LIBRARY

OF

USEFUL KNOWLEDGE.

NATURAL PHILOSOPHY.

II.

POPULAR INTRODUCTIONS TO NATURAL PHILOSOPHY.

NEWTON'S OPTICS.

DESCRIPTION OF OPTICAL INSTRUMENTS.

THERMOMETER AND PYROMETER.

ELECTRICITY.

GALVANISM.

MAGNETISM.

ELECTRO-MAGNETISM.

WITH

AN EXPLANATION OF SCIENTIFIC TERMS,

AND

AN INDEX.

LONDON:
BALDWIN AND CRADOCK, PATERNOSTER-ROW.

MDCCCXXXII

THE THERMOMETER AND PYROMETER.

The ancients were unacquainted with any more certain mode of marking the variations of temperature, than the indications of the senses, and the limited knowledge derived from observing the melting or combustion of different substances. In modern times, instruments have been invented for noting variable degrees of heat and cold, which, under the designation of *thermometers*, or *thermoscopes*, *pyrometers*, or *pyroscopes*, are now in general use in every part of the civilized world. Their names are derived from the Greek terms θερμος, πυρ, signifying *heat*, *fire*, and μετρον, σκοπος, a *measure*, an *investigator*.

The principle on which all such instruments are constructed, is *the change of bulk which every body undergoes by alteration of its temperature*.

All homogeneous bodies, except water, within a few degrees of its freezing point, expand by heat and contract by cold.* Their expansion, then, may afford a relative measure of the increase of temperature; and their contraction, of its diminution. This law holds good in gases, liquids, and solids; and, accordingly, matter in those three states of existence has been employed in the construction of instruments for measuring the intensity of heat and cold.

The changes of volume which gases or aeriform bodies undergo, were first employed for this purpose; liquids, such as spirit of wine, oils, or mercury were next used; and lastly, the changes in the bulk of solids were applied to measure the variations of higher temperatures, which would have too much expanded gaseous and liquid bodies.

The designation of *thermoscope* or *pyroscope* might be, with most propriety, applied to such instruments; but, in conformity to common usage, it is proposed in this treatise to apply the general term *thermometer* to the instruments depending on the expansions of aeriform and liquid bodies, and *pyrometer* to those in which the expansion of solids is the measure of the elevation of temperature; and the subject will be treated under the following heads.

I. Of the common Thermometer.
 1. Its history and construction.
 2. The precautions necessary in its construction and graduation.
II. Of the Pyrometer.
III. Of Register Thermometers.
IV. Of the Differential Thermometer, and its modifications.
V. Of some peculiar applications of the Thermometer.
VI. Of the imperfections common to all instruments for the indication of heat.

Chapter I.

Of the Common Thermometer.

§ 1. *History and Construction of the Thermometer.*

The invention of the thermometer, like almost every other discovery of great utility, has been claimed for different philosophers; and national vanity has occasionally been enlisted in support of the pretensions of rival claimants. There seem, however, but two whose titles are worthy of notice.

The Italian writers generally give the honour to their countryman *Santorio Santorio*, long a physician at Venice, and afterwards a professor at Padua, who flourished about the beginning of the seventeenth century; and who had obtained just celebrity by his discovery of the insensible perspiration of the animal frame: the Dutch philosophers as unhesitatingly ascribe it to *Cornelius Drebbel*, a physician of Alkmaar, who appears to have enjoyed a high reputation as a chemist, a mathematician, and an inventive mechanical genius.

* Clay, a seeming exception, is not a homogeneous substance, of which afterwards.

Santorio expressly claims the invention as his own,* and he is supported by Borelli † and Malpighi; ‡ the title of Drebbel is considered as undoubted by Boerhaave § and Musschenbroek.|| It would now be difficult, perhaps, to decide the controversy; but it is worthy of remark, that Santorio, who was born in 1561, and died in 1636,¶ did not publish his claim to the invention till 1626;** and, although thermometers are alluded to by Robert Flud, within the first quarter of that century, yet as he travelled both in Germany and Italy for six years, we can draw no inference from that circumstance. Certain it is, that thermometers were constructed about the same time, both in Italy, and in Holland, on the same principle; and though the instruments of Drebbel were well known in Holland and England, before the fame of Santorio appears to have reached the North-West of Europe, the most recent writers have generally considered the latter as the real inventor of the thermometer. It is, however, by no means improbable that each may be justly entitled to the merit of a discoverer.

Be this as it may, the instrument was, from its imperfect construction, of little use in the hands of either, and required the successive labours of different philosophers to render it a tolerably accurate indicator of the variations of temperature.

The thermometer ascribed to Santorio and to Drebbel, is precisely the same in form and principle. It consists of a glass tube, with a ball blown on one of its extremities A, (*fig.* 1,) and having the other end open. A portion of the air in the ball is expelled by heat, and then the open end of the tube is immersed in any liquid contained in the cup *c*. As the ball cools, the included air diminishes in volume, and the liquid is forced into the stem, as at *b*, by the pressure of the atmosphere, until it replaces the volume of air which was expelled by the heat. When a heated body is applied to the ball A, the air will again be expanded, and depress the liquid in the stem; and, if this stem be a cylinder, a scale of equal parts applied to it will enable the observer to form some idea of the difference between the relative temperature of bodies applied to the ball. On the removal of the heated body, the volume of the included air again diminishes, and the liquid again rises in the stem by atmospheric pressure, until the elasticity of the air within the instrument is in *equilibrio* with that of the surrounding atmosphere. Instruments constructed on this principle are termed *air thermometers;* because their action depends on the elasticity of air; and from their having been originally employed to mark the changes of atmospheric temperature, they are described by the older writers under the name of *weather-glasses;* a denomination also given to barometers.

Fig. 1.

Drebbel appears to have devised a variety of the instrument more delicate in its indications. The globular form of the common bulb, and its small size, rendered it less susceptible of slight changes than a flattened bulb of larger diameter; and Boerhaave describes the bulb of Drebbel's thermometer, as composed of two shallow segments of large spheres, as in *fig.* 2. A, united at their edges, and in *fig.* 2. B, where it is seen in profile.

Fig. 2. A.

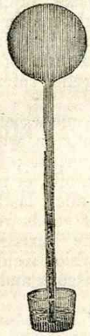


Fig. 2. B.

In the obscure, and often almost unintelligible, writings of our countryman, Dr. Robert Flud, published about the beginning of the seventeenth century, frequent mention is made of the thermometer, or, as he calls it, *speculum*

* Comment. in Galen. et in Avicen.
† De Motu Animalium. Prop. clxxv.
‡ Opuscula Posth. p. 30.
§ Elementa Chemiæ, tom. i. p. 152.
|| Elem. Phil. Nat. § 780.—Tentam Exp. Acad. Cim.
¶ Tiraboschi Storia, tom. viii. P. 1, 323.
** Commentaria in Avicennam.

Calendarium; and the common air thermometer is repeatedly figured in his singular work, *De Philosophia Moysiaca*,* with its stem equally divided into an ascending and descending series, each of 7 degrees, respectively appropriated to winter and to summer. It is obvious, that the size of an air thermometer, on such principles, is only limited by convenience, and the length of the column of liquid which the pressure of the atmosphere can sustain in the tube. As originally made, they were unwieldy, they could not be applied to high temperatures, and were, besides, liable to two very important objections, as indicators of the atmospheric changes of temperature,—they were liable to be affected not only by heat and cold, but by the varying pressure of the atmosphere; and the scales adapted to them were arbitrary, and without fixed points for the comparison of observations made with different instruments.

The first objection was foreseen and obviated by the scientific members of the Florentine academy *del Cimento*, assembled under the auspices and patronage of Fernando II., Grand Duke of Tuscany. In the first article in the published transactions of that learned body,† we find a full description and delineation of a thermometer from which the influence of atmospheric pressure is excluded. The expansion of spirit of wine is employed to ascertain the temperature, instead of the dilatation of air; and the instrument is sealed *hermetically*, as it is termed, or has its orifice closed by melting the glass, after the introduction of as much spirit as fills the bulb and a portion of the stem. The method employed by the Florentine academicians is nearly that still used by the makers of the instrument; namely, by heating the bulb in the flame of a lamp, to expel the air, and then immersing the open end of the tube in the liquid destined to fill the thermometer. As the ball cools, the atmospheric pressure forces the liquid into the stem and ball, to supply the *vacuum;* and the orifice is closed by melting with the blowpipe the end of the tube, from which any excess of the liquid may be previously expelled by again heating the ball. (*Fig.* 3.)

The Florentine academicians appear also to have been aware of the necessity of adapting some fixed scale to the tube; but their attempts were not very successful. They described the thermometer as consisting of a ball and tube of such relative size, "that on filling it to a certain mark of its neck with spirit, the cold of snow and ice will not cause it to fall below 20 degrees measured on the stem; nor, on the other hand, the greatest heat of summer expand it more than 80 degrees."* This method is undoubtedly erroneous, inasmuch as the last point could be of no determinate temperature; and their method of graduation is in itself rather rude. The tube is directed to be divided by compasses into ten equal parts, these divisions are to be marked "by a little button of *white* enamel; and these may be further subdivided by the eye, and the intermediate degrees marked by buttons of glass, or of *black* enamel."

Fig. 3.

This instrument was variously modified by them to suit different purposes. The ball was occasionally enlarged, and the tube reduced in thickness to render the instrument more sensible; and in the work already quoted, we find a figure of a thermometer of this sort, with the stem spirally twisted to render it more portable, and less liable to accident.

Another invention of those philosophers to indicate changes of temperature may be here noticed. It consisted of hermetically sealed spherules of glass, of different specific gravities, introduced into a wide tube filled with pure spirit. The degree of the Florentine thermometer at which each sank was noted, and by hanging this instrument in an apartment, it somewhat slowly showed the variations of the temperature of the surrounding air.† Imperfect as these attempts were, they paved the way to very important improvements in thermometers.

The indefatigable Boyle appears early to have turned his attention to the improvement of the thermometer, and his first attempts were on the air thermometer, or the weather-glass, as it was then styled. He rendered the instru-

* Folio, Goydæ, 1638.
† Saggi di Naturali Esperienze.

* Saggi di Naturali Esperienze, p. 4.
† Saggi, p. 10.

ment more convenient, by making one reservoir for the liquid and for the air at the bottom of the tube; and thus the thermometer might be conveniently dipt in a fluid, or applied to any body for ascertaining its temperature. "The thermometer," he says, "being made by the insertion of a cylindrical pipe of glass (open at both ends) into a phial or bottle, and by exactly stopping with sealing wax, or very close cement, the mouth of the phial, that the included air may have no communication with the external, but by the newly mentioned pipe."* If a portion of any liquid sufficient to cover the lower extremity of the pipe, be contained in the bottle, it is obvious, that the expansion of the enclosed air will elevate the included liquid in the cylindrical pipe; and this liquid will again descend on the contraction of the enclosed air: *fig.* 4, 5. Mr.

Fig. 4.

Fig. 5.

Boyle likewise showed that no dependence could be placed on the indications of *open* air thermometers, under different degrees of atmospheric pressure; and he states, that on plunging the bulbs of different thermometers in liquids of very different specific gravities, as mercury and water, the liquor in the stem stood at unequal heights, though both had been long exposed to the same temperature.

