buckets. About 1829, Crosley modified Wren's bucket gauge and attached to it a train of wheels similar to those he had previously used for gas meters. In the following year this was followed by Horner's vibrating double bucket gauge, which is nearly identical with it. Later modifications were introduced by Halliwell and others, and modern recording instruments also embody this principle.

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185. KOREAN RAIN-GAUGE.

According to the Royal Diary of the Ri-dynasty of Korea, in year 24 of King Sejo (A.D. 1442), the King caused instruments of bronze to be constructed to measure rain. These were distributed to the provinces and cantons, and the results of the observations were forwarded to the Court. The instrument here represented dates from A.D. 1770 (year 46 of King Eijo), when it was erected at Taiku, a city in the interior of the southern part of Korea.

It consists of a bronze cylinder mounted on a granite pedestal on which are engraved three large Chinese characters, indicating that it is an instrument to measure rain, and seven small ones, intimating that the instrument was constructed in the fifth month of the cycle of the year, a date in the Chinese calendar corresponding to the year 1770. The early occurrence of the rain-gauge in Korea was probably a necessity owing to the importance of rain in the cultivation of rice.

(*See* Q. J. R. Met. Soc., 1911, p. 83.) Inv. 1922–157.

186. HOWARD'S RAIN-GAUGE. Made by Knight. Lent by H. L. P. Lowe, Esq.

This form of gauge was used by Luke Howard during the early part of the nineteenth century, and described by him in his "Climate of London" 1818.

In construction and design it is similar to more recent instruments, but differs in the method of graduating the measuring glass, a paper scale being used to indicate the rainfall, while, in later instruments, etched scales are employed.

Inv. 1902–86.

187. CROSLEY'S REGISTERING RAIN-GAUGE. Lent by L. Casella, Esq.

This instrument, which was devised by Crosley in 1829, is a modification of Wren's bucket gauge, and is fitted with a train of wheels similar to those used for gas meters.

It is a 10 in. square gauge, with oscillating bucket and a set of counters contained within the case. Each movement of the bucket caused by the weight of water conveyed alternately to its right and left halves by the gauge, is transmitted to the wheel-work of the counters by a lever acting between two projecting plates on the bucket. There are three counters for cubic inches, tenths and hundredths respectively. A pipette-shaped measure is supplied for testing the accuracy of the registration. This measure will contain 5 cub. in. of water, and its contents should, as the gauge has an area of 100 sq. in., advance the hand of the hundredths counter five divisions. Inv. 1893–159.

188. EAST INDIA COMPANY'S RAIN-GAUGE. Lent by G. J. Symons, Esq., F.R.S.

This instrument is a modification of the Crosley recording rain-gauge from which it differs chiefly in the recording arrangements.

In this gauge the oscillating bucket and the wheels for recording its movements are separated by a partition. The bucket, which is constructed to tilt with every tenth of a cubic inch of water, actuates a pin wheel of somewhat large diameter. The wheel is marked on its periphery by tenths from 1 to 5 cub. in., and as the vibrations of the bucket turn the wheel, the amount of rainfall within these limits can be read from an opening in the side of the case. For higher readings, a dial marked for 5 to 100 cub. in., which is in connection with the graduated wheel, is used. Inv. 1893–132.

189. RONALDS'S RAIN AND VAPOUR GAUGE. Lent by The Meteorological Office.

This instrument was designed and constructed at the Kew Observatory in 1843 by Mr. Francis Ronalds, for indicating a mean result from the quantity of water which may have fallen between any two given periods, minus the quantity of vapour which has evaporated in the same time on and from a circular plane of one foot diameter.

It consists of two cylindrical vessels, connected by a tube, the one being 1 ft. in diam., and open at the top, whilst the other is 3 in. and (with the exception of a small hole) entirely closed by a cover, which carries a frame, holding a circular divided arc, with an index moving over it. The index is attached to a small pulley, over which a cord passes, having its end fixed to the float in the cylinder. This, rising and falling with the changes of water level, indicates the amount of rain or evaporation on the metal scale.

(*See* Brit. Assoc. Rept., 1844, p. 128.) Inv. 1876–797.

190. RAIN RECEIVER. Lent by G. J. Symons, Esq., F.R.S.

This type of receiver, which is made of stoneware instead of glass, was introduced by Casella about 1850, with the view of reducing the frequency of breakages. Inv. 1893–126.

191. GLAISHER'S RAIN-GAUGE. Lent by Messrs. Pastorelli & Co.

This is an example of an early type of rain gauge designed by Glaisher.

It consists of a cylinder of 8-in. diam., containing a funnel to the lower end of which was fitted a U trap. The receiver is fitted with a tap, through which the rain water is drawn off into the graduated measuring glass. Inv. 1860–35.

192. SNOWDON RAIN-GAUGE. Lent by Negretti and Zambra.

This is an example of the standard 5-in. Snowdon rain-gauge which, according to experiments of Mr. G. J. Symons, F.R.S., gives practically the same results as an 8-in. gauge.

It consists of a cylindrical receiver of copper, containing a deep funnel, by which means the rain is led into a collecting can contained within the lower portions of the instrument. The receiver is fitted with a stout and accurately turned brass rim, which ensures the entrance remaining circular. A glass bottle, graduated in ½ in., is provided, and also a graduated glass measure, which enables a more accurate reading to be taken. Inv. 1908–192.

193. SYMONS SNOWDON GAUGE. Lent by L. Casella, Esq.

This type of gauge was designed in 1864 by Symons, for use in the district round Snowdon.

It is provided with a Snowdon rim consisting of a cylinder rising 4 in. vertically from the edge of the cone of the funnel, which is suitable for the collection of snow. A collecting bottle and pail are provided together with a measuring jar which is graduated to 0·50 cub. in. Inv. 1893–151.

194. BRADFORD WATER WORKS GAUGE. Lent by L. Casella, Esq.

This gauge was designed by Sir Alexander R. Binnie for use on the gathering grounds of the Bradford Corporation.

It is a five-inch gauge 24 in. in length, with a cylinder above the funnel, and fitted with a Snowdon rim. The cylinder is found of advantage in obtaining more accurate measurements, especially in the case of snowfall. The collecting pail will hold about 15 cub. in., and the measuring jar is graduated to 1·00 cub. in. Inv. 1893–150.

195. RAIN-GAUGE. Lent by Messrs. F. Newton & Co.

This common form of rain-gauge was designed to enable a rough estimate of rainfall to be made.

It consists of a copper funnel, which serves to collect the rain water and lead it into a receiving bottle. A graduated measuring glass is provided which enables the quantity of water to be measured and the rainfall to be determined. An evaporating pan is also supplied. Inv. 1865–4.

196. RAIN-GAUGE. Lent by Messrs. F. Darton & Co.

This simple form of gauge is designed for obtaining an approximate indication of the rainfall.

It consists of a funnel fitted to the neck of a receiving bottle, care being taken that the water running down the outside of the funnel is not collected in the receiver. The water collected is measured in the graduated glass provided. Inv. 1876–772 & 1876–852–3.

197. RAIN-GAUGE. Lent by Messrs. P. Harris & Co.

This rain gauge is designed for approximate determination of rainfall.

It resembles closely No. 196, and consists of a funnel, receiving bottle and measuring glass. Inv. 1888–129.

198. RAIN-GAUGE. Lent by Prof. H. Möhn, Christiania.

This type of gauge, designed by Prof. Möhn, was used during the latter half of the nineteenth century at meteorological stations belonging to the Norway Meteorological Institute.

The instrument, which exposes a square surface, 15 by 15 cm. and has a height of 60 cm., is designed for catching snow, while the lower part is protected against evaporation. The rain (or melted snow) water is to be poured out of the gauge through one of its upper corners, into a measuring cylindrical glass, divided to show the height of fallen rain in millimetres. Inv. 1876–779.

199. SYMONS STORM-GAUGE. Lent by The Meteorological Office.

This instrument, which was used by the British Rainfall Organisation for over 30 years, is designed to enable observers to ascertain the most minute details of heavy rain during thunderstorms, and is not intended for yielding continuous records. With one of these instruments in London, on June 23rd, 1873, rain was ascertained to be falling for 30 seconds at the rate of 12 in. an hour, or 288 in. a day. It is the second type of storm gauge designed by Symons, and is much stronger than the earlier form.

The rain passes into a copper cylinder in which is a float, which rises as the rain falls. The float has a string passing round a pulley and kept tight by a counterpoise and therefore when the float rises, the pulley turns. At the extremity of the axle of the pulley there is fixed a hand similar to the minute hand of a clock, and the size of the parts is so arranged that this hand completes a revolution when one inch of rain has fallen. Inside the case there is a very simple wheelwork, whereby another short hand, like the hour hand of a clock completes a revolution for five inches. With this gauge it is therefore quite easy to read from a window the fall of rain to hundredths of an inch, and by doing this, say every 30 sec., full details of the fall of rain can be ascertained. Inv. 1921–261.

200. RAIN AND SNOW-GAUGE. Lent by J. Sidebotham, Esq., F.R.Met.Soc.

This instrument was invented in 1879 by Mr. Sidebotham for the determination of the fall of snow.

It is an eight-inch gauge with its lower part surrounded by an external jacket. Warm water is poured into the angular tube, and when the snow, with which it is never in contact, in the funnel is melted, the water is run off by the tap, and if needed, a fresh supply is added. By this arrangement any mistake from adding a wrong quantity of water is impossible.

The collecting can is protected by a box with glass front, which encloses also the lower part of the gauge. The measuring jar is graduated to 0·50 cub. in. Inv. 1893–115.

201. SEATHWAITE RAIN-GAUGE. Made and lent by Messrs. Negretti and Zambra.

This gauge was constructed under the directions of Dr. H. R. Mill especially for use in outlying districts, where the instrument is visited at long intervals only.

It is arranged so that a large quantity of water may be collected from a 5-in. funnel, as advocated by the British Rainfall Organisation, in a receiver of 8 in. diam.

The water is collected in the usual type of bucket having a capacity of 30 in. of rain, and is protected from frost and evaporation by an insulated casing surrounding it, which is sunk in the ground up to its junction with the conical funnel. In order to ascertain the rainfall by this instrument, the funnel is removed and the approximate depth of water in the bucket ascertained by means of the graduated cedar rod. The dipper, which is a copper receptacle holding exactly 5 in. of rain, is used to remove the water, as far as possible, the remainder being emptied out and measured in the graduated glass cylinder.

Inv. 1921–589.

202. PRUSSIAN RAIN AND SNOW-GAUGE. Lent by G. J. Symons, Esq., F.R.S.

This apparatus was designed by Hellmann about 1885, and was used in the Prussian Meteorological Service.

It consists of a cylindrical chamber 6·25 in. diameter, fitted with a turned brass rim and provided at the lower end with a stop cock. It is constructed to be supported above the ground by means of a stake. Inv. 1893–127.

RECORDING RAIN-GAUGES.

203. ELECTRICAL SELF-RECORDING RAIN-GAUGE. Lent by Messrs. Yeates & Son, Dublin.

This gauge is similar in principal to Crosley's, but consists of two distinct parts, the gauge and the recorder.

The former, which is fitted with a funnel, is of square section and of 10 in. side. The rain collected by the gauge passes by the funnel to an oscillating bucket, so made and supported that the weight of a cubic inch will cause it to tilt to discharge its contents. This act of tilting is made use of to record the amount of rain received. The recorder has two dials, graduated to read to cubic inches and hundredths, and is supplied with a train of wheels, the movement of which is controlled by the armature of a pair of electro-magnets. The gauge, the recorder and a battery being connected by wires, the oscillation of the bucket completes the circuit, and the electro-magnets, acting by their armature, move forward the hand on the dial. A record of each 0·01 cub. in. of rainfall is thus obtained. The advantage of this system is, that the recording dials may be kept under cover and thus preserved from damage by exposure, while at the same time they may be readily consulted. Inv. 1893–121.

204. CASELLA RECORDING GAUGE. Lent by The Meteorological Office.

This instrument, which is of the balance pattern, was used by Dr. H. R. Mill, of the British Rainfall Organisation, at Camden Square, London, N.W., where it gave continuous records of the rainfall for more than thirty years.

The rain is received by a large funnel of 9·5 in. diam., whence it is conveyed by a curved pipe to a bucket attached to one end of an arm, and counterpoised by a weight at the other end. The arm carrying the bucket and counterpoise is suspended from two pillars, and is also connected by a linked parallel movement to the pencil or pen which records the rainfall on the drum of the instrument. As the rain enters the bucket, it depresses it and draws the pencil across the moving chart to a distance corresponding to the amount of water received.

When the bucket contains the correct quantity of rain (0·2 in. or 5 mm.) it automatically tips over, and the water flows away through an outlet pipe at the bottom of the gauge. After releasing its contents the bucket returns immediately to its former position, and provision has been made for the accumulation of the rain during the second or so in which the bucket is inverted, so that none is lost.

Inv. 1921–263.

205. HALLIWELL'S RECORDING RAIN-GAUGE. Lent by Messrs. Negretti and Zambra.

This has an 8-in. copper receiver, the funnel of which conveys the rain into a cylindrical vessel containing a float. Attached to this float is a vertical rod carrying a pen which, rising with the water in the receiver, records on a revolving drum the rate of rainfall.

By the action of a metal plate attached to the vertical rod the pen is made to fall when it reaches the top of the paper and is thus brought into position for a continuation of the record.

This work is effected by the pressure of the metal plate on a lever and the consequent bringing into position of a siphon-tube to empty the cylinder containing the rain.

By a rise of the float in the vessel into which the water drawn off by its action is emptied the siphon is brought back to its original position.

The paper on the drum is ruled for each 0·02 of an inch of rainfall, and the graduations range from 0·00 to 1·00. The driving clock is contained within the drum and is so arranged that two-hourly records may be taken for a week.

Inv. 1908–191.

206. HYETOGRAPH. Lent by The Meteorological Office.

This instrument which was patented by Mr. F. L. Halliwell in 1908, was designed to produce a continuous record of rainfall duration, and depends on the use of a siphon which is started by hand instead of automatically.

The rain falling into the funnel passes down the central tube into a chamber below the base plate. As the collected water rises in the chamber it lifts a float, to which is attached a vertical spindle provided with projecting studs, which engage with a plate attached to the pen lever. When the spindle has risen, an amount equivalent to 0·5 in. of rainfall, the pen arm disengages from the stud on which it was resting and falls until it is held by the next lower stud, so that at every half-inch of rainfall the pen returns to zero on the chart and begins its upward curve again.

The pen rises and falls while the rain is being collected until the container holds a maximum of about 4·5 inches. When about an inch or more of rain has collected in the chamber, it may be removed, very easily and conveniently, by lifting the pen arm and swinging it clear of the vertical spindle, which is raised about 2 in. and pressed down sharply, thus forcing water over the head of the siphon and putting it into action.

(*See* Patent Spec. 27,174, 1908.) Inv. 1921–76.

207. RECORDING RAIN-GAUGE. Lent by Messrs. Negretti and Zambra.

The gauge is constructed on the "tilting bucket" principle, and is designed to furnish a continuous record of the rainfall.

The rain entering the 8-in. funnel is led into one of the buckets, which tips over when 0·01 in. of rain has fallen, and the water is deflected into the other bucket. This motion is transmitted to a ratchet which by means of a cam, gradually raises the pen until 1 in. of rain has fallen. When this position is reached the pen returns to zero.

The chart is graduated to read 0·05 in. and under normal conditions makes a complete revolution in one week, but if a more open scale is required a different drum may be fitted which revolves once in 24 hours or once in 3·5 days.

Inv. 1921–322.

208. CONCENTRIC SIPHON RAIN-GAUGE. Lent by Messrs. C. F. Casella & Co., Ltd.

This instrument was designed in 1920, in order to furnish a continuous record of the rainfall.

Rain is collected by the funnel and led into a chamber carried by the lower portion of the apparatus. A float contained in this chamber is connected to a vertical rod which carries the pen, and the pen therefore rises as water collects in the chamber. To the side of the collecting chamber and in connection with it, is attached a small cylindrical auxiliary chamber up the centre of which runs a small tube reaching almost to the top. As water collects in the main chamber it rises also in the auxiliary one, until the float and the pen have reached their highest position, when the liquid in the auxiliary chamber overflows down the axial tube, which thus forms a siphon and removes the water until the pen and float have reached their zero positions again. The pen is made to record its motion on a chart carried on a revolving drum, and a continuous record of the rainfall is thus obtained. Inv. 1921–313.

EVAPORIMETERS.

209. EVAPORATION AND RAIN-GAUGES. Lent by G. J. Symons, Esq., F.R.S.

These instruments were designed by Dr. Dalton, F.R.S., and were used for nearly half a century.

They are circular copper vessels of 10in. diam. which by means of funnels deliver the rain into receivers set under the stand on which they are placed. The evaporation-gauge differs from that for rain in having within it an upright 0·5 in. tube, 4·5 in. in length, connected with the funnel tube. In use, this gauge is filled to the level of the top of this tube and placed at about 1 foot from the rain-gauge, both being set 3·5 in. above ground.

With dry weather evaporation causes the water to sink below the level of the top of the tube, and this loss has to be replaced before any water can pass into the receiver. If after a fall of rain a measure be taken of the contents of the receivers of both gauges, the difference will give the amount of water evaporated from the surface of the evaporation-gauge during the dry days.

(*See* Symons's "British Rainfall," 1869 and 1870.) Inv. 1893–130.

210. NEWMAN'S EVAPORATOR. Lent by H. L. P. Lowe, Esq.

This instrument is designed for measuring the quantity of water evaporated from a surface by the action of the atmosphere.

It consists of a metal reservoir, glass-graduated tube, and metal pan, which with their support form an instrument, 2 ft. 9 in. high. The glass tube is graduated, and a condensing syringe is fitted together with taps for regulating the water supply. The evaporating pan is of circular form, and has a diameter of 10 in.

To prepare the apparatus for use, water is poured into it, to the level of the zero of the scale. By means of the condensing syringe, the water is then forced up into the evaporating pan until the desired level is obtained, when the tap is turned. To measure the water lost by evaporation during a certain interval, the tap is turned again and the water allowed to flow back into the tube. Its height, as shown by the scale, will indicate the number of cubic inches evaporated during the time of its exposure.

(*See* Scoffern and Lowe s " Practical Meteorology," 1860.) Inv. 1902–87.

211. ATMOMETER OR EVAPORIMETER.

This instrument was designed by Professor Prestel, Emden, for determining the quantity of water evaporating from the surface of water as well as from different kinds of soil.

It consists of a shallow dish, 15 in. diam., containing a perforated zinc plate, and fitted with a vertical graduated tube. The tube is entirely filled with water, after which it is inverted, and placed in position at the edge of the dish. The tube serves as a reservoir, from which any evaporated liquid is replaced, the variation in the head of water serving to determine the amount of evaporation which has occurred. Inv. 1876–754.

212. REGISTERING EVAPORIMETER. Photograph presented by Prof. D. Ragona.

This instrument was designed by Prof. Ragona, of the University of Modena, for recording the evaporation taking place from the surface of water.

The dish containing water is supported on a balance arm which is maintained horizontal by a counterweight. Decrease in weight due to evaporation causes the dish to rise carrying with it a pen which records the motion on a chart rotated by clockwork. Inv. 1876–731.

213. PICKERING'S EVAPORIMETER. Lent by L. Casella, Esq.

This instrument was designed for measuring evaporation under atmospheric conditions from a surface.

The surface from which evaporation takes place is a piece of blotting paper 100 mm. long by 50 mm. wide, which is set in a frame above a small copper cylinder containing water. To keep this paper moist there is connected with it a narrow strip of the same material, which dips into the water. The amount of evaporation is read from a glass gauge at the side of the cylinder, which is graduated to express directly by a number of cubic centimetres or cubic inches the evaporation from each square centimetre or square inch of surface. Inv. 1896–66.

214. PICHE EVAPORIMETER. Made and lent by Messrs. Negretti and Zambra.

This instrument was designed about 1890, in order to indicate, in a simple and convenient manner, the amount of evaporation at any place.

It consists of a graduated cylindrical tube of glass, 8 in. long and closed at one end. The other end is ground flat and covered by a disc of porous paper about three times the diameter of the tube. This is kept in position by a metal clip, provided with a disc of the same diameter as the tube.

The instrument is filled with water and hung vertically with the closed end upwards, so that as the water evaporates from the wet paper, small bubbles of air rise in succession to the upper portion of the tube, and the amount evaporated is indicated on the scale of cubic centimetres graduated on the tube.

Inv. 1921–590.

215. EVAPORATION GAUGE. Lent by W. H. Dines, Esq., F.R.S.

This instrument was designed and used by Mr. G. Dines for measuring evaporation.

In making observations with this gauge, the cylindrical vessel is placed in a large tank of water, so that its temperature may be kept the same as that of a large body of water, and it is set with its edge about half an inch above the surface.

With the cylinder is connected, by a pipe passing through the tank, the rectangular graduated vessel which registers the level of the water in the cylinder, and from the readings taken, the evaporation for any period of time can be found. The graduations represent a depth of 0·1 in. of water, but a depth of 0·01 in. can be measured. An overflow pipe is provided in case of rain, which should lead into the measuring glass of a rain gauge. Since the evaporation diminishes when the water sinks below the level of the top edge of the cylinder, it is advisable for accurate observations that the high level of the water should be maintained as far as possible. Inv. 1893–163.

CLOUDS.

The clouds formed one of the earliest meteorological phenomena to attract the attention of man, and frequent reference to them is to be found in the earliest writings. No classification of them was attempted, however, until 1801, when Lamarck proposed one based on their appearance, in which he described about twenty different and easily recognisable forms. Two years later, Luke Howard introduced a classification based on four fundamental types, intermediate forms being noted by combinations of these four fundamentals. Commencing with the lowest he proposed the terms (1) nimbus, for rain clouds; (2) stratus, for the widespread flat formation; (3) cumulus, for the rounded piled-up forms, and (4) cirrus, for the high, feathery or wisp-like types. This classification found general acceptance, and his essay was reproduced in 1832, translated into various languages, and the classification was adopted almost unchanged by the various official meteorological services. Many other classifications have been suggested since Howard's time, but the majority of them are really slight modifications of Howard's classification, and very few entirely new systems have been proposed. One of the latter was that suggested by Clayton in 1889, based on the origin of the cloud, and enumerating five types. In 1894 Clement Ley proposed a new classification into four main divisions: (1) radiation clouds, fog types; (2) interfret clouds, horizontal current types; (3) inversion clouds, cumulus types; (4) inclination clouds, cirrus types.

In order to secure uniformity, the International Meteorological Conference agreed in 1890 to establish an international cloud classification, and ten types of clouds were agreed upon. Four years later, the committee appointed to prepare an atlas representing the forms, with the nomenclature proposed by Hildebrandsson and Abercromby, defined the ten types of cloud proposed, while in 1896 an international cloud atlas, due to Hildebrandsson, Riggenbach and de Bort, was published.

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216. SKY SKETCHES, a series of 533, in 72 frames, taken between September, 1883, and September, 1886. Drawn and lent by W. Ascroft.

These sketches illustrate optical phenomena attributed to the eruption at Krakatoa in the Java Straits, August 27, 1883. Inv. 1888–156.

217. CLOUD PHOTOGRAPHS. By G. A. Clarke, Esq. Acquired 1921.

Photographs illustrating typical examples of the various types of clouds, and arranged in accordance with the international cloud classification.

1. *Cirrus.*—These extensive curved threads, exhibit the familiar wisps and form part of a huge plume of cirrus.

2. *Cirrus.*—Tufts of cirrus with extremely delicate thread-like continuations. The cirrus is moving in the direction in which the lines are lying, the tufts preceding, and the tails following.

3. *Cirrus.*—In this irregular thread-like cloud, long threads can be seen along which there occur nuclei from which other threads spread outwards more or less transversely to the main threads.

4. *Cirro-stratus.*—Part of a widely spread sheet of dense cirro-stratus, a considerable height above the cumulus clouds along the horizon. The straight edge of the cloud is noticeable.

5. *Cirro-cumulus.*—An example of the variety termed "speckle-cloud"; the globules of cloud are excessively minute toward the edges of the sheet, where they become mixed with very delicate threads of cirrus.

6. *Cirro-cumulus.*—Part of a sheet of fine globular cirro-cumulus which exhibits double undulation, the transverse system being rather irregular. This example formed very rapidly from a previously uniform cloud-sheet.

7. *Cirro-cumulus.*—Here cirro-cumulus cloudlets are shown massing together into an irregular waved form.

8. *Cirro-cumulus Lenticularis.*—A very large compound lenticular cloud-bank with several small detached single clouds. This photograph shows a wonderful sunset effect upon the rippled under surface of the cloud bank. The system of double undulation shown by the ripples is remarkable.

9. *Alto-stratus.*—The characteristic grey pall of intermediate cloud through which the sun is shining weakly. Some loose "scud" in dark ragged masses—the forerunners of the coming nimbus—may be seen moving up below the alto-stratus. This is an example wherein the alto-stratus is quite structureless.

10. *Alto-cumulus*—An example of cloudlets without shadows; in this case the waves are sinuous instead of straight. The thinness of the cloud-layer is very obvious, especially on the left-hand side of the picture, but this was the case only at the edge of the layer, at the point where the photograph was taken. Farther to the right, the cloudlets were much denser and showed the normal shadowed appearance.

11. *Alto-cumulus.*—The most typical form of alto-cumulus, all the characteristics of that cloud-type as described in the International classification being present in this picture. The two wave-systems crossing each other ("double undulation") are very clearly shown, and the solid character of the cloudlets is well brought out by the slight shadows upon them.

12. *Alto-cumulus Lenticularis.*—A series of these cloud-banks well depicted at sunset. The relatively great density of the central parts is plainly to be seen, as also is the comparative thinness at their edges. In the upper part of the photograph, the individual cloudlets are seen passing out of one bank and entering another. The proper method of distinguishing between cirro-cumulus and alto-cumulus when they are massed into banks of this type is to examine the individual cloudlets that are nearest to the observer, for the banks themselves give very little indication of any difference when they are at all dense or very distant.

13. *Strato-cumulus.*—The typical form of this cloud. The masses are heavily shaded, and tend to fuse into each other within the sheet, while at the edges of the sheet they appear separated, so that the blue of the sky can be seen between them.

14. *Strato-cumulus.*—This is a heavier form of strato-cumulus, and is the type of cloud sheet that may cover the whole sky for days together, especially during the winter months. The cloud is dark grey with bright yellowish-white interstices where the sun is shining through the thinner parts of the sheet. The edges of the clouds are fused together; little or no blue sky can be seen between them.

15. *Cumulus.*—Typical cumulus clouds. The dome-shaped or pyramidal structure is very evident in the smaller one, and protruberances which indicate rising currents may be seen, while the flatness of the dark base which marks the level of condensation is also well shown.

16. *Cumulus* (*and Fracto-cumulus*).—Small cumulus clouds mixed with a considerable amount of the broken variety known as fracto-cumulus. The latter form seems to be accompanied by much turbulence and is found often in squally weather.

17. *Cumulo-nimbus.*—A large thunder-cloud with a very flat base from which rain is falling in the far distance. In the near front of the cloud-mass the moisture in the rising currents is condensing and spreading out into a large "anvil" which is fringed with false cirrus threads. Far in the rear there may be seen more false cirrus from other parts of the cloud-mass, which latter seems to be formed by the union of several cumulo-nimbus clouds.

18. *Cumulo-nimbus.*—This is an example showing rapidly-growing vertical columns of cloud that are uniting to form a huge thunder-cloud, of which this photograph includes less than one-fourth. A quantity of loose fracto-cumulus is floating round the main mass.

19. *Cumulo-nimbus.*—This hail squall cloud is moving from left to right and showers are falling from it over the sea. As the cloud moves forward the rising moist air forms in front of it a line of growing cumulus which lies round the front of the main cloud like a collar.