The Florentine thermometer was about that time introduced into England, and duly appreciated by both Boyle and Hooke. The specimen seen by these philosophers was filled with *colourless spirit*, but they made use of spirit of wine, tinged by cochineal, "of a lovely red;" and, says Boyle, "'tis pleasant to see how many inches a mild degree of heat will make the tincture ascend in the cylindrical stem of one of these useful instruments."* Boyle was fully aware of the imperfection of the scales hitherto applied to the thermometer, and sought to discover a remedy. He proposed to obtain a fixed point in the scale, by marking the height of the liquid in the stem of the instrument, when the ball was placed in thawing oil of aniseeds; a point which he preferred to that of thawing ice, because the former could be readily obtained at any time of the year. His method of making two or more comparable thermometers, however, would be found extremely difficult, if not impossible, in practice; it is best explained in his own words. "For if you put such rectified spirit of wine into a glass, the cavity of whose spherical, and that of its cylindrical part, are as near, as may be, equal to corresponding cavities in the former glass, you may by some heedful trials, made with thawed and recongealed oil of aniseeds, bring the second weather-glass to be somewhat like the first; and if you know the quantity of your spirit of wine, you may easily enough make an estimate, by the place it reaches to in the neck of the instrument, whose capacity you also know, whether it expands or contracts itself to the 40th, the 30th, or the 20th part, &c. of the bulk it was of, when the weather-glass was made."†

Boyle mentions that an "*ingenious man*"‡ had proposed the freezing of distilled water, as a fixed point in the scale of thermometers; but he himself evidently gives the preference to the congealing point of aniseed oil. Dr. Halley proposed to regulate the scale by the uniform temperature of such a cavern as that under the Observatory of Paris, or the point at which *spirit boils;* and he also suggests the fixing of the scale from the *boiling of water*. This point he considered as an invariably fixed one, not liable to alteration from external circumstances; and the same idea was entertained by Amontons. With a single point so fixed, the method attempted by Boyle, Halley, and Hooke was to calculate the proportion of the stem to the ball, and thus to determine the increase in bulk of the whole liquid, by a certain temperature. Dr. Hooke describes a method of obtaining this by comparing the expansions

* Works of Hon. Robert Boyle, folio, vol. ii. p. 247.

* Works, vol. ii. p. 249.
† Works, vol. ii. p. 247.
‡ He undoubtedly alluded to Hooke.

of the thermometer to be graduated, with those of the liquid in an accurately formed cylinder of metal, two inches in diameter and depth, and having cemented to its top a glass pipe, just $\frac{1}{10}$ of the diameter of the cylinder:* measure off two inches of the stem, above the cylinder of metal, and divide the space between them into 10 equal parts, so that each division of the stem will = $\frac{1}{1000}$ of the capacity of the cylinder. The thermometer to be graduated has the commencement of its scale, or 0°, fixed by marking the point at which the included liquid stands in the stem, when the bulb is plunged in distilled water just begining to freeze; and the rest of the process he details in these words. "Fill this cylindrical vessel with the same liquid wherewith the thermometers are filled, then place both it and the thermometer you are to graduate in water that is ready to be frozen, and bring the surface of the liquor in the thermometer to the first mark, or 0°; then so proportion the liquor in the cylindrical vessel, that the surface of it may just be at the lower end of the small glass cylinder; then very gently and gradually warm the water, in which both the thermometer and the cylindrical vessel stand, and as you perceive the tinged liquor to rise in both stems, with the point of a diamond give several marks on the stem of the thermometer, at those places which, by comparing the expansion in both stems, are found to correspond to the divisions of the cylindrical vessel; and having by this means marked some few of the divisions on the stem, it will be very easy by these to mark all the rest of the stem, and accordingly to assign to every division a proper character."† This ingenious method is, however, more difficult in execution than any one, unacquainted with such operations, will readily suppose; and it presupposes, what is not easy to accomplish, a very perfect adjustment of the metallic cylinder and the glass stem in the standard instrument.

Dr. Hooke appears invariably to have used in his thermometers spirit of wine "highly tinged with the lovely colour of cochineal, which he deepened by pouring in it some drops of common spirit of urine."

The sagacity of our illustrious Newton saw the importance of improving thermometers. He appears to have been early aware of the inconvenience of spirit as a thermometric fluid, and employed linseed oil to fill his thermometer. It has the advantage of being able to endure a very considerable temperature, without endangering the bursting of the tube, and therefore can be applied to a higher range of temperature than a spirit thermometer. It has the disadvantage, however, to be more sluggish in its movements, and to adhere much to the inside of the tube, while it differs greatly in its fluidity at different temperatures. Newton perceived the convenience of having two fixed points in the construction of the scale; and he used the freezing and boiling points of water as the most suitable for this purpose.* His method of graduating his oil thermometer is given in the *Principia*. The oil, at the temperature of melting snow, was supposed to consist of 10,000 equal parts, which, when heated to the temperature of the human body, expanded to 10,256; at the temperature of water strongly boiling to 10,725; and at that of tin beginning to congeal, to 11,516 parts. In the first instance the ratio of expansion is as 40 to 39; in the second as 15 to 14; and in the third as 15 to 13 nearly. Hence, by taking the temperature of the oil in the ratio of the rarefaction and assuming 12 as the heat of the human body, the temperature of water briskly boiling will be 34 degrees, and of congealing tin 72 degrees.†

Newton continued his scale of temperature farther by observing the rate of cooling of heated bodies, until he could apply his thermometer to them, on the principle that equal decrements of temperature take place in equal times. It was thus he estimated the temperature of iron heated to the utmost intensity of a small kitchen fire equal to 194 degrees, and in a fire of wood about 200 or 210 degrees of the same scale.

It is perhaps unfortunate for the philosophy of heat that more sublime and dazzling objects drew Newton to other pursuits. Though he led the way to just views of the subject, neither he, nor any of his predecessors, appear to have been aware of the influence of the varying atmospheric pressure on the boiling points of liquids; nor do any of

* Micrographia.
† Micrographia, p. 39.

* Phil. Trans.
† "Ponendo caloris olei ipsius, rarefactione proportionalis, et pro calore corporis humani scribendo 12, prodest calor aquæ ubi vehementer ebullit partium 34, et calor stanni ubi liquescit prodest postea 72." Princip.

them seem to have considered that the varying expansions of the thermometric liquids at different temperatures, and the expansions of the glass of the instrument, must have materially affected every attempt to subdivide the stem of the thermometer into fractional parts of the whole bulk of the contained liquid.

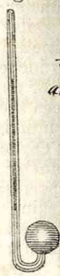
One of these questions, however, seems to have about that time engaged the attention of philosophers, *viz.* whether equal increments of temperature caused equal expansions of the thermometric fluid. Dr. Brooke Taylor tried the experiment with an oil thermometer, by mixing definite portions of hot and cold water, and measuring the temperature of the mixture. His conclusion was in the affirmative, but the delicacy of his instruments was unequal to the solution of this nice problem, although he has the merit of pointing out how the problem is to be solved.

The construction and uses of thermometers early engaged the attention of the French *Académie des Sciences;* and several were constructed by Mr. Hubin for that learned body; but neither these, nor the thermometers placed in the observatory of Paris by De La Hire, appear to have been graduated on any fixed principle. The *Memoirs of the Academy* contain several descriptions of thermometers, and an account of many interesting observations, with these instruments; but the first alteration in their construction deserving of notice is the air thermometer of Geoffroy, which from the short description appears to be an improvement on that of Boyle, inasmuch as it is not affected by atmospheric pressure. He describes the tube as without any opening, except one, which descends almost to the bottom of the ball, and there dips into a small portion of coloured liquid.* There is no figure given in the original, and but a very rude one in our *Philosophical Transactions*,† seemingly from the description. It is not stated how the ball was joined to the tube, but it was most probably by cement, as represented in *fig.* 6.

Fig. 6.

M. Amontons clearly saw the importance of fixed points in the thermometric scale, and proposed to obtain them from the boiling point of water.* His thermometer consisted of a tube four feet in length, ending below in a ball bent upwards, as in *fig.* 7, and open at the other extremity. The measure of the temperature was the elasticity of a given portion of air included in the ball, and subjected to a pressure equal to *two atmospheres*, by adding to the usual atmospheric pressure that of a column of mercury of 28 French inches. Each half-inch of his tube is therefore equal to one inch under the usual pressure; and hence at a mean pressure of 28 French inches, the volume of the compressed air is really equal to 56 inches under the usual pressure.

Fig. 7.



vide addª p.64

In passing from the mean temperature of a Parisian spring to the heat of boiling water, Mr. Amontons found that these 56 inches were increased by one-third, or 18 inches 8 lines, and therefore he fixed the boiling point of his scale at $56+18{,}8=74$ inches 8 lines. To measure this on Amontons's principle a tube of 47 inches is quite sufficient; for 74 inches 8 lines minus 28 inches, the atmospheric pressure which need not be considered in the length of the tube, is equal to 46 inches 8 lines; and, indeed, as in Amontons's process, the compression at high temperatures is rather more than in the duplicate ratio of the air we breathe, the mercury in boiling water will not rise above 45 of his scale.† There is a slight discrepancy between the original account of Amontons's thermometer and that given by Martine, who states its boiling point at 73 inches, and its freezing point at $51\frac{1}{2}$ inches; but, according to the Academicians, the latter will be at 52 inches and about 8 lines. The ingenious contrivance of the double pressure enabled him to apply the instrument to measure the temperature of boiling water, by a tube less than four feet in length.‡

Although the idea of Amontons was a fine approximation to an universal standard for a thermometric scale, the instrument is liable to such objections

* Mém. Acad. tom. xiii. p. 120. It was read in May, 1700.

† Phil. Trans. vol. xxiii. p. 962.

* Mémoires de l'Acad. for 1702.

† Mémoires de l'Acad. des Sciences, tom. xv.

‡ Mém. Acad. des Sciences, tom. xv. for 1702

that its principle seems scarcely ever to have been put in practice, except by its inventor and the Marchese Poleni.* It is difficult to construct two instruments which shall correspond, from the varying expansibility of air according to its moisture or dryness; the indications are liable to be affected by the fluctuations of atmospheric pressure; it is liable to be deranged by the escape of a portion of the included air, when the instrument is moved about; it is, moreover, too unwieldy, and very liable to be broken.

Much about the period when those attempts to perfect the thermometer were made in France, important improvements on it were effected in the north of Germany and in Holland, by the introduction of quicksilver as the thermometric fluid.

The objections we have stated to the use of the spirit thermometers, and to the oil thermometer of Newton, led the way to the employment of quicksilver in the construction of the instrument. Dr. Halley alludes to several advantages of quicksilver as a thermometric fluid, but seems to have rejected it on the ground of its slight expansion by heat,† although this objection might have so easily been obviated by increasing the disproportion between the bulb and the diameter of the tube. On this account the claim set up for his title to priority of invention may justly be denied. It is most probable that science is indebted for this great improvement to Roëmer, the celebrated astronomer of Dantzic, to whom the invention is ascribed by Boerhaave, as well as the first idea of the scale now known as that of Fahrenheit. Boerhaave further adds, that as early as 1709, Roëmer observed with that instrument a natural cold so intense as to sink the mercury to the beginning of the scale.‡ Thermometers of this construction began to be made by Daniel Gabriel Fahrenheit, a native of Dantzic, who afterwards lived at Amsterdam, in so admirable a manner, that he has generally been considered the original inventor; they were speedily spread over the north of Europe under his name, and still maintain their ground in several countries, especially in Britain.

It has commonly been alleged, that at the time when Roëmer's or Fahrenheit's scale was proposed, its zero was derived from the artificial cold produced by a mixture of salt and snow, then supposed to be the lowest possible reduction of temperature. This, however, seems to be inaccurate: Boerhaave* gives a different account of the matter, which is repeated in the *Philosophical Transactions.*† The zero was fixed from "the lowest cold observed in *Ysland,*" (Iceland); which was supposed to be as low a temperature as was likely to become the object of philosophic investigation: but when artificial methods of reducing the temperature of bodies much lower, and occasional natural colds brought the mercury below that point, a scale of equal parts was extended below the 0°; the ascending series of degrees being distinguished by sign + or *plus*, and the descending series by the sign − or *minus*.

The principle which dictated the *peculiar division* of the scale is as follows. When the instrument stood at the greatest cold of Iceland, or 0 degree, it was computed to contain 11,124 equal parts of quicksilver; which, when plunged in melting snow, expanded to 11,156 parts; hence the intermediate space was divided into 32 equal portions, and 32° was taken as the freezing point of water: when the thermometer was plunged in boiling water, the quicksilver was expanded to 11,336 parts; and therefore 212° was marked as the boiling point of that fluid.‡ *In practice*, Fahrenheit determined the divisions of his scale from two fixed points, the freezing and boiling of water: *the theory* of the division, if we may so speak, was derived from the lowest cold observed in Iceland, and the expansions of a given portion of mercury.