20. *Cumulo-nimbus.*—An advancing hail shower cloud, showing some growing cumulus in front. The passage of the cloud overhead was accompanied by a heavy squall with hail.

21. *Nimbus.*—Actually a shower falling from the nimbus-base of a large cumulo-nimbus cloud. It is impossible to photograph the typical nimbus cloud because the rain, when general, is not visible to the camera. It is only when an isolated shower shows dark against the lighter sky beyond that the rain can be shown.

22. *Stratus.*—This is the really typical form of stratus, a grey pall of cloud without any detail, and rendered visible only by the fact that the summit of the distant hill is immersed in the cloud, which is trailing along its flanks in the ragged masses called fracto-stratus.

23. *Line Squall Front.*—This shows the line of cumulus cloud losing its cumuliform character, and beginning to show some vertical arrangement, while small wisps of condensation were moving up and down below the cloud front.

24. *Nimbus with Rainbow.*—A screen of rain is falling and a primary rainbow with a very faint outer secondary bow base becomes visible. Inv. 1921–17.

218. CLOUD PHOTOGRAPHS TAKEN FROM THE AIR. Prepared in the Museum from Negatives lent by Capt. C. K. M. Douglas, R.A.F.

These photographs of clouds were taken from the air by Capt. C. K. M. Douglas, R.A.F., in 1918, and give a general indication of the appearance of the various types of clouds when viewed from above.

1. Strato-cumulus with tops at 5,000 ft. over France. In the distance clouds and haze can be seen on the horizon over England, while over the Channel it is clearer. The form of the clouds indicates turbulence, which is due in this case to heating at the surface. Immediately above the clouds the dry bulb temperature rose from 45° to 53°, and that of the wet bulb fell from 45° to 53°, the relative humidity thus suddenly falling to 23 per cent.

2. Low strato-cumulus cloud, with another larger one in the background. The density and great thickness of the cloud may be seen from the large dark shadow in the foreground.

3. This photograph shows the top of a cumulus cloud growing up through a cloud sheet. The upper surface of the cloud sheet was at 8,000 ft. and the cumulus reached 11,000 ft. In this case there was no temperature inversion below 11,000 ft. the conditions being those of a cool westerly type within a depression. This combination of clouds is commonly seen, but if there is a temperature inversion above the clouds, the cumuli do not stand out so boldly, and when growing through a thin cloud sheet often break up altogether, particularly if the humidity above the clouds is low.

4. This illustrates the top of a cloud forced up from the lower air when the upper air was in a stable condition. Underneath are dense clouds of the strato-cumulus type, and some showers, while at 8,000 ft. the clouds were 5° F. colder than the air at that level. The cloud seen in the photograph reached an altitude of 13,000 ft., and was associated with the passage of a very small V-shaped secondary.

5. Row of large towering cumuli forming the summits of rising air columns the highest of which has risen to over 10,000 ft.

6. Large cumulus towering from 1,000 to 11,000 ft. This cloud is the same as that on the left of No. 5 and was photographed five mintues later from a distance of only two or three miles. The tops of the rising air columns are seen remarkably well in this view.

7. This photograph illustrates three cloud summits towering vertically upwards from a layer with an unstable lapse rate of temperature. It is a form not uncommon with cold west or north-west winds. There were a large number of cumulus clouds between 2,000 ft. and 3,000 ft. and some of those that reached the unstable layer above 4,000 ft. grew up very rapidly, but the tops were broken off in every case. The tops of these clouds were at an altitude of 7,800 ft. at which "Inversion" occurred, thereby preventing their further growth.

8. The tops of the towering cumuli of No. 7 soon became detached and are shown in this photograph. The intervening parts of the cloud pillars have evaporated and cumuli may be seen below, while in the background there is a cloud layer at an altitude of about 7,000 ft. just below the inversion.

9. The towering cumuli of No. 7, the tops of which are shown detached in No. 8, are here seen several minutes later, when the detached fragments are dissolving, and rapidly disappearing.

10. Cumulo-nimbus (thunder-cloud), up to 20,000 ft. with dense masses of lower cloud in the foreground. The top of the cloud consisted of snow and was photographed from an altitude of 12,000 ft.

11. A long narrow strip of cloud rippled into waves, and formed in a damp layer at 4,000 ft., the wave-length being from 150 to 200 yards. The strip lay along the current at its level, and the waves were across the current. Below may be seen a large number of small cumulus which had formed at 1,000 to 1,500 ft. from a sheet of stratus. As there was an inversion of 30° F. above the cloud but none above the clear area to south-east, it appears that there was a marked local increase of wind velocity just above the strip which gave rise to the waves.

12. A view taken from 13,000 ft. showing snow showers from the high clouds. The lower clouds were forced up in a high bank of which the round top on the right was part. On the east side of the bank there was strato-cumulus up to 6,500 ft. with an inversion of 3° above it, while on the west there was strato-cumulus with no inversion. The bank was apparently forced up as the result of colder air arriving near the surface.

13. Parallel rolls of cloud, two or three miles apart and approximately forty miles long, covering the Boulogne region of France, and a portion of the Channel. The rolls were in lines from south-west to north-east, but the actual motion was from west-south-west. A portion of the coast line is visible through the nearest gap. The clouds were at an altitude of 4,000 ft. to 4,500 ft. and there were other layers higher up.

14. A nearer view of two parallel rolls of cumulus cloud.

15. A portion of a long narrow irregular strip of cumulus photographed from 13,000 ft. The strip which was 20–30 miles long was caused by the spread of a surface breeze from north-west to west-north-west, but the clouds moved themselves with the south-west current. The cloud was evidently due to upward movement originating near the surface, as the clouds were 2° colder than the air at their level elsewhere, and were extraordinarily turbulent.

16. A close view of the upper surface of a turbulent sheet of strato-cumulus. The top of the sheet was 5,000 ft. high and an inversion of 10° F. occurred above it, but the clouds were forced upwards in a few places in spite of this large temperature inversion. These upward currents were due partly to an unstable lapse rate of temperature in the clouds and partly to complicated wind currents near the ground.

17. The top of a strato-cumulus cloud sheet at a height of 9,700 ft. considerably above the average height of this particular type of cloud. The cloud billows are very clearly shown, one system of waves or folds crossing the other at an angle of about 30°. There was an inversion of 3° above this cloud sheet, a thin layer at 10,000 ft. and more turbulent clouds lower down at 9,000 ft.

18. Layer of strato-cumulus with the upper surface at an altitude of 2,500 ft. Ripples can be seen crossing the current obliquely, while a straight bank is also visible in the background.

19. Strato-cumulus sheet moving west-south-west, with the camera pointing south. The clouds were at an altitude of 4,500-5,000 ft. and there was only a very slight temperature inversion above them.

20. Strato-cumulus sheet with well-marked furrows. The waves are close together and are probably therefore across the current, but slightly oblique to it. Similar but rather larger waves, are common along the current but are also frequently slightly oblique. They must be set up by a difference of wind velocity between different layers.

219. STORM CLOUD. By Capt. A. G. Buckham.

This photograph was taken at an altitude of 6,000 ft. and shows a cumulo-nimbus cloud on the right from which heavy rain is falling, with lightning flashing beyond. Fracto-cumulus clouds resembling small cirrus have become detached by the strong wind. Inv. 1921–133.

220. TOP OF CLOUD LAYER. By Capt. A. G. Buckham.

This photograph which was taken at an altitude of 16,000 ft. shows the top of a cloud belt, approximately 10,000 ft. thick, above which is a sheet of alto-stratus covering practically the whole sky. The temperature above the cloud belt was 17° F., and in the cloud 27° F. Inv. 1922–132.

221. WATERSPOUT. By J. W. Knight, Esq.

This waterspout was photographed in the Black Sea, on October 1st, 1920, at 4 p.m. The phenomenon was seen at a distance of 2·5 to 3 miles, and was visible for a period of about 3 minutes. The second photograph was taken after an interval of 12 seconds. Inv. 1922–134.

222. APPARATUS TO ILLUSTRATE THE FORMATION OF TORNADO CLOUDS. Designed by W. H. Dines, F.R.S.

The apparatus for this experiment, as made by Mr. Dines, is of a simple and inexpensive form; that shown is of a somewhat more substantial character, to adapt it for exhibition.

Three glass plates, 18 in. by 24 in., are set in each of two frames, so as to form when put together a hollow hexagonal prism. These frames are placed upon a table with their edges apart and slightly overlapping, to allow of the entry of air obliquely. A board, with a hole in its centre, in which is set a fan that can be rotated by a pair of pulleys, forms a cover to the prism, and a shallow copper evaporating pan and a burner complete the essential parts of the apparatus.

If, when sufficient steam is generated from the water in the pan, the fan is rotated, a column will be produced in many respects similar to that of a Tornado Cloud.

The points of resemblance to the actual tornado cloud formation are stated by Mr. Dines to be:—

1. A distinct rotary motion round the centre, increasing in violence towards the centre.
2. A strong up-draft.
3. A decrease of pressure in the centre of the column.
4. The hollowness of the column.

(*See* Q. J. R. Met. Soc., January, 1896,) Inv. 1897–39.

223. GODDARD'S CLOUD MIRROR. Presented by J. T. Goddard, Esq.

The original mirror was devised in 1851 and exhibited at the Great Exhibition of that year. The example here shown was designed and exhibited in 1862, its purpose being to ascertain the direction of motion of clouds.

In making observations, the mirror is laid horizontally near a window and set so that the point marked North is directed to the South point of the horizon; the several points will then be reversed. The reflection of the edge of a conspicuous cloud is brought to the centre of the mirror and the point of the compass noted where it passes off the edge. This indicates the direction from which the clouds are approaching. Inv. 1863–1.

224. FINEMAN'S NEPHOSCOPE. Lent by The Meteorological Office.

This instrument, which was designed towards the end of the last century, is a modification of Fineman's earlier model, and is representative of modern reflecting nephoscopes.

It consists of a disc of black glass mounted on a tripod stand which allows of accurate levelling. A vertical pointer, which can be raised or lowered by a rack and pinion motion, is attached to the circumference of the disc in such a manner that it can be rotated about the disc. A scale of millimetres engraved on the edge of the pointer gives the height of its tip above the glass surface, and on the glass surface three concentric circles are marked, the radii being in arithmetical progression.

In making an observation, the observer stations himself in such a position that the image of the cloud in the glass and the central point of the mirror are seen in the same straight line. He then rotates the pointer and adjusts its length until its tip is also brought into this straight line. This done, he moves his head so as to keep the cloud image and the tip of the pointer in coincidence, and notes the radius on which the image appears to travel. This radius marks the direction of cloud drift. A compass needle mounted below the disc enables the observer to identify the direction.

The velocity height ratio of the cloud may be determined by noting the number of seconds required for the image to travel from the centre of the mirror to the first circle, or from one circle to the next. If a be the radius of the inside circle, b the height of the tip of the pointer above the reflecting surface, and t the time required for the cloud image to traverse the distance a, the value of the velocity-height ratio is given by the expression

$$\text{Velocity-height ratio} = \frac{a}{bt}$$

The instrument is fitted with a circular spirit level, which enables it to be adjusted truly horizontal. Inv. 1921–78, S.M. 1433, L.S.

225. TRAVELLER'S POCKET NEPHOSCOPE. Lent by The Royal Meteorological Society.

This instrument, for observing the direction and velocity of clouds, was designed by C. G. Fineman, and made by J. L. Rose at Upsala. It is an improvement on Fornioni's nephoscope, and consists of a circular black-glass mirror of 2⅝ in. diameter, on which are marked radial lines in the direction of the principal points of the compass, a dot to indicate the centre of the mirror and two concentric circles set at a distance of 26 mm. from each other. This mirror forms the cover of a shallow brass box, in which is pivoted a compass needle whose point can be seen through a semicircular hole at the N point graduation of the mirror. This arrangement of the compass needle permits of correct orientation of the instrument.

At the south end of the mirror is hinged a jointed arm, some 2½ in. high, with pointed end. This is made to fold over the mirror, except when observations are being made. The compass box is supported on gimbals and carries a counterpoise, the whole being supported on an upright which can be screwed to the lid of the box forming its case.

The instrument being properly oriented, a point in a cloud is brought to the centre of the mirror and the jointed arm raised to a sufficient height to allow of the observer seeing the reflection of the cloud point over its top. The direction of the cloud can then be told by the direction of displacement of its image and its velocity determined by the time taken by the cloud point in moving the definite distance between one circle to the other of the mirror.

Inv. 1908–194, S.M. 1436, L.S.

226. BESSON'S COMB NEPHOSCOPE. Lent by The Meteorological Office.

This nephoscope, which is of the direct vision type, was designed at the end of the last century to facilitate the rapid determination of the direction of motion and velocity of clouds.

It consists of a brass rod, about 9 ft. long, bearing at its upper end a cross-piece to which a number of vertical spikes are attached. The rod is mounted in a vertical position in such a manner that it can rotate freely, and its height is adjusted so that a fixed mark on the rod is at the level of the observer's eye.

When using the apparatus the observer stations himself in such a position that the cloud selected for observation is seen in the same straight line as the central spike of the nephoscope. He then turns the cross-piece until the cloud appears to travel along the line of spikes while he himself remains motionless. The cross-piece will then be parallel to the line of motion of the cloud, the direction of which can be read off on a graduated circle which is provided for the purpose. The rod may be turned by an observer standing at some distance away from it by means of two cords tied to a shorter cross-piece attached to its lower extremity.

The velocity-height ratio may be determined by noting the time taken for the cloud to pass from spike to spike. If a be the distance between the spikes, v the distance from the upper cross-piece to the marked point on the rod, which has been adjusted to the level of the observer's eye, and t the observed time we have

$$\text{Velocity-height ratio} = \frac{a}{bt}$$

In order that a constant difference of level may be maintained between the cross-piece and the observer's eye, the instrument should be erected on a level site. Inv. 1921–79, S.M. 1435, L.S.

227. THE RAYNER TELEPHONIC HEIGHT FINDER (No. 1). Lent by The National Physical Laboratory.

The Rayner telephonic height finder, which is sometimes referred to as the L.C.C. pattern, is the first height finder designed on the principle suggested in January, 1916, by Lieut. Mansell Pleydell and G. T. Bennett, Esq., F.R.S., and known as the Bennett-Pleydell principle, by which the height of an object is determined, as distinct from its range, by the measurement of two angles only.

This instrument was designed in 1916 by Dr. E. M. Rayner, and consists of two stations, one at each end of a base a mile long. At each station there is a wooden stand holding a rectangular sighting frame capable of rotation about a horizontal axis. At one end of each instrument is a dial and pointer arrangement giving at once the angle between the horizontal plane, and the plane of the sighting wire attached to the rotating framework. At the other end of *one* instrument (that exhibited) is a "plotting board," rigidly attached to the upright and engraved with a series of equidistant horizontal lines marked in thousands of feet. In addition to these lines there is a semicircular scale of degrees over which a loose arm may be swung at will. Rigidly attached to the rotating framework is a second arm. The inner edge of each of these arms passes through its own axis of rotation, and the distance between these axes represents the distance between the "home" and "distant" instruments on the same scale as the vertical distance between either axis, and any one of the horizontal lines represents the height marked on that line.

In measuring the height, of an aerial object the sighting frames at both stations are turned so that the plane of each wire rectangle passes through the object. The angle of elevation of the "distant" plane is then telephoned to the "home" station, and the free arm is set to this angle on the plotting board. The arm fixed to the "home" frame automatically gives the same information for the "home" station, and, in fact, the triangle formed by the inner edges of the two arms, with the horizontal line passing through their axes of rotation, is a reproduction to scale of the triangle formed by the lines joining the two stations and the target. Hence the height of the object sighted may be at once read off from the position of the intersection point of these arms. In practice several observations a minute can be made. A suitable length for the base is one to two miles.

This apparatus was the first to be generally installed in the war for air defence. It was designed so as to be capable of being made very rapidly by practically unskilled labour. Inv. 1921–594.

228. DARWIN-HILL POSITION FINDER. Presented by The Ministry of Munitions.

This "stereometer" or position finder was designed in 1916 by Sir Horace Darwin, F.R.S. and A. V. Hill, Esq., F.R.S., and primarily used for Anti-aircraft research, but as it enables the position of a body in space to be determined, it has been employed in the observation of clouds, for determining the velocity and direction of wind at different altitudes, and for re-calculating various artillery trajectories by the observation of shell bursts.

The complete equipment comprises two instruments placed at the extremities of a measured base, and adjusted so as to be in correct alignment.

Each instrument consists of a specially selected sheet of plate glass, 2 ft. 4 in. square, the lower surface of which is silvered and ruled into centimetre squares. Two vertical sighting wires are provided to enable the two mirrors after having been levelled to be adjusted, so that the lines of both station instruments are parallel to each other and to the line joining the two stations. The eyepiece, which is carried at a known distance above the mirror on a tripod support, is adjusted vertically over one end of the base line ruling, so that its image in the mirror coincides with this point.

The object is observed in the mirror by means of this eyepiece, and the position of the image on the mirror followed by a metal pointer. On the receipt of a predetermined signal, its position is noted, which, together with a simultaneous observation with the second mirror, enables the position of the object in space to be determined.

Two eyepieces are provided at different heights from the mirror, thereby increasing the range of the instrument. Inv. 1919–269.

229. DARWIN GIMBAL MIRROR. Presented by The Ministry of Munitions.

This instrument, which was designed by Sir Horace Darwin, F.R.S., in 1916, embodies the Bennett-Pleydell "roof" principle, by means of which the altitude can be ascertained by measuring the inclination of two planes capable of rotation about horizontal and parallel axes, situated at the ends of a known base.

The complete installation comprises two identical instruments known as the "Far Station" and the "Plotter Station," and situated a known distance apart. Each instrument consists of a stationary horizontal mirror across the centre of which are drawn two fine lines at right angles to each other, sights being provided to enable the instruments to be correctly lined up with their axes parallel. The object is observed in the mirror through an eye-piece carried by a long arm having freedom of motion about two horizontal axes. By moving this arm the image is kept on the centre line of the mirror and the inclination of the arm can be read off on a graduated scale over which passes a pointer carried by the arm mounting.

This reading, when combined with that of the distant station, enables the altitude of the object under observation to be ascertained.

With this instrument, it is impossible to see objects overhead, while in addition it is only with great care that an accuracy of 0·1° can be attained.

Inv. 1919–270.

230. MASON'S TILTING MIRROR. Presented by The Ministry of Munitions.

This instrument, which is an improvement on the Darwin Gimbal Mirror, was designed by Mr. C. C. Mason in 1916, to enable an observer to see directly overhead, and embodies the Bennett-Pleydell "roof" principle.

As in other height finders, two instruments comprise a complete equipment, the "Far Station" and "Plotter Station" being identical, and consisting of a plane mirror tilting about a horizontal axis which is perpendicular to the line joining the stations. The image of the object under observation is observed in this mirror by a "Plotter" which is carried on an arm free to rotate in a horizontal plane about a vertical axis through the centre of the instrument. The "Plotter" is an eyepiece provided with two horizontal and parallel cross-wires between which the image is brought by suitably tilting the mirror with the aid of milled heads. Continual adjustment of the mirror by the observer enables the image to be kept in position mid-way between the cross-wires.

The inclination of the object is given by a graduated arc on the left of the instrument and a graduated disc in the rear, which enables the angle to be read to 0·1° and estimated to 0·01°.

With this instrument it is possible, while looking horizontally, to observe directly overhead and also backward, while the provision of a telescope enables the object to be picked up at a greater distance than with other instruments.

Inv. 1919–271.

231. ELECTRICAL HEIGHT FINDER (No. 2). Lent by The National Physical Laboratory.

This instrument which depends upon the Bennett-Pleydell "roof" principle was devised in 1916 at the National Physical Laboratory by Messrs. C. C. Paterson and J. W. T. Walsh in order to enable a continuous indication of the height of an aerial target to be obtained.

The complete installation consists of a height indicator, an electrical circuit and two transmitters, one of which is fitted with a plotting board and pointers.

At each station, enclosed in a semicircular iron tank is a uniform resistance supported horizontally at a fixed distance below the axis of the sighting frame, and with its centre directly under this axis. Attached rigidly to the axle of this frame, and in continuation of the plane of the sighting wires, is a phosphor-bronze bar which presses against the horizontal resistance. In this way the distance between the *centre* of the resistance and the point of contact of the bar is always proportional to the cotangent of the angle of elevation of the sighting frame. Thus if it be arranged that there is a constant current passing through the resistance, the difference of electrical potential between the bar and the centre of the resistance is also proportional to this quantity. By means of a local battery, voltmeter and regulating rheostat, the voltage drop across a given length of resistance is maintained at the same constant value at both home and distant stations. The distances between the axes of rotation of the sighting frame and the horizontal tracks of the phosphor-bronze bars on the resistances are also the same at both stations, so that by connecting line conductors between the stations in such a manner as to put the two voltage differences in series, a milliammeter with a suitable swamping resistance in the circuit gives at once a reading proportional to the difference of the contangents of the two sighting angles. It follows that in order to obtain a direct reading of height, the instrument must be provided with a reciprocal scale. For the purpose of increasing the range, two scales are provided, one from 1,600 to 5,000 ft., and the other from 5,000 to 20,000 ft. The more open scale is brought into operation by pressing a key switch which normally short-circuits a shunt to the moving coil of the instrument. The series resistance of the milliammeter is variable, and is so adjusted in relation to (i) the actual voltages employed at the two stations, (ii) the sensitivity of the milliammeter, and (iii) the ratio of the base length to the vertical distance between the axes of the sighting frames and their respective resistances, that a given base length corresponds with a definite series resistance for all instruments. Corresponding values are tabulated in the instrument box, and so any instrument can be used with any length of base by suitably adjusting the series resistance.

The chief errors to which the instrument is liable are (i) leakage in the insulation of the main conductors between the stations, and (ii) change of resistance of these conductors with change of temperature. On this latter account these conductors are required to be as heavy as possible so that their resistance may be properly swamped by the series resistance of V.

(*See* Pat. Specn. No. 4379 of 1916.) Inv. 1921–594.

INVESTIGATION OF THE UPPER AIR.

The scientific investigation of the conditions of the upper atmosphere dates from about the middle of the eighteenth century, when Bouguer, during a geodetic expedition to Peru, fixed the height of the freezing point in different latitudes by means of observations on the slopes of mountains. The first use of the kite as a scientific instrument is due to Wilson and Melville, when, at Glasgow in 1749, they raised thermometers to considerable heights in this way, while three years later Franklin performed his famous experiment in atmospheric electricity. The next investigation of the upper air was made by Jeffries in 1784, when he ascended with a number of instruments in a free balloon, and determined the rate of fall of temperature with altitude. Free balloons were also used by Robertson in 1803-4 in his ascents from Hamburg and St. Petersburg, and by Gay Lussac in 1804 at Paris. In 1822-3, Fisher and Parry, using self-registering thermometers, obtained temperatures with the aid of kites in the Arctic regions, while in 1840 Espy employed kites to verify his calculation on the heights of clouds from measurements of humidity, seven years later Birt flew kites from the Kew Observatory to ascertain changes of temperature, humidity and wind with height. In 1850 Barral and Bixio ascended in free balloons, and in 1852 Welsh made four ascents from the Kew Observatory for the British Association. This work was continued by Glaisher, who with Coxwell made twenty-eight ascents between 1862 and 1866, to investigate the variation of temperature, humidity, magnetic force and electric potential. In 1877 Secretan was the first to send up india-rubber balloons or pilot balloons when investigating the change of wind direction with height, and determining the heights of clouds. During the four years commencing 1875, Tissandier ascended on several occasions in free balloons while between 1888 and 1901 Glaisher's work was repeated by Berson. Later experiments with free manned balloons have been chiefly confined to lower altitudes and principally for the verification of results obtained by other means. In 1883-5 Archibald used kites with steel piano-wire to obtain the wind velocity, while about this time McAdie repeated Franklin's experiments in America. In 1890 Eddy redesigned the kite, and in 1894 sent up the first kite to carry a continuously recording instrument. *Ballon-sondes* carrying continuously recording instruments had been proposed in 1809, and also in 1873, but were not actually used until 1893, when Hermite employed a varnished paper balloon, and later one of gold-beater's skin, a silk one being eventually used in 1894. In 1896 the International Meteorological Conference organised a series of ascents of *ballons-sondes* simultaneously in different countries, which were extended to include Austria and Italy in 1898, Belgium 1899, and England in 1901, while in 1898 the kite and kite-balloon were included in the apparatus of all the principal observatories. After Glaisher's work in 1869, captive balloons were little used on account of their tendency to oscillate and rotate, until Siegsfeld and Parseval produced their kite-balloon which was used at Strasburg in 1898, since which it has been employed regularly by the Prussian Meteorological Service.

In 1901, Rotch, and in the following year Dines, Berson and Elias, experimented with kites over the sea, while in 1902-3 Teisserenc de Bort, at Hald, in Jutland, employed kites night and day whenever possible over a period of nine months, and in addition investigated the conditions of the upper air by means of a large number of *ballons-sondes*. In 1904, Hergesell made a number of kite ascents in the Atlantic, as did Teisserenc de Bort and Rotch in 1905-6.

Subsequently excellent work has been done in this country by Dines, Cave, Ley and others, the results of which are published in the Weekly Weather Report by the Meteorological Office.

Kites have now been superseded by aeroplanes and *ballon-sondes*; pilot balloons are used regularly with theodolites for determining the direction and velocity of the wind at various heights. Observations are also made with *ballons-sondes* on days appointed by international arrangement and also in the course of investigations on the upper air in many countries.

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232. DINES BALLOON METEOROGRAPH. Lent by The Meteorological Office.

This instrument, which was devised by Mr. W. H. Dines, F.R.S., for use with registering balloons (*ballons-sondes*), produces a record of air pressure and temperature from which the altitude can be computed. It has been adopted by the Meteorological Offices of the United Kingdom, Canada and Australia, and, with some modifications, by that of India.

The meteorograph consists essentially of a small aneroid box mounted in a light frame, one side of the frame carrying a small thin plate on which the record is made, and the other side the recording pens. The plate is electroplated with copper, and then silver, thereby producing a surface which is free from scratches, and which is not susceptible to corrosion.

The thermograph depends for its action on the relative contraction of a strip of thin German silver as compared with the invar steel rod on which it is supported. This motion is multiplied by a lever mounted across the ends of the strips, and communicated to a scratching point, which writes upon the metal record. To facilitate measurement, a second pointer is attached to the invar rod. The fall of pressure is determined by the expansion of an aneroid box, which moves the recording point over the metal record in a direction at right angles to that given by change of temperature. During the descent of the instrument, the points are lifted clear of the plate by an automatic arrangement, at a point where the pressure is about 0·95 mgd. per sq. cm. (28 in. of mercury). In this way, the last 500 m. of the descent is lost, but a record is obtained which is free from blur. The instrument is protected by a bright metal case, and is well ventilated, so as to eliminate the effect of solar radiation.

Before the ascent, the meteorograph is calibrated by causing the pen to make marks upon the metal record corresponding with known temperatures and pressures, over the range required. After an ascent has been made, the plate is placed upon the micrometer stage of a special microscope, and corresponding values of temperature and pressure experienced during the ascent can be determined by comparing the record with the calibration marks. To obtain the values of height and temperature, the following equation is employed :—

$$h = kT \log \frac{p_0}{p}$$

where h = height,
T = temperature (absolute),
p_0 = pressure at ground-level,
p = pressure at height h,
k = a constant.

A graphical method, employing semi-logarithmic paper, is used for this determination. Inv. 1919–518, S.M. 1426, L.S.

233. BALLOON METEOROGRAPH. Made by Richard, Paris. Lent by Capt. C. J. P. Cave.

This balloon meteorograph, or barothermo-hygrograph, was designed by Richard for use in balloons, to give a continuous record of temperature, humidity and altitude.