The mercurial thermometer was used by the Italian philosopher Renaldini before the end of the seventeenth century: and he proposed, in 1694, an ingenious method of graduating it between the freezing and boiling points of water, by successive mixtures of determinate weights of boiling and ice cold water.

The great advantages of Fahrenheit's thermometer over every other previous invention, consisted in its applicability to a greater range of tempera-

* Phil. Trans. No. 421.
† Phil. Trans. vol. xvii. p. 652.
‡ Boerhaavii Chemiæ, tom. i. p. 720.

* Chemiæ, tom. i. p. 720.
† Vol. xliv. p. 680.
‡ For 11156 — 11124 = 32, and 11336 — 1124 = 212.

ture, from the freezing to the boiling point of quicksilver, in its not soiling the containing tube, and in its receiving the impressions of heat and cold more readily, while its density rendered capillary tubes filled with it perfectly visible; and thus the instrument became more portable and delicate. We may also remark, that at the period of its invention, there was no other scale in use that could pretend to vie with it in accuracy; and it still possesses the peculiar advantages, that from the lowness of its 0°, the observer is seldom troubled with *negative* degrees, and from the number of its divisions has rarely, in ordinary operations, to use fractions of a degree.

We are indebted also to Fahrenheit for the knowledge of the fluctuation of the boiling point of water, according to the difference of atmospheric pressure.* Le Monnier, in 1739, confirmed this fact, by noting the temperature of boiling water on the top of Mount Canigou, one of the Pyrennees; and in 1744 it was fully established by Martin Folkes, who found that water boiled on the summit of Pic du Midi 15° of Fahrenheit's scale lower than at Bagneres; and at the latter place 3½° lower than at Bordeaux; while he proved that elevation in the atmosphere had no sensible influence on the stability of the freezing point.† These facts led to an important correction in fixing the boiling point of water or other liquids.

It would now be a waste of time to describe minutely the various thermometers which were in use in France and England before the time of Fahrenheit. They were all without fixed points in the scale; and though they were vaunted as constructed after the models in the Royal Observatory at Paris, or in the apartments of the Royal Society of London, they gave most discordant results. An analysis of the most noted of them has been elaborately and ingeniously attempted by Dr. Martine in his valuable Essays, and the results presented in the very convenient form of a tabular view. We shall therefore pass at once to notice some of the other more accurate thermometers that have been employed in different parts of Europe, although the principle in them all is similar to what has been already described.

The thermometer with which the Dutch philosopher Cruquius made the observations published in the *Philosophical Transactions*, (vol. xxxiii. No. 381,) was an air thermometer, on which he states the freezing point of water to be indicated by 1070°, and boiling water by 1510°: the lowest known cold, which seems to have been the beginning of his scale, he gives = 1000°.

The objections to the thermometer of Amontons are clearly stated by Reaumur,* who proposed to adopt the freezing and boiling points of water as fixed points in the scale, but employed spirit as the thermometric fluid. He unquestionably fell into error when he stated that 1000 parts of strong spirit dilated to 1087.5 parts in passing from the freezing to the boiling point of water; for how could strong spirit sustain so high a temperature without being partially converted into vapour? His proposal was to use spirit of just such strength, that between these two temperatures it should expand from 1000 to 1080; and, commencing his scale or 0° at the freezing point of water, he made the boiling point 80°. The principle of this construction was good; but Dr. Martine has shown that from the large size of the bulbs of his thermometers, which were from 3 to 4 inches in diameter, and the short time they were immersed in the freezing mixture, they could not have acquired an uniform temperature; and accordingly Martine found their freezing point too high,† and the error in the boiling point from the cause already alluded to, must have been still greater.

These errors might have been obviated by the use of quicksilver instead of spirit. This was accordingly soon done; by whom first is uncertain, although there is strong reason to believe by De Luc; and the mercurial thermometer, with the 0° at the freezing point of water, and 80° as its boiling point, soon became general in France, and well known over Europe under the name of *Reaumur's Thermometer*. The only material objections to such a scale, when the instrument is accurately made, arise from the largeness of the divisions rendering fractional parts of a degree of frequent occurrence, and the elevation of 0° often introducing + and — degrees in a series of observations, even at common natural temperatures.

The mercurial thermometer of Mons.

* Phil. Trans. xxxiii. No. 381.
† Phil. Trans. vol. xliii. p. 32.

* Mémoires de l'Acad. des Sciences, for 1730.
† Martine's Essays, Edin. 1792, p. 23.

J. De Lisle of St. Petersburg, differs little in principle from the instruments just mentioned; but its graduation is inverted. His 0° is at the boiling point of water, and he continues the graduation *downwards:* and conceiving the mercury, at that temperature, to be divided into 100,000 parts, he determined the degrees by the contractions of the whole mercury as it cooled, expressed in such parts.* The distance between the freezing and boiling points of water on this scale is 150°, as ascertained by Dr. Martine, who examined one of Dr. Lisle's original thermometers: but this thermometer seems to possess no advantage over those just described, and never came into general use except in Russia, where it is still employed.

Our countryman, Dr. Stephen Hales, employed another thermometer in his experiments on vegetable physiology. The 0° was at freezing water, and the highest point was ascertained by placing the instrument in hot water, on which wax was just beginning to congeal; the intervening space was divided into 100°.† This near approach to a true centesimal scale was defeated by the uncertainty of the upper point, arising from his using spirit instead of mercury in the tube, and the difficulty of ascertaining the exact moment of the congelation of the wax.

In the year 1742, the Swedish philosopher Celsius, professor at Upsal, divided *centesimally* the thermometer known in the north by his name, and which has, since its tacit adoption by the French chemists, obtained additional celebrity as the *Thermomètre Centigrade.* Celsius commences his scale at the freezing point of water, and divides the space between that point and the height of the mercurial column in boiling water into 100°. This appears a more natural and simple division than any that had been previously proposed, and it possesses several advantages; but it has two inconveniences of some importance in many practical operations. Thus, from the high position of the 0°, natural colds are frequently to be noted by a descending series of figures, and one column of observations may be hence embarrassed by + and − degrees; while from the large space intercepted between the degrees, the observer is frequently obliged to compute fractional parts of a degree.

* Phil. Trans. vol. xxxix. p. 221, for 1736.
† Vegetable Statics, vol. i. p. 58.

M. de la Lande, in 1804, proposed a new thermometric scale, the 0° or mean point of which he would fix at the mean temperature of the earth; which he gives as = to 9°.5 of Reaumur's scale; and his degrees were to be the ten millionth part of the volume of the mercury in the instrument. Among the advantages of such a division, he considers the simplification of expression in meteorological observations—thus, 30° would express the heat of summer and cold of winter; 40° a hot summer and severe winter; while the smallness of the degrees would obviate the use of fractions of a degree. The boiling point of water would be at + 133, and the congelation of mercury at − 74°; ice would melt at − 18°, and the zero of Fahrenheit would be at − 44.*

This proposition has never been adopted; and its advantages seem overrated by the inventor. It only obviates one of the objections urged against the scale of Celsius, and is inferior in simplicity either to a millesimal division of the interval between the freezing and boiling point of water, or to the thermometric scale proposed by the late Dr. Murray of Edinburgh. That acute philosopher proposed to employ the freezing and boiling points of mercury itself as the extremes of his scale, and to divide the intervening space into 1000°. It is a more natural division than any hitherto proposed, inasmuch as it is taken from relations of the best thermometric fluid itself to heat: and if we suppose these two points to have been accurately fixed at − 40° and + 655° of Fahrenheit, the freezing point of water would be 99°, and its boiling point 347° on Murray's scale.

The advantages of this scale, are that it will very seldom, in natural temperatures, render the introduction of − degrees necessary, and the smallness of the divisions supersede the employment of fractional parts of a degree, in ordinary cases; two circumstances of considerable importance in a long series of thermometric observations.

Magellan informs us,† that M. Achard of Berlin invented a thermometer for ascertaining high temperature, which is a true *Pyrometer*, and might have been introduced in the next section. It consists of a ball and tube of semitranslucent porcelain, highly baked,

* Journal de Physique, 1804. Nicholson's Journal, 8vo. vol. ii. p. 61.
† Sur la Théorie du Feu Elémentaire, 1780.

containing a fusible alloy of two parts of bismuth, one of lead, and one of tin. In the temperature of the air, it remains solid in the tube; it becomes fluid about the boiling point of water; then, as a fluid, expands by increase of temperature; and its expansion being seen through the semitranslucent tube, which is divided into equal parts or degrees, becomes an indication of the temperature applied to the ball.

This invention promises to be of considerable utility, and is capable of extension by the employment of less fusible metals. From the simplicity of its construction, it is rather surprising that it has not been more generally known, and employed in potteries, where the instrument could be easily made. An instrument on this construction would be a better method of uniting the scales of the common thermometer and pyrometer than any heretofore employed.

Of these various thermometric scales there are but three in very general use, *viz.* that of Fahrenheit, Celsius, and Reaumur. Fahrenheit's is chiefly used in Britain, North America, and Holland: the scale of Celsius was adopted by the French, and is now employed in most parts of the north and middle of Europe: Reaumur's was the only one used in France before the Revolution, and is still that best known in Spain and in some other continental states; but it is further important, as affording the terms in which numerous very valuable observations are recorded.

For these reasons it is useful to have formulæ for readily converting one scale into the equivalent degrees of the other two. The freezing point of *water* on Fahrenheit's scale is at 32°, and on those of Celsius and Reaumur at 0°, while it boils on each respectively at 180°, 100°, and 80°, above that point. Hence the degrees of Fahrenheit are to those of Celsius as $180 : 100 = 18 : 10 = 9 : 5$, and to those of Reaumur as $180 : 80 = 18 : 8 = 9 : 4$ —, or 9° of Fahrenheit are equal to 5° of Celsius and to 4° of Reaumur. Therefore, when we wish to convert the degrees of Celsius into those of Fahrenheit, we have to multiply the number of the former by 9, divide by 5, and add 32; to reduce the degrees of Fahrenheit into those of Celsius, the *converse* of the proposition will give the required result; that is, from the degree of Fahrenheit subtract 32, then multiply by 5, and divide by 9. When we wish to convert the degrees of Reaumur into those of Fahrenheit, we have to multiply by 9, divide by 4, and add 32; and subtracting 32 from the given degree of Fahrenheit, multiplying the remainder by 4, and dividing by 9, will give the equivalent degree of Reaumur's scale.

The following short formulæ will apply to each case:

1. $$F = \frac{9\,C}{5} + 32.$$

2. $$C = \frac{(F - 32) \times 5}{9}.$$

3. $$F = \frac{9\,R}{4} + 32.$$

4. $$R = \frac{(F - 32) \times 4}{9}.$$

These formulæ apply to all degrees above the ~~freezing point of water~~ zero of each scale; but when negative degrees of Celsius are to be converted into the equivalents on Fahrenheit's scale, multiply the degree of Celsius by 9, divide by 5, and the difference between the quotient and 32 is the required degree of Fahrenheit: or when negative degrees of Fahrenheit are to be reduced to their equivalents on the scale of Celsius, add 32 to the given degree of Fahrenheit, then multiply by 5, and divide by 9. By substituting 4 for 5, the same formulæ will apply to Fahrenheit and Reaumur, all which may be thus expressed:

1. $$-F = \frac{9\,C}{5} \backsim 32.$$

2. $$-C = \frac{(F + 32) \times 5}{9}.$$

3. $$-F = \frac{9\,R}{4} \backsim 32.$$

4. $$-R = \frac{(F + 32) \times 4}{9}.$$

The formulæ are convenient for reducing a few examples from one scale to another; but when they perpetually occur in reading or writing it is very useful to have comparative tables, from which, by one glance, the desired information may be obtained.

§ 2. *Precautions necessary to be observed in constructing accurate Thermometers.*

A general idea has been already given of the mode of constructing a thermometer, but where much accuracy is required there are many niceties that demand attention.

1. The tube should be of equal diameter throughout the whole stem. As obtained from the glass-house, the tubes are in reality frusta of very elongated hollow cones, which, by extension, become more or less nearly cylindrical; and as the divisions of the scale are usually equal, it is very important that the tube should not perceptibly differ from a true cylinder.

For these purposes, after a tube has been chosen by the eye as equal in calibre as possible, the best makers blow a bulb on it, and introduce a short column of mercury into the stem, perhaps an inch in length, which is accurately measured on a fine scale of equal parts, in different portions of the tube, as the column is, by the heat of the hand, moved from the bulb to the open extremity of the tube. Should the mercurial column subtend the same number of divisions on the scale in every part of the tube, it may be considered as a perfect tube for a thermometer.

The late Mr. Wilson, of Glasgow, introduced thermometric tubes of an *elliptical* bore. The advantage of this form is, that a very small column of mercury is much more visible when it is expanded at right angles to the line of vision. If due precaution be taken to ensure the equality of the tube this form answers well, especially for ordinary purposes; but where great nicety is required, we would recommend the cylindrical tube.

2. The form and proportion of the bulb may vary according to the purpose for which the instrument is to be applied. The larger the bulb in proportion to the stem, so much more delicately susceptible of changes of temperature will be the thermometer. The spherical bulb is to be preferred, for this shape is least likely to be affected by the varying pressure of the air; but when the bulb is very large this form renders the thermometer less susceptible of minute changes of temperature, and pyriform or cylindrical bulbs are usually adopted. All large bulbs are more or less sensibly affected even by slight pressure. An examination of more than fifty common thermometers, with large spherical bulbs, in the work-shop of an excellent artist, afforded the writer of this article an opportunity of observing that by slightly compressing their bulbs between the finger and thumb, the mercury in the stem rose and fell alternately several degrees, as the pressure was increased or diminished. The bulb and stem are usually in the same straight line, but for various purposes the bulb is occasionally placed at various angles to the stem.

In forming the bulb the mouth must not be employed to blow it, otherwise moisture will condense in the tube, which is expelled with much difficulty, and if suffered to remain, will greatly impair the value of the thermometer. Good instrument-makers use a small bottle of caoutchouc, or elastic gum, fastened by a thread on one end of the tube, while the other extremity is softened by the flame of a tallow lamp, urged by a blowpipe. By compressing the bottle, after the orifice of the softened end of the tube is closed by the aid of another rod of glass, a bulb is formed of any required size; but a neat workman will rarely consider the first blown bulb sufficiently well formed for his purpose. It is generally dilated till it bursts; the glass, while still soft, is compressed into a rounded mass, and a fresh bulb formed of a regular shape, and size proportioned to the calibre of the tube. Should the artist not intend to fill the tube immediately, he usually hermetically seals the other end of the tube to prevent the entrance of damp air or dust.

3. The precautions necessary in filling thermometers with mercury are exceedingly well given in Nicholson's *Chemistry*.*

The mercury should be clean, dry, and recently boiled, to expel air as much as possible. Mercury is often cleaned by thermometer-makers by agitating it in a phial, for some time, with sand, and then straining it through leather; for nice instruments it should be distilled from iron filings, or reduced from its sulphurets, in clean iron vessels, at a moderate heat.

The bulb to be filled is heated in the flame of a lamp, and the open extremity of the tube is immersed in the mercury; as the bulb cools, the pressure of the atmosphere forces the fluid into the tube and ball. Mr. Nicholson recommends, that the bulb should be but moderately heated at first; so as, on cooling, to become only half filled. He advises the open end of the tube to be

* Edition 3rd, p. 24.

kept under the surface of the mercury, and the instrument to be retained as nearly in the horizontal position as possible, while the flame of a newly snuffed candle is applied to the bulb, so as to boil the included mercury. Thus the remaining air will be expelled; and on removing the candle, the mercury will suddenly fill the ball and part of the tube.

4. To ensure a delicate thermometer, the mercury is next to be boiled in the thermometer. For this purpose a slip of clean writing paper is to be rolled tightly around the upper part of the tube, so as to form, beyond the orifice, a cup or cylinder capable of containing as much mercury as the bulb: secure this round the tube with a thread, put a drop of mercury into the paper cavity, and again apply heat to the bulb, holding the tube by the part covered by the paper. The mercury will soon boil, and about one-half of the contents of the ball will rush up into the paper cup. On removing the bulb from the candle, the mercury will suddenly return. Repeat this operation again and again, until the speedy boiling of the mercury, and the diminished noise and agitation, show that the whole has been well heated, and air and moisture expelled from it.

Should there be the least moisture in the tube before this part of the operation, it is very likely to burst the bulb; and the same accident is likely to happen, if the mercury be too strongly boiled the first or second time.

An experienced eye will readily judge what range of scale the thermometer will have; but this point can easily be ascertained, before the tube is closed, by heating the bulb in the mouth, and then immersing it in cold water or melting ice. When the latter is used, the operator can at pleasure fix how far from the bulb he will have the freezing point; for, by keeping the tube more or less filled, he can adjust that point to any desired height.

5. The tube is now to be *hermetically sealed*, that is, closed by the fusion of the glass at the upper extremity, which for this purpose is previously drawn to a capillary orifice. When it is intended to free the tube entirely from air, which is the best method with mercurial thermometers, heat is again to be gently applied to the bulb, which at the same moment is to be softened by another flame, and closed in the usual way, as soon as the mercury reaches the extremity of the tube. When the ball has cooled a little the sealing is rendered more secure by fusing the glass more fully around the top, so as completely to obliterate the orifice. If the vacuum be perfect, the mercury will fall to the extremity of the tube on inverting the thermometer, unless the calibre be absolutely capillary; in which case capillary attraction will overcome the force of gravity, and the mercury will retain its position in the tube, in every situation of the instrument.

Where there is a complete vacuum in the tube, the mercury must be well boiled before the sealing, as above directed; and when we choose a thermometer, the ready falling of the mercury, on inversion of the tube, is the best test we can have that the mercury has been well freed from air and moisture. This vacuum is not, however, so essential to the true action of the thermometer as was once supposed. A thermometer with a small dilatation of the tube when sealed, containing some common air, has lately been recommended as preferable to the instrument with a vacuum on the surface of the mercury.

M. Flaugergues* first called attention to the fact, that when old thermometers are placed in melting ice, they seldom fall quite so low as the mark of freezing on their stems, especially when the whole air has been expelled from them. This difference he found to amount sometimes to 0.9 of a degree. The same fact has been confirmed by MM. De la Rive and F. Marcet,† and also by Bellani‡ and Arago.§ The writer of this article possesses three thermometers; one very delicate, made by Ramsden, and two well made instruments by Lovi of Edinburgh, all which have been in his possession upwards of a quarter of a century. On lately placing them in a vessel filled with pounded ice, in a warm apartment, they all showed a slight elevation of the freezing point. That made by Ramsden has a capillary tube and small spherical ball; the other two have small pyriform bulbs, and the mercury readily falls to the extremity of the tube on inverting them: yet Ramsden's stood about 0.6 of a degree above the freezing point, and the other were just perceptibly above it.

* Bibliothèque Universelle, tom. xx. 1823.
† Ib. tom. xxii.
‡ Giornale di Fisica, tom. v.
§ Annales de Chimie, tom. xxxii.

M. Flaugergues attributes this change to the effect of long continued atmospheric pressure on the bulbs of thermometers, in which there is no air to counteract it. De la Rive and Marcet give the same explanation, and remark how this circumstance must affect the result of all experiments on the cold produced in vacuo.

Arago is not inclined to attribute this elevation of the zero to atmospheric pressure on the bulb; since he found it equally affecting thermometers with very thick and very thin bulbs. He inclines to ascribe it to the disengagement of air, which either adhered to the glass or the mercury, and its accumulation in the upper part of the bulb, so as to affect the column in the stem.

The most complete observations on this point are those of Bellani,* who acknowledges two sources of variation in the zero of thermometers. That elevation of the zero, first noticed by Flaugergues, according to him, goes on gradually increasing for a limited period, but ceases after a year or two. He ascribes it to the extreme slowness with which glass once softened has the equilibrium among its particles restored. He found, that some months after graduation, a thermometer did not sink quite to the freezing point when immersed in melting ice; if laid by for some months, and again tried, its zero will be still higher; but after some time this irregularity ceases. He found that this effect was not diminished by leaving the thermometer open at the top, and it was sensible even in spirit thermometers.

The other irregularity noticed by Bellani is detected in the following manner.—Let a thermometer, having such a range that $\frac{1}{10}$ of a degree is appreciable, after lying by for some months, be plunged into melting ice, and its height accurately noted, then into boiling water, and again into ice, it will now stand *lower* by about $\frac{1}{10}$ of a degree than at its first immersion in the liquefying ice. This effect he ascribes to the extreme slowness with which the expanded glass can regain its former state of contraction, compared to the mercury.

These deductions appear to be perfectly just; and we are further indebted to Bellani for an ingenious method of showing that the air, if not wholly, is chiefly retained in thermometers and barometers by the glass, not by the mercury. He introduced a portion of unboiled mercury into a bulb, containing mercury which had ceased to give out any air, and found that this introduction did not renew the agitations which the first application of heat to the bulb had occasioned.

The difficulty of freeing thermometers from air is admitted by Arago, while he recommends boiling the mercury in the bulb as the best method of effecting the expulsion of the air; and he quotes some unpublished experiments of Dulong, to show the tedious manipulations which are necessary for this purpose.

We would recommend the boiling to be performed in the manner stated, until the agitation of the fluid caused by the air ceases; and after the tube is closed, the observations of Bellani would incline us to recommend, for delicate instruments, that the attempt to fix the freezing point should be deferred, until the glass might be supposed to have contracted to its state of equilibrium; after which, there would probably be little change in the dimensions of the bulb.

6. We come now to the last and most delicate step of the process, the adaptation of the scale to the instrument.

In the *manufacture* of thermometers this is conveniently done by plunging the new instrument, along with a standard thermometer, into two liquids at different temperatures: but the graduation of *this standard instrument* is a work of such nicety and importance, that a committee of seven members of the Royal Society was formed to investigate the subject, and their elaborate report is given in vol. lxvii. part ii., where all the requisite circumstances are distinctly noticed, and the best manipulations minutely described.

Two fixed points are sought; and the freezing and boiling points of water are most convenient for that purpose. To find the first, nothing more is necessary than to place the thermometer to be graduated, after it is filled, in melting snow or ice, in such quantity around the ball and tube, as to bring it to the desired temperature. When the mercury has become stationary in the tube, a mark is to be made on the tube with a file, just opposite to the top of the mercurial column; and that mark fixes the freezing point of the scale of the instrument. The determination of the boiling point

* Bellani, Giornale di Fisica, tom. v.

is much more difficult, because it is affected by atmospherical pressure, and even by the form of the vessel in which the water is heated.

The Committee of the Royal Society* recommend that the boiling point ought to be fixed under a barometrical pressure of 29.80 inches. For the graduation of the thermometer they recommend that the bulb should not be immersed in the water; because they found, that according to the depth of this immersion the mercury rose to a greater height in the tube. They recommend a vessel of tin plate, provided with a cover which fits easily on, and rendered steam-tight by a ring of woollen cloth between it and the vessel. This cover has two apertures—a chimney, with an area not less than half a square inch, and two or three inches high, to carry off the steam of the boiling water; and a hole for a cork, through which the thermometer tube is inserted in such a manner, that the ball does not touch the surface of the water, but may be surrounded with an atmosphere of steam; while no more of the tube should be above the cork than is sufficient to show the height to which the mercury rises when the water is briskly boiling. When all things are thus adjusted, a thin plate of metal is to be laid over the chimney, to prevent the escape of the steam as it is formed; heat is to be applied to the bottom of the vessel; and when the mercury has remained a few minutes stationary in the atmosphere of steam, its height is carefully to be marked with a file on the tube.

The water may be distilled, or any soft water, such as clear rain water, be used; for, if there be much saline ingredient in the water, this will affect the boiling point, and may lead to error.

Various mechanical contrivances have been proposed for more conveniently fixing the tube in the cover, but they are of little comparative importance. Some prefer plunging the ball into the water to the depth of two or three inches: in this case there is no necessity for a plate of metal on the chimney, nor for the tightness of the cover; but the adjustment of the boiling point is to be made for the barometer at 29.50 inches. To those unprovided with such a vessel the following method is recommended. Wrap several folds of linen, or flannel, round the tube, nearly as high as the supposed boiling point, which may be guessed at by previous immersion of the bulb in boiling water: hold the thermometer in an ascending current of boiling rain water about two or three inches below the surface; pour boiling water three or four times on the covering of the tube, at intervals of some seconds; and waiting a few seconds, after the last affusion, to allow the water to be in brisk ebullition, mark the height of the mercury in the tube, which will be the boiling point of the instrument.