It consists of a vertical drum, uniformly rotated by clockwork, upon which is mounted the chart. The upper record is the thermogram, the pen of which is operated by a Bourdin thermometer tube situated beneath the base of the instrument and connected to the pen by a long lever. The hygrogram, which indicates the atmospheric humidity, is recorded by a pen actuated by the expansion or contraction of a length of hair. On the lower record the altitude is recorded in feet, the scale ranging from sea-level to 70,000 ft. A measure of the barometric pressure is provided by a set of three aneroid boxes, the expansion or contraction of which is communicated through a system of levers to the lower pen. Inv. 1920–663, S.M. 1428, L.S.

234. BALLOON THEODOLITE, MARK B. Made by Watts & Son. Lent by The Meteorological Office.

This instrument is specially designed for measuring the azimuth and altitude of a pilot balloon at frequent intervals during the ascent.

It differs considerably from the surveying theodolite, although constructed on the same general principle. The telescope tube is in two parts, which are at right angles to one another, a prism being placed at the right angle to deflect the rays of light from the object-glass towards the eyepiece. The tube in which the eyepiece is mounted lies in a horizontal plane, and rotates about the vertical axis of the instrument so that, at all altitudes of the balloon, the observer is always looking in a horizontal direction. As the balloon ascent may continue for half an hour, such an arrangement eliminates the discomfort that would otherwise ensue with a straight telescope tube when the observed angular altitudes were considerable. The telescope is set at infinity focus, for after the first half-minute the distance of the balloon from the observer is such that a fixed focus instrument is practicable.

If only one theodolite is employed, the path of the balloon can only be determined when its rate of ascent is known; but if two theodolites are employed, preferably separated by a base line of considerable length, the available readings suffice to fix the position of the balloon in space at any observation, and hence to lay down its path. Inv. 1919–508, S.M. 1427, L.S.

235. ASSMANN'S BALLOON THERMOSCOPE. Lent by Capt. C. J. P. Cave.

This instrument is designed for obtaining temperatures from a pilot balloon ascent when it is not expected to recover the balloon.

The instrument consists of a Bourdon thermometer tube, fitted with a lever, which at different temperatures makes a contact with a series of studs. Each of these studs is electrically connected to a firework suspended below the balloon, so that the corresponding firework can thus be exploded when the balloon reaches a layer of the atmosphere at some definite temperature. The balloon is observed with theodolites, and the height is determined trigonometrically each time a firework is seen to explode. Inv. 1920–720.

236. AIR-COLLECTING APPARATUS. Lent by Capt. C. J. P. Cave.

This instrument was designed by Teisserenc de Bort for collecting a sample of air at some definite height during the ascent of an unmanned balloon.

The instrument consists essentially of a Bourdon barometer tube, to which is connected a lever which makes contact with a metal stud when the balloon has ascended to a certain height. A small weight is released electrically and drops on to the finely drawn-out end of a sealed and exhausted glass tube, into which air is thus admitted. As the balloon ascends further, the barometer lever makes contact with another stud, and this causes a current to pass round a coil of platinum wire which is wound round the neck of the glass tube. The heat thus generated enables the neck of the tube to be sealed, enclosing a sample of air. Inv. 1920–719.

237. BALLOON FILLER. Lent by The Meteorological Office.

This apparatus is designed for use during inflation of the pilot balloon with hydrogen.

It is connected to the balloon, and hydrogen is allowed to enter. A series of graduated weights are provided, by means of which the "free lift" of the balloon, or the weight which it will just support when floating, can be determined. Inv. 1919–510.

238. BALLOON BALANCE. Lent by The Meteorological Office.

This instrument is designed for weighing pilot balloons to the nearest gramme.

It consists of a light metal pan suspended from the small arm of the balance, on which the balloon is supported. The longer arm, which is suitably weighted, travels over a portion of a circular scale, graduated to indicate the weight of the balloon in grammes. Inv. 1919–509.

239. PILOT BALLOON LANTERN. Lent by The Meteorological Office.

This simple apparatus is attached to pilot balloons when ascents are made at night, the light given by the lantern being sufficient to enable observations to be carried out when the balloon would otherwise be invisible. Inv. 1919–511.

240. PILOT BALLOON SLIDE-RULE. Lent by The Meteorological Office.

This slide-rule is designed for performing rapidly the computations required from observations on the ascents of pilot balloons.

On this instrument the tangent, sine and cosine scales are fixed, and the scale of natural numbers is carried on the principle slide and also on the inner slide. The tangent scale runs from 1° to 84°, the sine scale from 1° to 90°, the portion from 10° to 90° being repeated, so that the sine and cosine cursors may be set at any angles, e.g., 44°, without interfering with each other. The graduations of the sine scale between 70° and 90° are shown on an arc, so that they are equally spaced.

In the single theodolite method the rate of ascent of the balloon is computed from its weight and free lift, so that the height of the balloon is known at any instant during the ascent. If H is the height of the balloon, E is the angular altitude, and A is the azimuth measured from north, then the components of the displacement of the balloon towards the north and towards the east of the observer are, respectively,

$$H \cot E \cos A,$$

and

$$H \cot E \sin A.$$

The slide-rule is arranged for the rapid computation of these quantities over a series of regularly increasing values of H, combined with known values of E and A.

In a series of balloon observations, the observed angles change slowly, and, as the trigonometrical scales are fixed, the cursors which indicate the angles are only displaced slightly from one setting to the next. Inv. 1919–512.

241. BALLON-SONDE WITH METEOROGRAPH. Lent by The Meteorological Office.

This was designed by W. H. Dines, F.R.S., for recording on metal plates the temperature and pressure in the free air up to a height of 70,000 feet.

The pressure apparatus is an aneroid box, to the centre of which is fixed an upright plate connected with the side of the frame supporting the two writing points. The aneroid itself is attached at the back to the arm of the frame which carries the recording plate. The two arms are joined together by a spring which allows them to open out or close in as pressure decreases or increases. By this movement of pen and plate a record of pressure is scratched upon the latter in accordance with the altitude to which the instrument is carried by the balloon.

The temperature apparatus consists of a thin strip of German silver, 5 in. long, which, connected with an invar steel bar, causes by its contraction a pen to move across the plate and by the position of the line scratched by it relative to the datum line the temperature can be ascertained.

The frame with the instruments is supported in a light aluminium cylinder some 8½ in. long by 3 in. diameter which is carried up by a toy balloon.

A small parachute was attached to the enclosing cylinder with the view of lessening the chance of damage to the instrument on its falling, but this has now been found unnecessary.

A card is attached to the apparatus, offering a reward to the finder of it if returned to the Meteorological Office.

(*See* "The Free Atmosphere in the Region of the British Isles," by W. H. Dines, B.A., F.R.S. and W.N. Shaw, Sc.D., F.R.S. Inv. 1908–89.

242. BALLON-SONDE RECORDS. Lent by The Meteorological Office.

These records, which were obtained at Crinan, N.B., on the 27th July, 1908, and at Limerick 29th July, 1908, are on plates about 1 in. by 1⅛ in., which, in order to produce a surface free from scratches and not liable to corrosion even by sea-water, are first coated with copper and then with silver.

By careful calibration of the instruments by which the records are made, the height of the stratosphere and of ascent, also the temperatures at the lower limit of the stratosphere and at the maximum height, can be obtained. Inv. 1908–89.

243. METEOROGRAPH FOR BALLONS-SONDES. Lent by Capt. C. J. P. Cave.

This form of meteorograph was designed by Teisserenc de Bort to record humidity, temperature and pressure in the upper air simultaneously, and for this purpose was used the Observatoire de Trappes.

The record is made by three pens which register upon a cylindrical drum revolved by clockwork. The upper pen, which records the humidity, is actuated by the expansion or contraction of a length of hair, the motion being magnified considerably by a lever. The middle pen records the temperature and is controlled by a bi-metallic thermometer which consists of a compound strip of brass and steel, the curvature of which varies with temperature. A Bourdon barometer tube serves to operate the lower pen, which records the barometric pressure.

Inv. 1920–718.

244. KITE METEOROGRAPH. Lent by The Meteorological Office.

This instrument, designed by Mr. W. H. Dines, F.R.S., for use with kites, furnishes a record of pressure, temperature and humidity in the free air up to 10,000 ft.

A circular chart of 12 in. diam. is carried on a flat piece of thin wood, and turns uniformly on a stout brass pin. The record is made by three pens, which from left to right indicate humidity, pressure and temperature, respectively. The hygrograph, which measures the humidity, is actuated by the expansion and contraction of 6 in. of hair, the motion being multiplied eight times by a lever which moves over a scale ½ in. in length. The altitude, or more strictly the atmospheric pressure, is shown by the expansion of a single aneroid box of 2·7 in. diam., the motion being multiplied about 30 times by a single lever. The arrangement of the thermograph is similar, the pen being actuated by a small aneroid box in exactly the same manner. In this case, the aneroid box is filled with alcohol, and is in communication with 4·5 ft. of thin copper tube 0·125 in. diam., arranged in the form of a coil under the flat wooden frame.

In an improved model of this instrument, and arrangement for recording the velocity of the wind has been added, in which the wind pressure is measured by means of its action on a small celluloid sphere attracted by a thread.

The meteorograph is secured in the middle of the kite by four strings, which run from the corners of the instrument to points near the ends of the two long bamboos of the kite.

(*See* "Symons' Magazine," July 1904, Vol. XXXIX., and March 1906.)
Inv. 1919–515, S.M. 1429, L.S.

245. KITE AND METEOROGRAPH. Lent by The Meteorological Office.

These were designed by W. H. Dines, F.R.S., for recording pressure, temperature and wind-force in the free air up to 10,000 ft.

The instruments by which records are taken are attached to a light board, 12 in. by 15 in., which is suspended to a box kite. On the board is also a circular sheet of paper ruled for recording purposes, and a small clock for rotating the paper.

The apparatus for air-pressure and wind-force are set on one side of the clock, those for temperature and humidity on the other, and the writing apparatus is carried at the ends of light levers in connection with the four instruments.

The pressure instrument consists of an ordinary aneroid box, to the centre of which is fixed a knife-edge which, as pressure is reduced, pushes forward the lever which carries the pen. On any rise of pressure a spring keeps the lever in contact with the knife-edge so that it follows the backward movement of the aneroid case.

The temperature instrument is formed of a long spiral of copper tubing which is set at the back of board.

This tube opens into a small aneroid box containing alcohol. To the centre of this box is fixed a knife-edge which acts on the recording lever in much the same way as in the air-pressure instrument.

The humidity apparatus consists of a bundle of hairs at the back of the board, the elongation and shortening of which move the recording lever in one direction or the other over the dial.

For wind-force there is at the back of the instrument an arm to which can be attached a celluloid ball of 3 in. diam. and 100 grns. weight. This ball is hung at the end of 40 ft. of fine sewing-cotton and its movements set in action the writing-lever in connection with the arm.

The board of the meteorograph is secured to the middle of the kite by the four cords at its corners, the junction being near the ends of the two long bamboos.

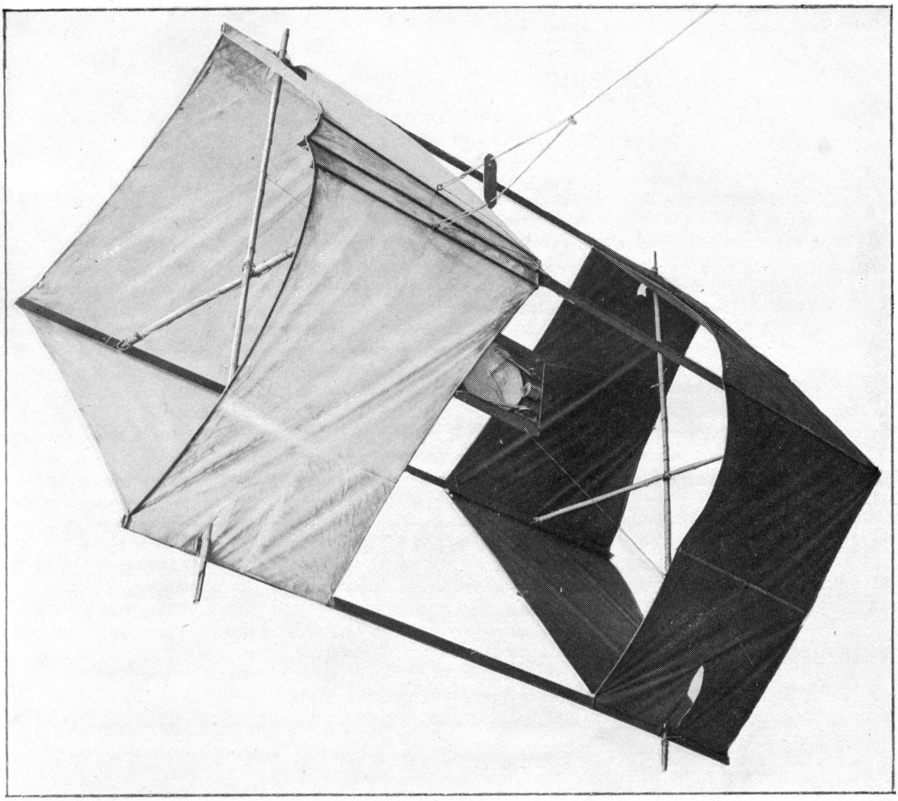
(*See* "The Free Atmosphere in the Region of the British Isles," by W. H. Dines, B.A., F.R.S., and W. N. Shaw, Sc.D., F.R.S.). Inv. 1908–80, S.M. 1445, L.S.