Having thus obtained two fixed points, the freezing and boiling points of water, it is easy to mark off corresponding divisions on the scale which is to be graduated. If the tube be truly cylindrical, nothing more is necessary than to divide the intervening space into as many equal parts as it is intended to have degrees between those points. Should the tube not be of uniform bore, the size of the divisions ought to be accommodated to the inequalities of the tube. This may be done by taking intermediate points in mixtures of water at different temperatures; and after marking them on the tube, proportioning the size of the degrees, at short intervals, to the varying diameter of the tube. This method of graduating from intermediate points ought, in nice instruments, to be adopted, however true the tube may appear; but a tube with sensible inequalities is in general to be avoided.

Although it would be advisable to fix the boiling point when the barometer is at the height above recommended, this may be attended with serious inconvenience to artists; and philosophers have therefore investigated the correction to be made for every ordinary variation of atmospheric pressure.

The first considerable series of experiments on this subject are those of De Luc, in 1762, published in his interesting *Recherches sur les Modifications de l'Atmosphere*,* which were extended and verified by Sir George Shuckburg† in 1775 and 1778. Employing Reaumur's scale, De Luc ascertained, that if y represent the height of the barometer, T the height of the thermometer above the freezing point, expressed in hundredths of a degree of this scale, when immersed in boiling water; and a the constant number

See adda p:64

* Phil. Trans. vol. lxvii. part ii.

Vol. i. 382 ; vol. ii. 338.
† Phil. Trans. vol. lxix. partii.

10387, the following formula will express the height of such thermometer when plunged in boiling water under every variation of barometric pressure.

$$\frac{99}{200000} \log y - a = \text{T};$$

or, as expressed in the more usual way of considering all the figures after the index as decimals, De Luc's formula would stand thus:

$$\frac{99 \times 100}{2} \log y - a = \text{T}.$$

De Luc's researches and his formula are reduced to English measures, and adapted to Fahrenheit's thermometer by Horsley, in a valuable paper in the *Philosophical Transactions*;* where a table is computed for the direction of artists in adjusting the boiling point. It is unnecessary to give his equation of the boiling point, because the later experiments of Shuckburg, and of the Committee of the Royal Society, enable us to present a more complete table for the direction of British artists in correcting the height of the boiling point in every ordinary fluctuation of the barometer.

Barometer when the boiling point is found by immersion in Steam.	Water.	Correction in 1000ths of the interval between freezing and boiling of water.	
	30·60	10	Lower.
	·50	9	Lower.
30·71	·41	8	Lower.
·50	·29	7	Lower.
·48	·18	6	Lower.
·37	·07	5	Lower.
·25	·95	4	Lower.
·14	·84	3	Lower.
·03	·73	2	Lower.
29·91	·61	1	Lower.
·80	·50	0	Lower.
·69	29·39	1	Higher.
·58	·28	2	Higher.
·47	·17	3	Higher.
·36	·06	4	Higher.
·25	28·95	5	Higher.
·14	·84	6	Higher.
·03	·73	7	Higher.
28·92	·62	8	Higher.
·81	·51	9	Higher.
·70		10	Higher.
·59			

The use of this table requires no further explanation: but it is necessary to remark, that it presupposes the thermometric tube to be cylindrical, or of equal dimensions throughout, before the indications of the table can be received as *quite* correct; yet, unless the irregularity of the tube be considerable, a *small* correction will scarcely produce any sensible error in the instrument.

In proportioning the bulb to the tube, the eye and experience of the artist are usually judged sufficient for the purpose; or they are copied as nearly as possible from standard instruments. M. Durand has, however, thought it necessary to propose an algebraic formula for determining the proportions they ought to bear to each other; but there are practical difficulties in the way of its application, which render his formula an exercise rather of his own ingenuity than of utility to the artist.

During the various improvements of the common thermometer, the air thermometer was almost wholly neglected until of late years; but the attention of philosophers was directed to the changes of bulk which *solids* undergo by alterations of temperature, as a measure of the relative degrees of heat.

Chapter II.

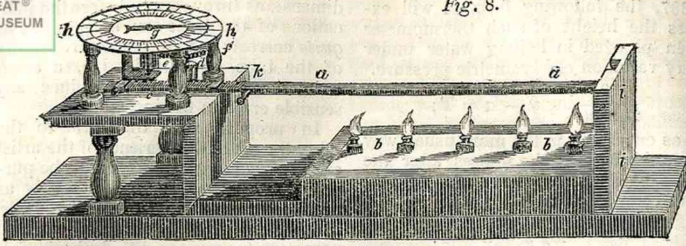
History and Construction of Pyrometers.

1. The impracticability of applying the known modifications of the thermometer to bodies much heated, induced the celebrated Musschenbroek, before the middle of the last century, to employ the expansions of solid rods of metal to indicate the temperature of such bodies; and he gave the name of *pyrometer* to his invention.

As the expansions of solids are extremely minute, it was necessary to devise some method of rendering them perceptible; and the mechanism represented in *fig.* 8 was the Dutch philosopher's arrangement for this purpose. *a* is a metallic prism 5.8 inches in length and 0.3 in thickness, resting in a notch in the upright *i*, where it is secured by a screw, and heated by the lamp *b* with five wicks. The prism is pinned to the end of a bar *c*, which has twenty-five teeth in one inch of its length, and forms a rack sliding smoothly on the table of the instrument through the two holdfasts seen in the figure, and playing in the six-leaved pinion *d* on the same axis as the wheel *f*, which is furnished with sixty teeth. This wheel plays in another pinion *e*, of six leaves also, which is on the axis carrying the index *g*, which

* Vol. lxiv. part i.

Fig. 8.



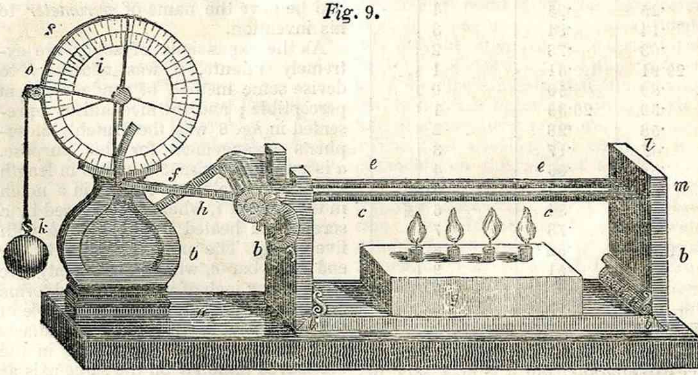
moves round the circle *h*, divided into 300°. The consequence of this arrangement is, that if the expansion of the metal were to push the rack *e* one inch forward, it would turn the pinion *d* $4\frac{1}{6}$ times round; and the wheel *f*, moving at the same rate, will carry the pinion *e*, and consequently the index $(10 \times 4\frac{1}{6}) = 41\frac{2}{3}$ round. Hence the index would have moved over $(41\frac{2}{3} \times 300)$, or 12,500 divisions of the scale; or each degree of the instrument is equivalent to $\frac{1}{12500}$ of an inch of the expansion of the prism *a*. Similar prisms of different metals applied in like manner to the instrument, enabled Musschenbroek to measure the different expansibility of steel, iron, copper, brass, and lead, with considerable accuracy:* but there is always some uncertainty in the movements of so many loosely connected teeth and pinions; and this pyrometer was improved by

2. Desaguliers,† who instead of prisms substituted cylinders, as wires are more easily procured than prisms of equal dimensions. For the first pinion he employed steel slightly roughened by the file in the same direction as the teeth. Thus a more equable motion was given to the instrument. The toothed wheel and second pinion were supplied by a wheel and roller, having grooves in their circumference for receiving a watch-chain, by which motion was communicated to the index. The dial plate was square and movable, in order to stretch the watch-chain as there might be occasion. A thin plate of rough steel $\frac{15}{100}$ inch wide, slightly convex towards the first roller, was substituted for the rack; and this last, which in Musschenbroek's pyrometer was made to travel lightly over a small bit of fine watch-spring, moved in Desaguliers over a well constructed friction wheel, or roller.

These changes improved the delicacy of the instrument very considerably; but it soon underwent other modifications.

3. The pyrometer of Mr. John Ellicot,

Fig. 9.



of London, is seen in *fig*. 9, *a a* is a flat plate of brass screwed to a thick mahogany sole, to which the three brass uprights *b b b* are firmly attached.

The pyrometric pieces consist of two metallic bars: the flat one *c c* is of

*Tentam Acad. del Cimento.
† Desagulier's Experimental Philosophy, i. 421.

steel, and is that by which the expansions of all the other metals are to be compared together. Its extremity to the right passes through a hole in the upright, and is fixed to a spring which may be tightened by the screw *m.* Its other extremity is free, and presses against a *snail* on the axis of the lever *f.* The other bar *e e* is a prism of any metal, the right end of which rests on the end of the screw *l*, while its other bears on a snail on the axis of the lever *h.* When the bars are expanded by the heat of the spirit lamp *g*, they move the levers, to each of which is attached a slender watch-chain: the chain from the lever *f* passes round a pulley $\frac{1}{4}$ inch in diameter, fixed on the axis round which the inner graduated circle *i* of the dial moves; the chain from the lever *h* passes round a similar pulley on the axis of the index, as seen in the figure; and the expansions of this bar are marked by the index on the fixed outer circle. Both pulleys have a thread wrapped round them in a contrary direction on each, and then passing over the pulleys at *o* to the weight *k*, which acts as a counterbalance to bring back the index and movable circle as the bars cool. The index and circle are both adjusted to the beginning of their scales by means of the screws *l*, *m*, at the commencement of each experiment; and when the temperature applied expands the standard bar to a given degree, as indicated on the inner circle, the index will show on the outer circle the relative expansibility of whatever metal is applied to the instrument at *e e.**

This instrument was chiefly intended by its ingenious inventor, a chronometer-maker by profession, for ascertaining the relative expansion of the metals usually employed in the construction of pendulums; an important object, for which many of the best pyrometers have been devised.

In this instrument the dial is about three inches in diameter; the levers two inches and a half in length, and the proportions of the several parts such that the expansion of $\frac{1}{20}$ inch in the bar will move the index wholly round the circle; or each degree will mark the $\frac{1}{7200}$ of an inch in the lengthening of the bar. From the mean of numerous experiments, Ellicot ascertained the following to be the relative expansions of seven metals:—

Steel.	Iron.	Gold.	Copper.	Brass.	Silver.	Lead.
56	60	73	89	95	103	149,*

which is more nearly in the ratio of the *conducting power* of the different metals, than of any other of their physical properties.

4. In the 44th volume of the *Philosophical Transactions* is a description of another pyrometer by Dr. Cromwell Mortimer, which, though less accurate and convenient than Ellicot's, is worthy of notice, especially as it may be employed to show the alterations of atmospheric temperature.

a, b, fig. 10, is a round rod of brass

Fig. 10. A.

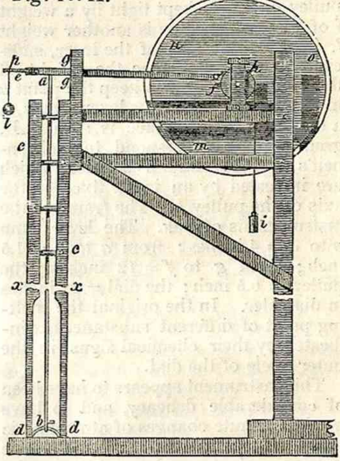
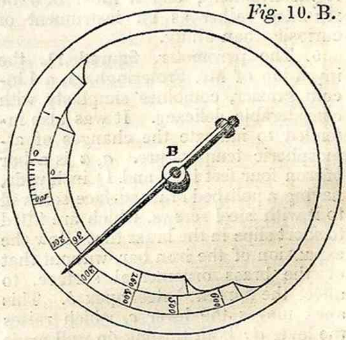


Fig. 10. B.



or steel, $\frac{1}{4}$ inch in diameter and three

* This description is taken from an original instrument now before the author.