246. MARVIN KITE METEOROGRAPH. Lent by The Meteorological Office.

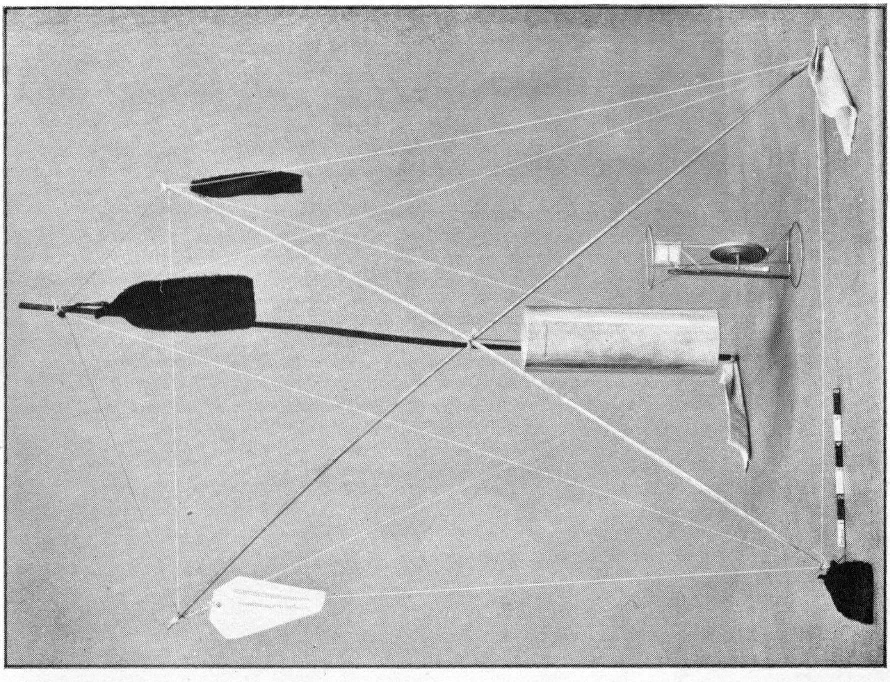
This instrument was designed by Prof. C. F. Marvin in 1898 to record simultaneously on a chart, variation of wind velocity, humidity, temperature and pressure, and is intended for use on kites, kite balloons or aeroplanes.

It is a baro-thermo-hygro-anemograph, the barometer of which is a large double aneroid with steel boxes. The thermometer consists of two annular

PLATE VI.



Kite and Meteorograph.



Balloon Meteorograph.

Bourdon tubes of very thin steel filled with alcohol, and the hygrometer consists of two bundles of hair. The thermometer tubes and hygrometer hairs are enclosed in a polished tube open at both ends. The anemometer originally used was a small instrument of the Robinson cup pattern, operating through an electro-magnet on a small hammer and recording on the drum in steps. In later patterns the anemometer was replaced by an Assmann anemometer, designed on the Woltmann fly wheel anemometer principle. It consists of an eight-bladed fan fitting into the end of the aspiration tube and operating through a train of cogwheels on the marking pen. The instrument when used with the anemometer is suspended by a wire some distance below the kite to avoid any disturbing effect due to the latter.

(*See* Journal Franklin Inst., Oct., 1899, p. 241, and Brit. Assoc. Report, 1909, p. 80.)
Inv. 1922–7.

247. BAROTHERMOGRAPH. Presented by The Royal Aircraft Establishment.

These five photographs show different views of the Barothermograph, designed at the Royal Aircraft Establishment for use on aircraft to record the atmospheric temperature and pressure.

It consists of a combination of an aneroid barometer and a bi-metallic thermometer, both connected to a point which records on a smoked paper chart. The barometer tends to move the point in an upward or downward direction while the thermometer tends to move it to and fro across the chart. The usual result is therefore a curved line moving diagonally over the chart. This trace is read by the superposition of a transparent scale which has been calibrated on the actual instrument under conditions of varying temperature and pressure.
Inv. 1921–9.

248. ALTIGRAPH. Made by Richard, Paris. Lent by The Meteorological Office.

This pocket instrument is designed to give a continuous record of altitude, and for this purpose is used in meteorological work.

It consists essentially of an aneroid box, the expansion of which is regulated by the atmospheric pressure, and is communicated by levers to a pointer carrying a pen which moves over the chart. This chart is mounted on two cylinders, which are rotated by clockwork, so that a record is produced from which the altitude at any given time can be determined. The altitude scale of the record indicates heights up to 20,000 ft., and at right angles to this is set the time scale.
Inv. 1919–517.

THE ATMOSPHERE AND ITS CIRCULATION.

The early navigators discovered that in the tropics winds blow almost continuously from the north-east at points north of the equator, and south-east at places south of the equator, with irregular winds from the west in extratropical regions, which they attributed to the fact that the earth rotating from west to east left the air behind it. Halley, however, in 1686, pointed out the inadequacy of this explanation, as it did not account for the calm belt under the equator, the south-west winds of the cost of Guinea, or for the Monsoons, and suggested the heating of the air by the sun and its subsequent expansion as a reason for the continuous movement of the atmosphere from east to west. Hadley, in 1735, disproved this and concluded that the effect of the diurnal heating of the sun would be to cause an air-blow inwards from all sides to the heated area, and especially from the regions in higher latitudes towards the tropics. In this way the air moving towards the equator is deviated towards the west, as its easterly motion falls behind that of the earth over which it passes. In rising it is cooled by expansion, and then on flowing away from the equator its tendency is gradually to fall, reaching the surface again in temperate latitudes, and becoming the prevailing westerly winds of the temperate zones.

Hadley's theory was generally accepted for over a century, until it was modified slightly by Maury in 1855, but Ferrel, in 1859, showed that the deflecting force due to the earth's rotation acts always at right angles to the direction of motion, a moving current of air being deflected to the right in the northern hemisphere and to the left in the southern hemisphere. The scheme of planetary circulation which Ferrel subsequently developed does not, however, conform with modern views, except at the surface and up to moderate elevations, and Bigelow, in 1898, from his study of cloud movements, was unable to detect the poleward currents in the upper strata, and the equatorward currents in the lower strata, with a calm stratum between, as required by Ferrel's theory.

In consequence of the earth's turning on its axis, the air over its surface is everywhere in cyclonic rotation, and even the air in an anticyclone possesses a cyclonic rotation, a fact which explains the temperature distribution within cyclones and anticyclones, while, in addition, the atmospheric drift towards the east in the middle and higher latitudes forms a gigantic polar cyclone.

Shaw, in 1893, pointed out the necessity for calculating and utilizing gradient velocities, and Dines has shown experimentally that the change in the velocity with altitude, brings the upper currents more into agreement with the theoretical wind computed from the surface gradient.

Gold, in 1908, showed that the separation of the isobars near the centre of an anticyclone, which is wide compared with that of a cyclone, is due to the fact that in an anticyclone the curvature gradient acts in the opposite sense to the general rotation gradient, whereas in the cyclone the curvature gradient and the rotation gradient are concurrent, thereby strengthening as a primary law of atmospheric circulation, the idea of balance of barometric gradient by velocity.

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249. AITKEN'S PORTABLE DUST-COMPUTER. Lent by J. Aitken, Esq., F.R.S.

This instrument depends upon the principle that the moisture of the air, when it condenses, forms rain drops around the dust particles contained in the atmosphere.

In using the computer the shallow cylindrical receiver at the top is first filled with air which has been freed from dust by a filter of cotton wool and saturated with moisture. A definite amount of the air to be tested is then introduced to replace dustless air. If now by means of a pump the air is expanded a lowering of temperature ensues, the vapour is condensed and rain drops are deposited on the glass plate at the bottom of the receiver. As this plate is divided into millimetre squares, the number of drops can, with the aid of the magnifying glass which forms the top of the apparatus, be counted per square and from this the number of dust particles in the air under test can be calculated.

The diameter of the receiver is 3 cm., its depth is 1 cm., and the tube in connection with it is graduated for 0·02, 0·05, and 0·1.

By means of a piston within this tube the impurity of the air under examination, when much laden with dust particles, can be reduced to the extent shown by the graduations on the tube.

The instrument is so arranged that, supposing the average number of drops on each square of the micrometer to be 5, then, using 0·05 impurity, the dust particles in a cubic centimetre of the air will be $5 \times 100 \times 50 = 25{,}000$.

Inv. 1908–193, S.M. 1440, L.S.

250. AIR-POLLUTION RECORDS. Lent by The Meteorological Office.

These records were obtained by the use of the Automatic Smoke Pollution Recorder invented by Dr. J. S. Owens in 1914 for measuring the amount of suspended impurity in the atmosphere.

The first record, December 13th-16th, 1921, shows the results obtained on a clear day during winter, while the second one resulted from the dense fog of November 9th-10th, 1921. The exceptional clearness of the atmosphere during the coal strike of that year is shown by the third record, which was taken on May 17th-18th.

In order to obtain the records a fixed volume of air is drawn at regular intervals through the filtering paper which is of sufficiently fine texture to collect on its surface the whole of the suspended impurities in the air, leaving it in the form of a discoloured patch. The amount of impurity is measured by the degree of discolouration and is estimated by comparison with a series of standard tints.

(*See* Pat. Spec. No. 8725, 1916.) Inv. 1922–12.

251. ORIGINAL OZONOMETER. Lent by John Smyth, Esq., Jun.

This was the first ozonometer designed by Smyth in 1864, for determining the quantity of ozone in the atmosphere, in connection with the bleaching of linen.

It consists of a glass-lined brass tube one end of which is open, while the other end is closed except for a glass delivery tube of 0·4 in. diam., carrying a large glass stopcock to admit air. A brass cap is provided for closing the open end of the tube, within which is a thick glass disc bearing a wooden frame and grooved for an india-rubber band which holds a test paper in position across its mouth. In this way the test paper is held across the entrance tube and at a distance of about 0·1 in. from it. A small tube from the other extremity of the box communicates with a large aspirator.

The amount of ozone is judged by its action on the test paper which after exposure is removed and compared with standard tints forming a scale. These papers are prepared in various ways, the substance used by Schönbein being iodide of starch.

(*See* Brit. Assoc. Report, 1865, ii., p. 37.) Inv. 1876–693.

252. OZONOMETER. Lent by John Smyth, Esq., Jun.

This ozonometer is a modification of Smyth's original instrument.

It consists of a cylindrical brass chamber lined with sealing wax, to the closed end of which a glass tube is connected. The other end, which is provided with a stopcock, carries a glass cylinder of slightly smaller diameter, which fits within the brass cylinder and supports the test paper in the current of air.

Inv. 1876–693.

253. IMPROVED OZONOMETER. Lent by John Smyth, Esq., Jun.

This is an improved form of ozonometer designed by Smyth in 1865 for the more accurate determination of the amount of ozone in the atmosphere, and by means of which air may be caused to impinge on an extended surface of a test paper while moving with a considerable velocity.

It consists of two wooden cylinders or boxes about 2 in. long and 2 in. external diameter, the smaller of which fits lightly into the larger, and is slightly shorter. Its extremity is grooved for an india-rubber band which holds the test paper stretched across its mouth. An entrance tube of 0·25 in. diameter introduces air through the end of the larger box when it impinges on the test paper and eventually passes out of the chamber through an exit tube at the opposite end, leading to an aspirator.

(*See* Brit. Assoc. Report, 1865, p. 37.) Inv. 1876–839.

CIRCULATION OF THE ATMOSPHERE.

254. ANEMOIDOGRAPH. Made by The Cambridge Scientific Instrument Co., Ltd. Lent by Sir Napier Shaw, F.R.S.

This instrument was designed by Sir Napier Shaw and Sir Horace Darwin for tracing the path of air moving with a definite angular deviation from circular isobars.

It consists of a carriage with a vertical tracing wheel, which can be set with its axis at any required angle to the length of the rod at the end of which it is fixed. The other end of the rod is attached to a carriage which travels along in a straight line, and can slip backwards and forwards so as to adjust itself to the increasing or decreasing distance of the tracing wheel. The two carriages are driven from a common driving wheel by a connection of pulleys and cords. One of them, the centre carriage, has all its wheels set parallel and thus can only move in a straight line; the other, the tracing carriage, has a single wheel attached to a rod which puts the two carriages into relation, and is guided by the setting of its wheel with regard to the rod. As the driving wheel is turned, both carriages are driven; one goes straight forward, and the other goes at a fixed angle to the rod which slides in a guide attached to the first carriage and allows any adjustment of the distance between them that the relative motion of the two carriages demands. In this way the conditions of relation between the motion of air with given incurvature from circular isobars drawn about a moving centre and the motion of the centre are exactly reproduced. With this apparatus, trajectories for various specified conditions can be traced, and the relative speed of the two carriages thus obtained should give the relation between the velocity of the wind and the velocity of the storm centre.

In the trajectories shown, the dotted line represents the path of the centre in each case, while a thick line indicates a trajectory.

Inv. 1920–731, S.M. 1441, L.S.

ATMOSPHERIC OPTICS.

255. ZOETROPE TO SHOW AIR MOVEMENTS. Constructed in the Museum.

This arrangement was devised by Sir W. N. Shaw, F.R.S., to illustrate the passage of cyclonic depressions and the motion of the air therein.

Round the inside of the cylinder is arranged a series of maps showing the isobars drawn for intervals of one hour throughout the day, while arrow-heads indicate the directions of the wind on the various charts. On rotating the cylinder, a representation is obtained of the motion of the storm centre, and also of the circulation of the air about the cyclonic depression. Inv. 1921–599.

256. AURORA PHOTOGRAPHS. By Prof. Carl Störmer, Norway. Acquired 1922.

These photographs are selected examples of typical forms of Aurora seen in Norway.

1. Auroral arc, photographed from Bygdo near Christiania, 11th October, 1921, at 11 hr. 13min. (Greenwich mean time). The photograph was taken looking east, with an exposure of about 40 seconds. The stars β and γ Ursæ Majoris are seen over the arc, and are somewhat deformed in consequence of the short focus of the camera lens.

2. Rays and curtains in the north, photographed from Christiania, 13th October, 1916, at 9 hr. 34 min., exposure 3 seconds. The most luminous short rays under the curtain to the right were red, the rest of the aurora being greenish yellow.

3. Curtain in the west, photographed from Bygdo at 12 hr. 57 min. in the early morning of 8th March, 1918, exposure 5 seconds. The star seen near the left edge of the curtain is Procyon.

4. Auroral drapery near the Zenith, photographed from Bygdo at 12.51 a.m. on 23rd March, 1920, with an exposure of only 1 second.

5. Auroral corona formed by beautiful blue rays photographed from Bygdo at 3.41 a.m. on 23rd March, 1920, with an exposure of 6 seconds. A series of twelve consecutive photographs of this corona was obtained.

6. Corona of green, yellow and red rays, photographed from Christiania at 9.10 a.m. on 16th December, 1917, with an exposure of 2 seconds. To the right are seen the stars of the constellation Auriga. Inv. 1922–1.

257. STEREOSCOPIC PHOTOGRAPHS OF AURORAE. By Prof. Carl Störmer, Norway. Acquired 1922.

These photographs, which are in pairs, were obtained in each case from the ends of a measured base, thereby enabling the altitude of the aurora to be calculated.

7. These photographs of auroral curtains were taken simultaneously at Bossekop (*a*) and Korsnis (*b*) at 7.27 a.m. on the 14th March, 1913, with an exposure of 10 seconds. The length of the base between the two stations was 27 km. The planet Venus is seen near the middle of the picture. From the different situation of the aurora compared with the stars, the altitude is calculated, the lower border in this case being found to be at a height of about 100 km.

8. Remarkable pulsating aurora photographed simultaneously at Bossekop (*a*) and Korsnis (*b*) at 1·26 a.m. on 15 th March, 1913, with an exposure of 10 seconds. The stars of the Ursa Major are seen on the photographs and are somewhat deformed owing to the short focus of the lens. The altitude of this phenomenon was between 90 and 100 km.

9. These fine auroral rays were photographed from Oscarsborg (*a*) and Bygdo (*b*) simultaneously at 10.6 a.m. on 4th March, 1920, the two stations being about 26 km. apart. The star Aldebaran is seen near the middle of the pictures, and the Pleiades to the right. The lower extremities of the rays were at an altitude of approximately 120 km.

10. This short auroral curtain was photographed at Kongsberg (*a*) and Bygdo (*b*) in the early morn of 23rd March, 1920, the base line having a length of 64 km. The exposure was 8 seconds. The stars Castor and Pollux are near the middle, and Jupiter to the left. The right edge of the curtain stretched from an altitude of 108 km. down to one of 82 km.

(*See* " Rapport sur une Expédition d'Aurores Boréales à Bossekop et Store Korsnes pendant le printemps de l'Année, 1913." Geophysical Publications, Vol. 1. No. 5. p. 72.) Inv. 1922–2.

258. MIRAGE PHOTOGRAPHS. From Negatives lent by Dr. W. H. Steavenson.

These photographs, which were taken in the desert at or near Kantara on the Suez Canal, illustrate the formation of a mirage caused by atmospheric refraction due to the vertical distribution of temperature near the ground.

The first photograph, taken at Kantara on 5th April, 1920, about one and a half hours before sunset, is reproduced for comparison with the second one, no mirage being visible. The foregound slopes away gently for a distance of two or three miles until it reaches a low ridge of sand a few feet high, capped by a series of low bushes. Beyond this the ground slopes upwards, in a series of ridges or undulations, to the horizon which is 15 to 20 miles distant. The light colour of the first ridge is probably due to a thin deposit of salt from a former inundation.

The second photograph is one of the same landscape taken about an hour before noon on 21st April, and shows what appears to be a complete reflection of the bush-covered ridge, the angular distance between the bushes and their images being between 1 and 3·5 min. of arc. It will be noticed that there is also an enlargement of the bushes in a vertical direction as compared with the first photograph.

The third photograph was taken on 8th February, 1920, at El Kab, four miles north of Kantara, the landscape in this case being a level stretch of sand extending between 5 and 10 miles, beyond which is a low range of sandhills forming the horizon. In this photograph the tops of these sandhills can be seen clearly and underneath them there appears to be inserted a layer of sky or water, in which is an apparent reflection of the hills, which now look like a series of islands in the sea. The mirage ends abruptly in a straight and well defined boundary the position of which is governed by the limiting angles at which rays may be refracted to the observer. Inv. 1921–284.

259. THE SETTING SUN. By G. A. Clarke, Esq.

These telephotographs of the sun were taken during the last half-hour of sunset on 6th June, 1921, and show the flattening of the sun's disc due to atmospheric refraction.

The camera was kept stationary whilst the plate was intermittently exposed at intervals of 6, 8, 6, 4 and 3 minutes. The trace of the sun's path on the plate is seen to be concave upwards, and the shape of the sun near the horizon is elliptical with the long axis horizontal, these effects being due to atmospheric refraction which increases the altitude but does not affect the azimuth of a celestial object. At the time of sunset the lower limb of the sun is raised more than the upper limb, and therefore the vertical diameter appears reduced, whilst the diameter measured on a horizontal circle is not affected by refraction. The distant hills were slightly above the true horizon so that the fullest effect of refraction cannot be seen. The last exposure was at 20 h. 48 min., the theoretical time of sunset being 20 h. 54 min.

Inv. 1922—296.

WEATHER.

The earliest known journal of the weather was kept at Oxford by the Rev. William Merle from 1337 to 1344, while the first attempt to study meteorological data over a large area was made by Halley in 1686, when he prepared a map of the winds over the tropics. The next development was in 1817, when Humboldt produced his map of temperature distribution over the earth. Brandes in 1820 studied European weather for each day during the year 1783, and prepared charts of isotherms, on which was also indicated pressure variation from the normal. From this work Brandes concluded that air moves from a high pressure to a low pressure region, but is deviated to the right by the earth's rotation, while barometric depressions in general move from west to east. These conclusions were borne out later by Espy, who also determined the speed of translation of a cyclone, and discovered the existence of an ascending current from its centre. Loomis, in 1840, stated that the temperature changes are inverse to those of pressure, and three years later drew up synoptic charts showing isotherms, isobars, wind direction and the state of the sky at each station, from which he was able to conclude that winds move spirally inwards round a depression in an anti-clockwise direction, while the translatory motion from west to east is probably caused by a westerly wind in the upper air. Towards the end of the eighteenth century, Lavoisier conceived the idea of a meteorological service, at all stations of which observations should be taken simultaneously, and Romme suggested using the aerial telegraph for giving warning of storms. Kreil, in 1842, proposed to transmit by telegraph observations made simultaneously at different stations, for the purpose of forecasting weather, and a few years later Col. Reid established at Barbados a semaphore signal to give warning of the approach of storms. In 1849, Glaisher in conjunction with the Electric Telegraph Co., organised a number of stations, and on 14th June of that year the "Daily News" published the direction and force of the wind and the state of the weather at these stations, while in the same year Descartes arranged for simultaneous barometric readings to be made in different parts of Europe.

At the Great Exhibition of 1851 the Electric Telegraph Co. exhibited a large chart indicating the direction of the wind, the barometric pressure and the state of the weather at various places in Great Britain, and copies, which were issued to the public, were the first daily maps to be printed.

Dove, in 1852, was the first to publish monthly charts of isotherms, and during the same year Buys Ballot published synoptic charts showing the relation between the direction of the isotherms and the wind. In 1860 he enunciated his famous law, and succeeded in organising the first regular weather forecast service in Europe.

In 1857 Admiral Fitzroy arranged for meteorological observations to be made simultaneously at a large number of stations, and shortly afterwards valuable data were provided by two storms of great intensity which passed over the British Isles.

During the following year an exchange of information between Paris and London was commenced, and in 1860 the Meteorological Department began to receive telegraphic reports from a number of stations in the British Isles, so that six months later, in February, 1861, Fitzroy was able to forecast a storm for the first time.

In 1860, Le Verrier organised a regular service of International weather telegraphy over Western Europe, and after three years published a daily chart of the weather, showing the isobars for Europe, while later, being furnished with information from the Atlantic and the Mediterranean, he issued a chart covering the region from America to Siberia.

Marié Davy showed that depressions move at uniform speeds and along practically constant routes, and put forward his theory that they originated from the contact of northerly and southerly air currents.

Francis Galton in 1863 was the first to notice the existence of a vertical ascending current from the centre of a cyclone, and a descending one at the centre of an anti-cyclone.

Two years later Buchan published a series of charts on which isobars were traced, to represent the barometer readings corrected to sea level, while isotherms, direction and force of the wind, and the state of the weather were also indicated. He confirmed the work of previous investigators, and stated that the form of the isobars is in general circular or oval, while the diameter of a depression is rarely less than 600 miles; the air moves anti-clockwise round a cyclone, and at an angle to the direction of the isobars, at a speed which is proportional to the pressure gradient.

Jelinek, at Vienna, in 1867, confirmed that each time a depression passes to the north of a station the wind turns successively from S. through S.W., W. and N.W., to N.

During the following year, Möhn confirmed in general the results of Buchan, adding that rain and snow are more prevalent in the anterior portion of a cyclone than after the minimum pressure has passed, a fact which was verified by Hildebrandsson, who, in 1871, pointed out that the isobars are closer together round a cyclone than round an anticyclone, and that the variation of water vapour pressure follows roughly the variation of temperature. During the following year, Rev. W. C. Ley published an important treatise on the laws of winds, in which he traced the life's history of a number of cyclones, and indicated for the first time laws concerning the winds of the upper air, which he had studied by observing the motion of the higher clouds.

In 1866 the Meteorological Service of this country was entirely reorganised, and the issue of storm warnings and forecasts discontinued, but the former were resumed during the following year, owing to the expression of public opinion. In 1869, the Daily Weather Report was first lithographed for issue to the public, and in 1872 was illustrated by maps, since which time it has been extended and modified considerably. In 1879 the issue of weather forecasts was resumed, and detailed forecasts first prepared for different districts of the United Kingdom, while ten years later the area embraced by the working map was extended in order to include observations from Eastern and Southern Europe. Further extensions were also made in January, 1907, July, 1907, and December, 1909, so that observations may be included from Iceland, Azores and Madeira respectively.

On 1st April, 1910, the first chart containing a "Further Outlook" was published, and on 1st January, 1911, the existing outlines for the charts were adopted.

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260. EARLIEST JOURNAL OF THE WEATHER.

This early weather record, the first page of which is here reproduced with its translation, was kept by the Rev. William Merle, Fellow of Merton College, and afterwards Rector of Driby, Lincolnshire, between the years 1337 and 1344, and is the earliest known journal of the weather. The manuscript is preserved in the Bodleian Library, and was translated and reproduced in 1891 by G. J. Symons.

The observations are climatological, and are written in latin in Old English characters. They represent the primeval stage of weather study, in which popular weather prognostics came to be drawn from the daily scanning of the heavens and general phenological observations, until the discovery of the barometer, which afforded an increased power of weather forecasting. Inv. 1922–135.

261. HALLEY'S MAP OF THE WINDS BETWEEN THE TROPICS.

This map was produced by Halley in 1686, when he explained the cause of the trade winds and monsoons observed over the sea, in the region of the tropics, an explanation which is still accepted almost without modification.

Halley regarded the previously accepted theory that the trade winds are produced by the retardation of the atmosphere relative to the rotation of the earth as being insufficient, and attributed their origin to the temperature difference between the equator and the poles and to the earth's rotation. According to Halley, the strongly heated air in the equatorial zone rises into the higher regions of the atmosphere, and is replaced by two in-flowing currents of air from the temperate regions to the north and south. Halley also demonstrated the existence of the counter-trade winds and put forward a correct explanation of the monsoons.

In the chart the wind direction is indicated by broken lines, the wind travelling along each of these small lines from the pointed end towards the end which is broader.

(*See* Phil. Trans. 1686. p. 153.) Inv. 1922–136.

262. CHART EXHIBITED AT THE GREAT EXHIBITION, 1851.

This chart was one of a series produced in connection with the great Exhibition of 1851, and may be regarded as a sequel to the work of Glaisher and the Electric Telegraph Company in 1849, when 30 meteorological stations were organised, while on 14th June, 1849, the *Daily News* published for these stations the direction and force of the wind, and the state of the weather.

From 8th August to 11th October, 1851, the Electric Telegraph Company exhibited at the great Exhibition a large chart on which each day was indicated the state of the weather, the barometric pressure, and the direction of the wind. This chart was reproduced lithographically each day and sold to the public.

The winds are represented by arrows, and the pressures are given in figures, while the weather is indicated by letters. Inv. 192–270.

263. CHART OF THE ROYAL CHARTER STORM.

Admiral Fitz-Roy who had been placed at the head of the British Meteorological Section in 1854, in presenting his report to the Board of Trade in 1857, proposed to observe the various meteorological elements simultaneously at a large number of stations, in order to investigate the diurnal variation of these elements. While this work was in progress two storms of exceptional intensity passed over the British Isles, on 25th October, 1859, and on 1st November, 1859, the former of which is known as the Royal Charter Storm.

This chart which indicates the conditions at 9 a.m. on 26th October, shows the storm directly over the British Isles, with the minimum pressure region over the northern portion of England. The depression has passed over Ireland where the pressure is increasing and has already reached a fairly high value, while the temperature is also rising. The wind can be seen in general to be circulating in an anti-clockwise direction about the centre of the depression, while the location of clouds, rain, and snow, is greatly facilitated by the manner in which their presence is indicated.

Pressures and temperatures are not indicated by isobars and isotherms, but by thick and thin lines whose ordinates above certain fixed lines of latitude give a measure of the pressure and temperature respectively.

(*See* " The Weather Book," by Fitz-Roy.) Inv. 1922–264.

264. EARLY WEATHER CHART WITH ISOBARS.

This chart, which was introduced by Le Verrier, the originator of International Weather Telegraphy, was one of the earliest charts produced for Western Europe; and was published in the autumn of 1863 in the " Bulletin International de l'Observatorie de Paris."

Between the years 1857 and 1863 Le Verrier arranged to exchange meteorological information, telegraphically, with the various European countries, and all observations received in this manner were published in the Bulletin from January 1st, 1858. From the autumn of 1863, the bulletin contained each day a chart of the state of the atmosphere over Europe, with the isobars. In the chart exhibited, the isobars are drawn for pressures of 755, 760 and 765 mm. of mercury while the direction and force of the wind are also indicated at a number of stations, where observations have been made.

(*See* " Comptes Rendus," 1859, p. 439.) Inv. 1922–271.