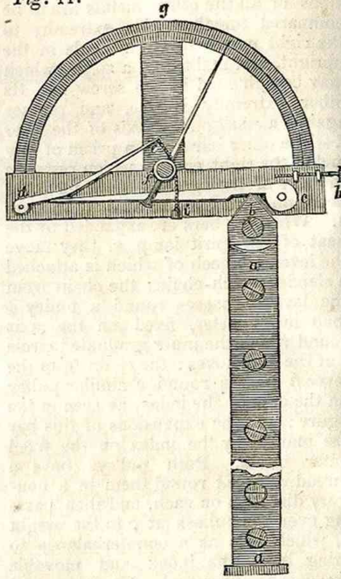
* Phil. Trans. vol. xxxix. p. 297.

feet long, its upper extremity terminating in a hardened steel point one inch more in length, and entering a hole in a steel plate on the under side of the lever *e*, while its lower end rests on a point attached to the metallic plate at *d*. *c*, *d* are plates of iron joined at *d*, and at different other points, as in the figure: at *x*, *x* they are turned half round, to allow the application of heated bodies, as sand or water, to the bar, which is immersed in the heated bodies to a certain mark as at *b*. In the original instrument this mark was at 1½ inch from the bottom: *e*, *f* is a lever moving round an axis in *g*. A string from the end of its longest arm passes twice round the pulley *h*, and is kept tight by a weight *i* of ½ lb., while there is another weight *l*, at the short arm of the lever, sufficient to counterbalance the weight of the longer arm, and to keep the point *a* in close contact with the lever. *m*, *n*, *o*, a dial, of which the face is seen at B, graduated to correspond to Fahrenheit's and Reaumur's degrees, which are indicated by an index fixed on the axis of the pulley *h*. The frame of the instrument is of oak. The lever from p to $a = 4$ inches; from a to $g = 1.5$ inch; from g to $f = 12$ inches; the pulley = 0.5 inch; the dial = 11 inches in diameter. In the original the melting point of different substances is indicated by their chemical signs in the outer circle of the dial.

This instrument appears to have been of considerable delicacy, and to have marked minute changes of atmospheric temperature very readily: but the size is inconvenient; and it must now be regarded rather as an instrument of curiosity than utility.

5. The pyrometer, figured 11, the invention of Mr. Froteringham, a Lincoln grazier, combines simplicity with considerable delicacy. It was also intended to indicate the changes of atmospheric temperature. *a*, *a* is a bar of iron four feet long and 1¼ inch wide, having a polished brass surface screwed to it with steel screws, which are fitted to short slips in the brass that allow the expansion of the iron bar, without that of the brass ornamental surface, to affect the hardened steel apex *b*. This apex moves the lever *c*, which raises the lever *d*; both turning on well made central disks. A chain from the extremity of the lever *d* is lapped twice round the pulley *f* on the axis of the

Fig. 11.



index, which moves round a graduated circle *g*. The counterpoise *i* brings back the index as the levers fall. The screw *h* is for adjusting the index to the beginning of the scale. It is very obvious that such an instrument would be capable of showing the expansions of the bar in proportion to the difference between the arms of the levers; and, it is said, that the original instrument, in the library of a philosophical society at Spalding, indicated the changes of the heat of the weather with great precision.*

6. All these instruments, however, yield in accuracy to the invention of the celebrated Smeaton, which is described in the *Philosophical Transactions*.†

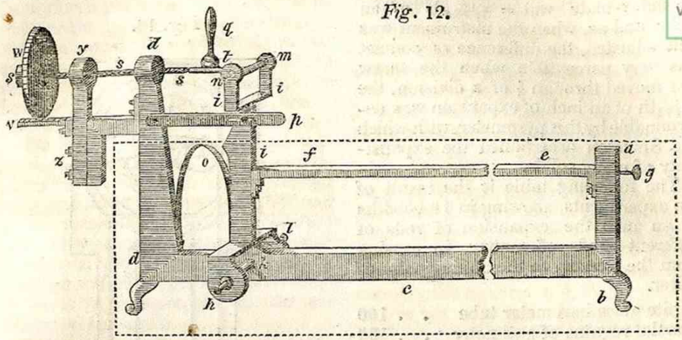
In this instrument the expansions of the metallic bars, heated by water, are measured by means of a micrometer screw; a principle which had been before employed by the great chronometer-maker Graham, for the adjustment of the rods of a pendulum.

From the principle of its construction, this instrument is called the Micrometer-Pyrometer, *fig*. 12.

The basis of this instrument *a*, *b*, *c*, *d* is of solid brass, which was chosen as

* Phil. Trans. vol. xlv. p. 125.
† Phil. Trans. vol. xlviii. p. 487.

Fig. 12.



of a mean expansibility among the metals. *e f* is the bar to be measured, resting on two notches, one attached to the fixed upright *a b*, and the other to the principal lever *h i*. *k* is a strong arbor fixed to the basis, and intended to receive the ends of two screws *h*, *l*, upon which the principal lever *h*, *i* turns; *o* is a slender steel spring intended to press the lever against the extremity of the bar; and *p* is a check-rod to support the lever, when the bar is removed. *t* is called the *feeler;* it is in the form of the letter T, and is suspended freely, but without shake, between the points of the screws *m*, *n*. *q* is the handle of the feeler, which is movable on a loose joint, so that the feeler may be moved by the handle without being irregularly affected by the pressure of the hand. The principal part of the instrument is *s*, the micrometer screw, and *w* the graduated circle or index-plate fixed on the screw, which indicates the revolutions of the screw on the index *v*. The micrometer screw passes through two solid heads perforated by a corresponding screw; the piece *y z* is made somewhat springy, and tends to draw the micrometer screw backward from *d;* by which its threads press uniformly against the corresponding threads in the holes, and keep the motion equable and easy.

When the instrument is used, its basis and the bar are immersed in a tin vessel containing water, as marked by the dotted line, which is heated by seven lamps applied below. The vessel is provided with a cover; and a delicate mercurial thermometer is suspended in the water, for regulating and ascertaining the temperature employed, which is not intended to exceed that of boiling water.

The expansion of the bar presses the lever and feeler towards the end of the micrometer screw, which, as well as the extremity of the feeler, is tipt with hardened steel. The handle *q* is laid hold of, and by it the feeler is moved up and down, while the screw is turned, until its steel point comes in contact with the end of the screw. Mr. Smeaton found that he could judge of that contact more accurately by the *ear*, than by the *eye* or the *touch*.

The turns of the index-plate counted by its edge and the divisions of the index, show the expansion of the bar; and its length when cool may be found in the same manner, either before or after the experiment above described. In this instrument the bar acts against the centre of a lever of the *second order*, the fulcrum of which is in the basis; and when both are expanded, the free extremity of the lever moves through a space double of the difference between the expansion of the bar and of the basis: hence, when we know the length of the lever from its axis to the point of suspension of the feeler, the distance from that axis to the point of contact of the bar, the number of threads of the micrometer screw in an inch, and the number of degrees on the circumference of the index-plate, we can compute the value of these degrees in fractions of an inch. In the original pyrometer the following were the proportions:

	Inches.
From axis of lever to point of suspension	5.875
—— fulcrum to point of contact	2.895
Length of 70 threads of the screw	2.455
Division of index-plate 100°.	

Hence the value of each division of the index-plate will = $\frac{10}{37863}$ds of an inch; and as, when the instrument was well adjusted, the difference of contact was very perceptible when the screw was moved through $\frac{1}{4}$ of a division, the $\frac{1}{231143}$th of an inch of expansion was determinable by this pyrometer, with which Mr. Smeaton ascertained the expansibility of many solids.

The following table is the result of his experiments, showing in 10,000dths of an inch the expansion of rods of different kinds of matter, in passing from the freezing to the boiling point of water.

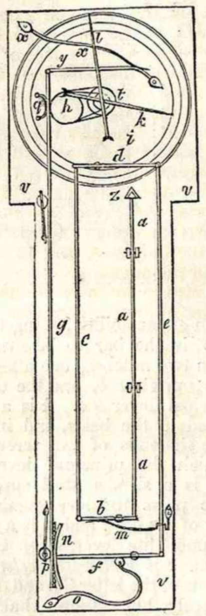
White glass barometer tube	100
Martial regulus of antimony	130
Bistered steel	138
Hard steel	147
Iron	151
Bismuth	167
Copper hammered	204
Alloy, 8 copper, and 1 tin	218
Cast brass	225
Alloy, brass 16, tin 1	229
Brass wire	232
Telescope speculum metal	232
Alloy, 2 brass, 1 zinc	247
Fine pewter	274
Grain tin	298
Soft solder, 2 lead, 1 tin	301
Alloy, 8 zinc, 1 tin, slightly hammered	323
Lead	344
Zinc	353
Zinc hammered out 1 inch per foot	373

These experiments correspond as nearly with the results obtained by Ellicot, as the difference of the instruments admit. They introduced a precision hitherto unknown in the law of expansion of solid bodies; and are still quoted with approbation in those nice disquisitions which have paved the way to the perfection of *horology*, and the modern refinements in *geodesical* operations, while they have extended our knowledge of the effects of heat.

7. The *metalline thermometer* of Mr. Keane Fitzgerald comes next in order of time; but it is chiefly applicable to mark the alterations of atmospheric temperature. Its general construction will be readily learnt from *fig.* 13.*

The basis of the instrument is a piece of well seasoned deal, on which a system of levers is fixed; *a a* is the pyrometric bar, 2 feet long, the upper extremity of which bears against the fulcrum *z*,

Fig. 13.



while its other end rests on a small hemisphere of metal on the short arm of the lever *b*. The long arm of this lever is $2\frac{1}{2}$ times as long as the other; *b* is joined by a pivot to the rod *c*, 2 feet 2 inches in length, which bears against the short arm of *d*, and the long arm of *d* is $2\frac{3}{4}$ times as long as the former. The rod *e* is 2 feet 4 inches long, and is jointed to *f*, as in the figure. The long arm of *f* is 4 times the length of its short arm, and terminates in a slender arch-head, which is attached to the lower end of the rod *g* by a watch-chain, as in the figure. This last rod is 3 feet long, and is kept perpendicular by sliding between two friction rollers *p*, *v*, its connection with the arch-head, its suspension from the lever *y*, and its friction on the pulley *h*. The weight of the levers, &c. is counterbalanced by the springs *m* and *o*, and the spring of *y* is nearly neutralized by the pressure of *x*. The pulley *h* is fixed at 2 feet 6 inches from the lower end of *g*, and is 3 inches in diameter. Two cords fixed to the spring *q*, pass twice round

* Phil. Trans. vol. li. p. 523.

the pulley *h* in different ways, and thence go over the pullies at *t*, respectively, 1 inch and $\frac{1}{4}$ inch in diameter. These last are put on the common axes of the indices *k*, *l*, in the same manner as the hands of a clock. The face of the dial is 12 inches in diameter, and from the construction, the index *l* ranges 48 times, and the index *k* 12 times as much as the bar *g*. The dial has on it three circular scales; the inner is divided into 240°, corresponding to those of Fahrenheit's thermometer; the middle is divided into 360°; and the outer into 1080 parts, marking 18 for each degree of the thermometer, and 12 for each degree of the circle.

This instrument may be used as a pyrometer in low temperatures; for the bar *a* is removable; and from the construction, each division of the outer circle is equivalent to an expansion of $\frac{1}{73840}$th of the bar.

Used in this way, Mr. Fitzgerald informs us that the dilatations of metallic bars 2 feet long, at the same temperature, were as follows:

		Divisions.
Spelter or zinc	=	1570
Zinc 18, copper 2 parts . .	=	1550
Brass	=	1120
Iron	=	785
Steel	=	695

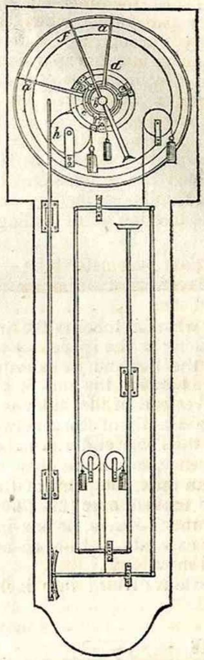
which agrees pretty well with the experiments of Smeaton and Ellicot.