265. GALTON'S WEATHER CHART.

Sir Francis Galton, in 1863, suggested a new method of publishing meteorological observations, to facilitate the construction of synoptic charts. Employing this method he studied the weather during December, 1861, over the greater portion of Europe, plotting three charts for each day, from which he deduced the existence of high pressure regions which he called " anti-cyclones."

In these charts of barometric pressure, a pressure of 29·20 or less is indicated by black disc, and between 29·21 and 29·45 by a black star. A black circle with a centre indicates between 29·46 and 29·70, and one without centre between 29·71 and 29·95, while red circle without centre represents a pressure between 29·96 and 30·20 and with a red centre from 30·21 to 30·45. Pressures from 30·46 to 30·70 are indicated by a red star, and above that value by a red disc.

On the chart for 1st December, the barometric depression is seen to be travelling from west to east, while the winds are circulating around the minimum pressure region in an anti-clockwise direction, and the temperature in general is high. The chart for 2nd December shows a wind circulating in a clockwise direction round a high pressure region, accompanied by a considerable fall of temperature. Galton, in discussing these examples, gives the first description of anti-cyclones, and indicates that the ascending current of a cyclone is replaced by a descending one in an anti-cyclone.

(*See* " Galton's " Meteorographica," 1863. Proc. Roy. Soc., 1863, p. 385.)
Inv. 1922–251.

266. BUCHAN'S METEOROLOGICAL CHART OF EUROPE.

Buchan in 1865, investigated the storms which occurred in Europe during October, November, and December, 1863, and prepared synoptic charts representing the conditions on eighteen days during this period.

Isobars are drawn at intervals of 0·2 in. of atmospheric pressure, the barometer observations being first reduced to sea level, while isotherms are indicated by dotted curves. From these charts Buchan drew the following conclusions. In general the form of the isobars is circular or oval, with the direction of its major axis coincident with the trajectory of the centre, which moves at a speed between

11 and 19 miles per hour, usually towards the east. The diameter of a depression is seldom less than 600 miles, while the air moves round it in an anti-clockwise direction, but at an angle to the isobars, while in a high pressure region the circulation is clockwise. Any variation of pressure is accompanied by a temperature variation in the reverse direction, so that the temperature rises as a depression approaches and falls as the depression passes.

(*See* Trans. Roy. Soc. Edin., Vol. 24. 1865.) Inv. 1922–272.

267. CHART OF STORMS OVER THE NORTHERN HEMISPHERE.

In 1868, Buchan published a paper on the storms of the Northern Hemisphere from March 13th to 22nd, 1859, which he illustrated by several charts. During this period six storms were observed, which are indicated on the chart exhibited by letters A to F, while in three cases the track of the storm is also given.

From these charts and tables of observations, Buchan verified his conclusions of 1865, and in addition determined that in a depression the large mass of air moving round the centre, gradually approaches the centre where it rises to a high altitude, and disperses, forming currents which are superposed over those of the lower layers. The spiral motion of the air towards the barometric centre he explains as being due to the earth's rotation.

(*See* Journ. Scot. Met. Soc., October, 1868.) Inv. 1922–273.

268. AIR-FLOW ROUND A DEPRESSION.

The Rev. W. Clement Ley, in 1872, traced the formation, development and subsequent disappearance of cyclones, with the aid of charts, and enunciated for the first time the laws of the winds in the upper air, which he studied by observation of the higher clouds.

This chart illustrates the spiral motion of the wind around a depression, and shows how the wind direction is inclined to the isobars.

As a result of his observations, Ley stated that, in general, centres of depression move in winter towards the south-east, and in summer towards the north-east, a cause of this being that in winter the isotherms lie in a north and south direction, while in summer they are directed from south-east to north-east.

Ley also showed that rainfall is always the first cause of the formation of a barometric depression, and demonstrated in a manner similar to Möhn, that the condensation of water vapour to the east of a depression is the cause of its motion in that direction, while he also concluded that in general the upper currents of the atmosphere move away from the regions of minimum barometric pressure and converge towards the high pressure areas.

(*See* Ley's "The Laws of the Winds prevailing in Western Europe," Part I, 1872.) Inv. 1922–274.

269. DAILY WEATHER REPORT, 1910.

This Daily Weather Report for 1st April, 1910, was the first report to include a "further outlook," and indicates a significant development.

On the first page is reproduced the data received by telegraph from twenty-nine British Stations, thirty-one continental stations, and seven stations in the Atlantic Islands of Iceland, Faroe, Azores, and Madeira.

This information is received in code form as arranged by international agreement.

Additional data is given in the three tables on page 4, the first table giving information from other stations in the British Isles, while in the second table, which was introduced at the request of the late Sir W. Harcourt, information extracted from the French "Bulletin International" for stations in Europe or Africa outside the range of our own telegraphic reports, is reproduced. The third table gives information received by radio-telegraphy from vessels crossing the Atlantic.

The first chart on page 2 shows the pressure readings and the isobars for sea-level pressure, with indications that are taking place at the time of observation, while the temperature and weather are represented on the second chart.

(*See* Shaw's "Forecasting Weather.") Inv. 1922–275.

270. WEATHER PROGNOSTICATOR.

This calendar was designed by Henry Troake in 1831, as an improvement upon Sir William Herschel's system. It is a framed card on which are four discs furnished with index hands, the whole serving as a calendar for a month.

The discs, with the aid of the hands, indicate :—

(*a*) The day of the week corresponding to each day of the month.

(*b*) The days of the month on which the moon is in syzygy and quadrature.

(*c*) The hour at which change of phase takes place throughout one lunation, and—based on this :

(*d*) The weather to be expected for the ensuing seven days.

Explanatory notes are printed on the card. Inv. 1907–60.

271. BAROMETRICAL INDICATOR. Lent by W. Hatfield, Esq.

This device was contrived and patented in 1879 by W. Hatfield, and was claimed to forecast the dates of storms and of fine weather from barometric observations.

It consists of a paper disc bearing barometric readings, mounted above and co-axial with a larger one which is graduated from 1 to 31 to indicate the days of a month. On the same axis a metal indicator is mounted, one hand of which is red, the opposite one being blue, while at right angles to these are two white ones.

In using the indicator, the graduation corresponding to the lowest barometer reading for the month is adjusted to the appropriate date, and the red arm of the pointer is also turned to that date, when the date opposite to the blue end indicates the next occurrence of bad weather, and the white arms mark the periods of good weather.

(*See* Pat. Specn. No. 3769 of 1879.) Inv. 1881–21.

272. LAMBRECHT'S POLYMETER. Lent by Messrs. Gallenkamp & Co., Ltd.

This instrument, which is a combination of a thermometer and a hair hygrometer, may be employed with the aid of the rules compiled by Dr. A. Troska, for forecasting weather. It is a modification of an earlier form of polymeter, the humidity scale of which has been re-calculated and extended.

The thermometer is made of Jena glass and carries on the left the usual Fahrenheit temperature scale, while the scale on the right indicates the maximum vapour pressure in millimetres of mercury corresponding to the temperature reading.

The hygrometer consists of a bundle of human hairs securely clamped at one end, and about 7 in. long, which controls the motion of a pointer over a dial bearing two graduated scales. The lower of these scales indicates the relative humidity of the atmosphere surrounding the polymeter, while the upper scale indicates the temperature difference between the existing atmospheric temperature and the dew point in degrees F.

In order that the instrument may be useful in indicating the humidity of artificially dried atmospheres, such as over-heated rooms, in which the relative humidity is less than 30 per cent., the relative humidity scale has been modified in accordance with results obtained by Gay Lussac and extended to indicate from 0 per cent. to 100 per cent.

The human hair if moistened with water does not expand to its maximum length as it does when exposed to a completely saturated atmosphere, but only to an extent equivalent to a relative humidity of 95 per cent., thereby furnishing a ready means of correcting the instrument. Inv. 1921–310.

273. WEATHER FORECASTER. Made and lent by Messrs. Negretti and Zambra.

The instrument was originally designed in 1915, by Mr. E. W. Kitchin, but was subsequently modified and improved by Negretti and Zambra. Its action is based on known meteorological laws, with certain modifications suggested by long continued observation of weather conditions and changes.

The forecaster consists of two concentric discs of brass, each capable of rotation irrespective of the other, while the larger one is surrounded by an annular ring of brass, within which it is free to rotate. This annular ring carries engraved scales for barometer height and wind direction, while the larger disc is provided with graduations indicating a falling, steady, or rising barometer in summer and winter. Upon this large disc are also engraved the forecasts, arranged radially so that the appropriate one is visible through a radial slot or window in the smaller disc.

In using the instrument, the wind direction and the height and state of the barometer are noted, after which the arrow on the larger disc, indicating the state of the barometer, falling, steady or rising, is set to the correct direction of the wind. The barometer pointer is now set to the barometer scale at the top of the instrument, when the forecast appears at the window. In the event of two forecasts being visible, a combination of the two should be taken.

(*See* Pat. Specn. No. 6276, A.D. 1915.) Inv. 1921–317

CLIMATE.

pendio o declivio

In its original and etymological sense, the word climate, from the Greek *κλιμα*, meaning a slope or inclination, was applied to one of a series of regions or zones of the earth running parallel to the equator, from which the earth's surface was supposed to slope to the poles. The first subdivision of the surface of the globe was carried out by the Greek philosophers, and was made on the basis of latitude. The division into the five zones used at the present time is generally ascribed to Parmenides, who flourished about 450 B.C., his zones being the torrid zone, two temperate zones, and two frigid zones, while early in the second century another system was put forward by Claudius Ptolemy, in which each hemisphere was divided into twenty-four climates or zones between the equator and the polar circle, each corresponding to an increase of half an hour in the length of the longest day, while between the polar circle and the pole itself, six additional zones were distinguished, each corresponding to an increase of one month in the greatest length of the day.

A subdivision of this nature, however, takes account only of the amount of solar radiation received per unit area of surface, which is but one of the factors in the determination of climate, but until comparatively recently subdivision according to latitude was the only one employed. Among other important factors exerting a controlling effect on climate may be mentioned altitude, proximity of mountains or mountain ranges, topography of the country, ocean currents, prevailing winds, and the relative distribution of land and water. If the world is first divided into zones according to temperature or prevailing wind systems, and these zones be further subdivided according to the topography of the zone, then a rational division of the globe into areas for which a general description of the climate in each case can be given, will be arrived at. In addition to the above-mentioned classifications, Koppen has suggested a subdivision of the world on a botanical basis, and Ravenstein has put forward one based on temperature and relative humidity, while a classification has been given by Herbertson, based upon a combination of temperature, rainfall, topography, and vegetation.

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274. NORMAL CLIMATOLOGICAL STATION.

At the International Congress of Meteorologists, which assembled at Vienna in 1873, it was resolved that three distinct types of meteorological stations should be recognised, based on the scheme of observations to be taken, though it has not been found practicable to adhere rigidly to this classification. The instruments exhibited represent the equipment of a Second Order or Climatological Station.

At this type of station observations are recorded at least twice each day of pressure, temperature (dry and wet bulb), wind, cloud, and weather, with the daily maxima and minima of temperature, daily rainfall, bright sunshine, and weather conditions.

The equipment of a normal or second order station consists of the following instruments :—

Station barometer.	Rain gauge.
Dry bulb thermometer.	Sunshine recorder.
Wet bulb thermometer.	Grass minimum thermometer.
Maximum thermometer.	Solar maximum thermometer.
Minimum thermometer.	Earth thermometer.

Inv. 1921–269-274.

275. RAIN-GAUGE. Made by Casella, Lent by The Meteorological Office.

This type of rain-gauge has been used for a considerable time at telegraphic reporting stations.

It consists of a large copper cylinder, fitted with a deep 8 in. brass " Snowdon " rim for the correct reading of snow and to prevent loss by splashing. The upper portion of the apparatus carries a large funnel at its lower end, and rain falling into the cylinder is collected by this funnel and flows into the collecting can which is placed inside the lower portion of the apparatus. The rain is measured by pouring the contents of the collecting can into the measuring glass which accompanies the gauge. This glass is graduated to hundredths of an inch and holds half an inch of rain. Inv. 1892–150.

276. SURFACE REPRESENTING THE MEAN TEMPERATURE OF GÖTTINGEN.

This surface represents the mean temperature at Göttingen for each hour of the day and for each month of the year.

The surface is divided from left to right into twelve sections representing the months of the year, and in a perpendicular direction into twenty-four sections corresponding to the hours of the day. In this way the surface is divided into a series of rectangles, each one of which represents by its height above the datum level the mean average temperature during a month at a certain time of the day.

From the surface it is easily seen that at Göttingen the maximum mean temperature occurs between 3 p.m. and 4 p.m. during July and August, and the minimum at about 3 a.m. in January. Inv. 1876-437.

277. MEAN TEMPERATURE DIAGRAM. Lent by The Meteorological Office.

This diagram indicates the mean monthly temperature at Edinburgh from 1801 to 1900.

A close inspection will show that during the second half of the year the mean temperature on the average decreases much quicker than it increases during the first half of the year. July and August are the months of maximum temperature, while the minimum temperature is experienced in January, the range being from about 60° F. to 35° F.

The highest monthly temperature of 64° was reached in July, 1852, while the lowest monthly record was 26·5° F. in January, 1814. Inv. 1915–357.

278. ONE HUNDRED YEARS' RAINFALL FOR LONDON. Presented by The Meteorological Office.

This chart indicates the total rainfall for London during each month from January, 1813, to December, 1912.

In general it would appear that the latter half of the year is wetter than the opening half, while the months of excessive rainfall occur more frequently in summer than in winter.

The month during this period in which the maximum rainfall was observed was October, 1880, when the amount recorded was 6·78 in. Inv. 1914–233.

279. RAINFALL DISTRIBUTION. Diagram lent by The Meteorological Office.

The diagram shows the distribution of rainfall at Valencia and Kew. The numbers in small figures indicate the rainfall in thousandths of an inch throughout the day in different months of the year.

Lines are interpolated at 20, 30, 40, 50, 60, 70, 80 and 90 thousandths of an inch, and the areas enclosed are shaded, a darker shade representing greater rainfall. Inv. 1915–358.

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