When used as a thermometer the index *k* marks 74 divisions in passing from the usual extremes of temperature in our climate, and 212 divisions from freezing to boiling water.

Mr. Fitzgerald experienced some difficulty in proportioning the strength of the springs to the weight sustained by the levers, and he improved the instrument by the adoption of pulleys and counterpoise weights, as in *fig.* 14, which he ingeniously converted into a register thermometer, by adapting two light index hands *a*, *a*, fixed to two brass circles moving between friction wheels, attached to a fixed circle *d*. They were so nicely fitted as to move readily by a weight of 8 grains hung on them. These hands are moved in opposite directions, by a small stud in the under surface of the index *f*, which receives its motion from a cord passing from the pulley *h* round a small wheel on its axis.

This alteration of the instrument was intended only to note the changes of the atmosphere, which it seems to have done with much delicacy; for it had a range

Fig. 14.



of 72 inches from the common changes of the heat of the weather in London; and it would show an alteration amounting to 50 or 60 degrees of its scale, when the pyrometric bar of the instrument was five or six times breathed upon.*

8. In Ferguson's *Lectures* two pyrometers, the invention of that great self-taught mechanician, are described.

Fig. 15 was merely intended to exhibit to his audience the expansions of bodies by heat, yet is worthy of notice.

a a, a mahogany board, on which are fixed four brass studs; of these *b* supports a screw for adjusting the pyrometric bar *f*, which rests in notches in the studs *c d*. The extremity of the bar presses against the crooked lever *g*, which acts on the index *i i*; the stud *e* holds the spring *h*, which brings back the index when the bar cools. The lever *g* (of the second order) has the portion between the point of contact of the

* Phil. Trans. vol. lii. p. 146.

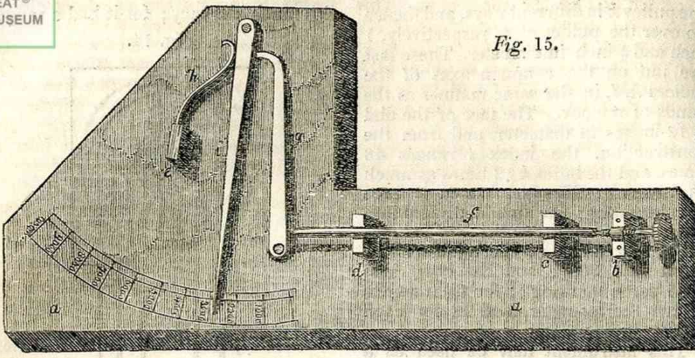


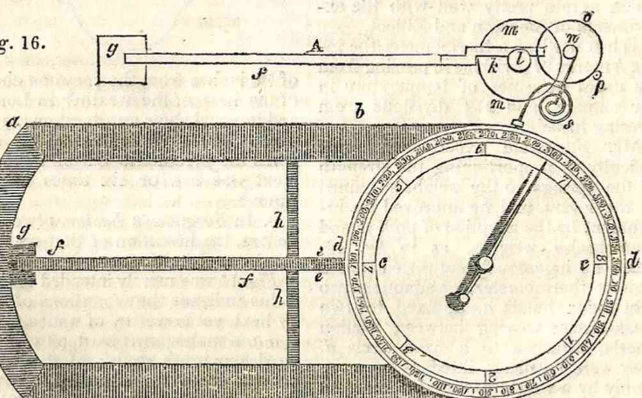
Fig. 15.

bar, and where it touches the index 20 times as long as the space between the point of the bar and its fulcrum; and the space between the end of the lever and the free end of the index is just 20 times the length of that between the point of the lever and the axis of the index; hence, when the bar expands $\frac{1}{400}$th of an inch, the point of the index will have moved over $(20 \times 20) = 400$ times as much space, or one inch; or if the bar expand $\frac{1}{4000}$th of an inch, the index will move $\frac{1}{10}$th.

The scale is divided into inches and tenths; and the mere friction of the bar *f*, which is removable at pleasure, with a piece of flannel till it becomes sensibly warm, will be sufficient to show variations of the index. Ferguson states that it gave the following results:—with bars of iron and steel, 3; copper, 4½; brass, 5; tin, 6; lead, 7.

9. In the supplement to his lectures there is however a much more delicate pyrometer described, (*fig.* 16,) which will show the expansion of a bar of metal to the $\frac{1}{45000}$th of an inch, or even to the 90,000th.

Fig. 16.



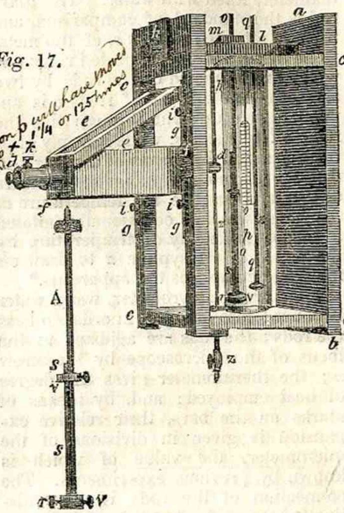
The frame *a b* is of mahogany, supported on short pillars, so as to admit a lamp under it for heating the bar *f*; one end of which lies in a cavity in the piece of metal *g*, and the other, after passing on a friction wheel over the cross-bar *h h*, presses against the short lever *e e*. The manner in which this short lever acts on the index is seen in the adjoining diagram A, where *k* is the short lever that moves under the dial *d* between friction wheels. On the side of *k* are 15 teeth in the space of one inch, which play in the twelve leaves of the pinion *l* on the axis of the wheel *m m*. This wheel has round its circumference 100 teeth, which work in the ten leaves of the pinion *n*, on the axis of the wheel *o* of 100 teeth, that gives motion to the pinion *p* of ten leaves, on the axis of which the index is fixed.

As the wheels *m* and *n* have each 100 teeth, and the pinions *n* and *p* ten leaves, it is obvious that when the wheel *m* has made one revolution the pinion *p*, and of course the index, will have made 100 revolutions; as the pinion *l* has twelve leaves, and the bar *i k* has fifteen teeth to one inch (equivalent to $12\frac{1}{4}$) it is obvious that ~~while *i k*~~ moves one inch the pinion *p* will have ~~moved~~ ~~$100 + \frac{1}{4}$, or 125 times round~~, and the index would at the same time be carried 125 times round the circle *d d*. This circle is graduated into 360 degrees, and being eleven inches in diameter, it is subdivided into half degrees. Hence each degree of that circle will be equivalent to an expansion of 125 × 360 = $\frac{1}{45000}$th of an inch of expansion in the bar *f*; and as the half degrees can readily be distinguished on the dial, the instrument will show expansions only amounting to $\frac{1}{90000}$th part of an inch. A silk thread is several times wound round the axis of *n* and passes to the slender spring *s*, which keeps the teeth of the pinions and wheels in close contact, and pulls back the train of wheels when the cooling of the bar *f* allows the short bar *i k* to recede.

The inner circle of the dial is divided into eight parts, corresponding to so many thousandths of an inch in the expansion of the bar *f*, or $\frac{1}{1000}$th of an inch for each degree of the outer circle over which the index has moved. Bars of different metals laid in *g* for a given time, and exposed to the same lamp, afford an indication of their relative expansibility; and to ensure equality in the bars it is recommended to have them *wire drawn* through the same hole. There is, however, in this instrument no accurate measure of the temperature applied to each bar; and, notwithstanding the delicacy of the movement, it seems inferior to Ellicot's pyrometer, as it wants a constant and uniform standard by which to compare the expansions in each separate experiment.

10. A new method of ascertaining the expansibility of different substances was suggested by the late Mr. Jesse Ramsden, and on his hint it was attempted by the ingenious and indefatigable De Luc, whose researches on the barometer gave this subject an increased interest to his mind. The object in view was to determine the relative expansion of solids by observation with a microscope furnished with a micrometer. The *microscopic pyrometer* of De Luc is seen in *fig.* 17, where *a b* represents a

Fig. 17.



strong board of even-grained deal; to which the frame *c c c c* is firmly joined, that when *a b* is suspended vertically from a strong post, the front of the instrument bearing the microscope *d d* is towards the operator.

The microscope is securely united to the frame by the braces *e e* and the cross-bar *f*; and the whole of this part of the apparatus can be moved up or down by the slides *g g*, which fit so tightly on their centres as to require slight blows with a hammer on the frame to cause them to move down, and may be further tightened by the screws *i i i*. The microscope is kept horizontal by the cross-pieces, and by an inner sliding frame not seen in the figure. The microscope is so adjusted that an object is distinctly seen when a full inch from its lens; and it is furnished with a micrometer, movable by *k*, for ascertaining the expansions of the rods subjected to experiment. A piece of thick deal *l* is seen at the top of the frame lying horizontally from a groove cut in the board $a\ b$ to the front of the frame; this is movable by means of the screw *h*, and is perforated by a piece of cork *m* firmly driven into it until level with its lower surface. The cork is then pierced vertically to receive the glass rod *o o o*, which is thus suspended in a thin cylindrical glass jar *p*, 21 inches high, and 4 inches in diameter, filled with water. The glass rod is the standard of comparison, and to it is attached a rod *s s*, of the metal to be tried, by two connected rings *r r*, which are tightened on the rods by two screws. Another set of rings *v* is applied higher up; but through this the rod *s s* freely slides, while it firmly clips the glass rod by means of a screw. A delicate thermometer hangs in the centre of the jar *p* to note the temperature of the water, which is occasionally agitated to secure uniformity of temperature by the rod *q q*. A syphon *z* to draw off the water completes the apparatus.*

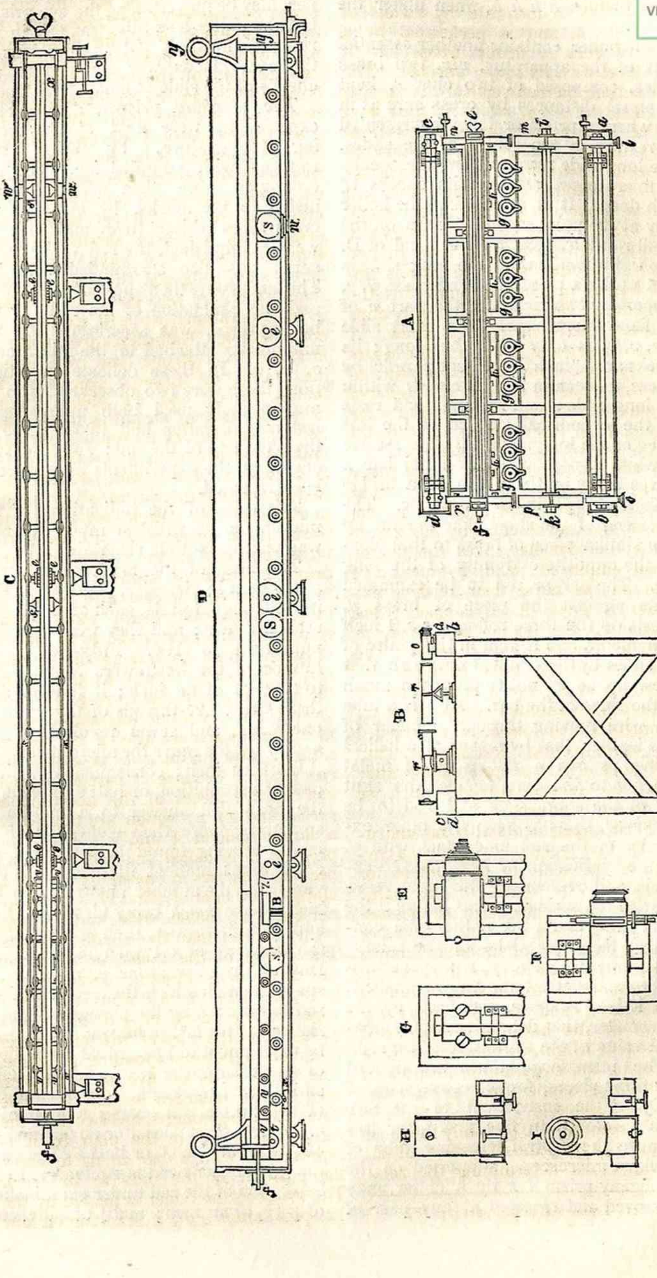
In using this pyrometer, warm water is poured into the jar, in order to heat the rods; the rods are adjusted to the focus of the microscope by the screw *n;* the thermometer gives the degree of heat employed; and, by means of marks on the bars, their relative expansion is given in divisions of the micrometer, the value of which is known by previous experiments. The connection of the rods is more distinctly seen at A; but it is unnecessary to give a more minute description of an instrument which has been superseded by the more accurate and more elegant contrivance of Ramsden, so elaborately detailed by General Roy, to which we shall presently advert.

11. From experiments with this instrument, De Luc ingeniously applied a correction to the scale of barometers for temperature, by what, in the same paper, he calls "*metallic thermometers.*" The scale of the barometer was fixed on a bar of metal of known expansibility, so as to raise the scale in exact proportion to the expansion of the mercury; and thus the mere inspection of the barometric scale will give the true height, without the trouble of applying the equation or formula of correction for temperature, as in ordinary observations.

12. We come now to certainly the most complex, but the most perfect of all contrivances for determining the relative expansions of solids, the *microscopic pyrometer of Ramsden*, contrived by that eminent artist, for determining with the utmost possible precision, the expansibility of the rods employed by General Roy, in the geodesical operations that are the foundation of the great trigonometrical survey of Britain. Fig. 18 contains plans and sections of this beautiful contrivance, and although we do not propose to enter into a minute detail of the different parts of the instrument, a general description will show, to those who have not considered such subjects, the nice precautions which are necessary to accuracy in like operations, while it explains its construction. Ramsden's pyrometer is attached to a strong and well joined deal table, or frame 5 feet long, 28 inches broad, and 42 inches high; of which an end elevation is seen *fig.* 18, B; the plan of its top will be best understood from an inspection of A. *a b* and *c d* are troughs of deal, (firmly screwed to the table) 3 inches in diameter, and a little longer than the frame; *a b* projects a little over the table, but *c d* is in a line with the frame, as may be seen at B. Each trough contains a cast iron prism, $1\frac{1}{4}$ inch on each side, firmly fixed in the troughs, at the ends *a* and *c*, by means of brass collars embracing the prisms, and tightened by screws as at G, while the ends *b* and *d* pass freely through loose collars, without any shake, when their dimensions are altered by temperature. The prism *a b* is called the *eye prism;* because it carries at each end the eye-pieces of the microscopes *l m n*, and *o p r;* which are figured on a larger scale at F and E. The other prism *c d* is called the *mark prism;* because it carries at one end the mark I, and at the other cross wires H; *e f* is a copper boiler $2\frac{3}{4}$ inches wide, and $3\frac{1}{2}$ deep, rather shorter than the wooden troughs. The centre of the boiler, or rather of the object lens standing perpendicular to it, is 5.81 inches from the cross wires of the mark in *c d*, and 20.33 inches from the wire of the micrometer attached to the corresponding eye-piece. The boiler rests on five small rollers, seen in the enlarged section D. The boiler, like the troughs, has a cock to the right hand; and in the plan A, it is represented with a bar in it, to show the position of the rods to be tried. The water in the boiler is heated by the 12 spirit lamps *g g g g*, standing on four

* Phil. Trans. vol. lxviii. part i. p. 437.

Fig. 18.



movable shelves, and showing only their handles *h h h h*, when under the boiler.

The boiler contains another essential part of the apparatus, *viz.* two brass slides, composed of two cheeks, kept at equal distances by cross bars as in C, where a prism or bar is represented as resting in the centre of the slides. The long slide reaches from microscope to microscope, and has its cheeks $1\frac{3}{4}$ inch deep. It is attached to the boiler only at the point *w*, and it rolls on the small roller *x*, near the left hand of D. The right hand end of the long slide is shut up by a piece of strong brass *y*, *y*, supporting two rings, for the part *n* of the fixed microscope. The short slide *v*, *v*, *v*, *v*, is only $14\frac{1}{2}$ inches long; its cheeks are $1\frac{1}{4}$ inch deep, kept parallel by braces, as seen in D. It moves within the long slide; and its outer end rests on the cylindrical surface of the last brace of the long slide, fitted to receive it, while a narrow longitudinal bar *z* moves freely in the notch of a bridge B, framed for it in the long slide. The outer end of the short slide is shut up by a similar piece of brass to that closing the opposite extremity of the long one. The bar or rod to be examined abuts against the piece of brass *y*, it rests on the three rollers *s s s*, 1 inch in diameter, and is kept in the centre of the slides by three milled nuts *e e e*, that screw up so as not to press too much on the sides of the bar. At *f* is a tube and wire moving through a collar of oiled leather, that by means of a helical spring presses a flat piece of metal attached to the wire, against the shut end of the short slide and rod to be measured, so as to keep the other extremity of the rod in contact with *y*. On the application of heat, the rod expands, and overcoming the slight resistance of the spring, carries before it the short slide, and with it the tube containing the object lens of the micrometer microscope *o*, *p*, *r*, a space proportional to the temperature applied; and it is this space, measured by the micrometer, that determines the numerical value of the expansion of the rod.

The microscope tubes are divided into three pieces, for the convenience of applying the instrument to measure rods shorter than five feet. For this purpose the central screening tube of the fixed microscope, supported on the mahogany prism *i k* by a collar, may be moved and *clamped* at any part of that prism; the eye-piece, in like manner, may be moved along the eye prism; but the object lens tube was left in the rings of the slide, and another lens of the same focus was clamped to the cheeks of the slide at suitable distances.

The standard prisms, during each experiment, were kept at the freezing temperature, by being surrounded with pounded ice. The microscopes were then accurately adjusted to the marks, by bringing the cross wires to bisect them, and until this was accomplished, the rod to be measured was also surrounded with ice. The lamps were then applied to the boiler, and the elongation of the rod, at the boiling heat, was ascertained by the micrometer attached to the microscope *o*, *p*, *r*. In these delicate investigations there were two observers, who simultaneously used both microscopes, lest any alteration had taken place in the fixed end of the rod; and to ensure accuracy, the experiments were twice at least repeated.

The value of the indications of the micrometer, on which so much depends, was previously thus ascertained:

The head of the micrometer screw = 0.9 inch in diameter, and was divided into fifty equal parts, each of which was reckoned two; and they were therefore numbered to 100. Fifty-five revolutions of the head were found equal to 0.77175 of an inch; it follows that there are 71.27 threads of the screw in one inch; and seven revolutions and *nearly* $\frac{13}{100}$ths move the micrometer wire $\frac{1}{10}$th of an inch; consequently $\frac{1}{100}$th of part of a revolution, or half a division of the head, will answer to a motion of something more than 0.00014th of an inch. Having found 7.13 revolutions equal to 0.1 inch at the wires, it is obvious that the number answering to 0.1 inch at the *mark* being also found and added to the former, their sum will give the measure of 0.1 inch at the object lens of the microscope *o*, *p*, *r*, or the space through which the free end of the rod has moved by the change of temperature. This last point was ascertained by experiment to be = 24.93 revolutions of the micrometer head; which being added to 7.13 = 32.06, "for the number of revolutions measuring a motion of 0.1 at the object lens, or an expansion of $\frac{1}{10}$th of an inch," or half a division of the micrometer head is equivalent to an expansion of the rod under examination of $\frac{1}{32000}$ of an inch; and $\frac{1}{4}$ of a division, which may readily be seen by the eye, $= \frac{1}{64000}$.

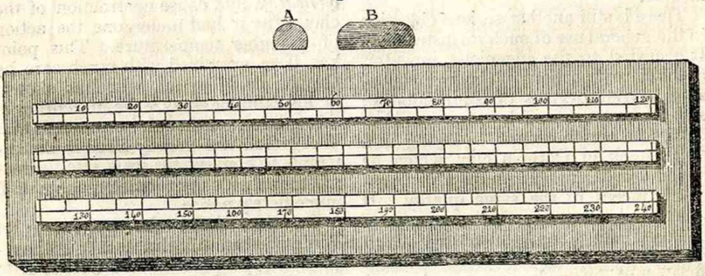
Such is the *microscopic pyrometer* of Ramsden; an instrument not indeed suitable for ordinary purposes, but admirably adapted for obtaining an accurate estimate of the comparative expansibility of different solids; an object of the highest importance, not only in bringing to perfection the delicate instruments required by the refinements of modern philosophical investigations, but essential to the perfection of different kinds of machinery in daily use, and even to a successful investigation of the laws and nature of heat itself. With this instrument Roy determined the expansion of the seven solids in the annexed table.

Expansion of

	By 180°. Revolutions. Parts.	By 1°. Parts.	Inch. on 5 feet.	Inch. on 1 foot.
Dutch brass	35.69 =	19 $\frac{83}{000}$ =	0.111323 =	0.0222646
English plate brass, a rod .	36.41 =	20 $\frac{23}{100}$ =	0.113568 =	0.0227136
Ditto, in the form of a trough	36.45 =	20 $\frac{25}{100}$ =	0.113693 =	0.0227386
Steel rod	22.02 =	12 $\frac{23}{100}$ =	0.068684 =	0.0137368
Cast iron prism	21.34 =	11 $\frac{86}{100}$ =	0.066563 =	0.0133126
Glass rod	15.54 =	8 $\frac{63}{100}$ =	0.048472 =	0.0096944
Ditto tube	14.93 =	8 $\frac{29}{100}$ =	0.046569 =	0.0046569

13. The instruments hitherto noticed are inapplicable to very high temperatures, or to ascertain the heat of closed fire-places; an object, in many processes in the arts, of the utmost importance. To supply this deficiency, our celebrated Wedgwood took advantage of the property which clay has of *contracting by heat*, and remaining afterwards in that state of contraction. This property is not, strictly speaking, an exception to the general law of expansion by increase of temperature: clay is not a homogeneous body, but a mechanical mixture of argil and silex, which by the influence of heat are brought into more intimate union, and therefore diminish in bulk; until a temperature sufficiently high to melt them, that is, to convert them into a homogeneous mass, is applied: after which the product obeys the general law of expansion by heat. Availing himself of this property, Mr. Wedgwood employed as *pyrometric pieces* cylinders of fine porcelain clay, slightly flattened on one side, as seen in A B, *fig.* 19,* formed by pressing the clay into an iron tube, and baked in a potter's furnace. It was found, after repeated trials, that the pieces of clay contracted more and more in an uniform ratio to the degree of heat communicated to them, and permanently retained this contraction; so that by applying them when cold to a scale, an indication of the degree of heat was obtained.

Fig. 19.



The scale employed by Wedgwood consisted of two brass rods ¼ inch square, and two feet in length, fixed on a brass plate *convergingly*, so that they were distant at one end just 0.5, and at the other 0.3 inch. For convenience the rods are usually divided and fixed as in the figure on the plate, forming two nearly parallel grooves.† With the above-stated convergence the whole

* Phil. Trans. vol. lxxii. lxxiv. lxxvi.

† The degree of convergence being only one-tenth of an inch in a foot, is not perceptible in the figure.

groove is divided into inches and tenths, making 240 degrees in the whole scale; and the higher the temperature to which the pyrometric piece has been exposed, the further will it slide up the scale.

In order to compare his scale with Fahrenheit's mercurial thermometer, which cannot measure a temperature much beyond 600°, Mr. Wedgwood was compelled to make use of the *expansions* of a pyrometric piece of fine silver, applied to a gage on the same principle as that above described. By this, the expansions of the silver for 50° and 212° Fahrenheit were first noted; and then the silver and clay pyrometric pieces were compared at the same temperature. By such means Wedgwood estimated the value of each degree of his scale at 130° of Fahrenheit; and he reckoned that the 0° of his scale corresponded with the 1077°.5 of the common scale. On this principle comparative tables of the two thermometers have been constructed; but their accuracy depends on two circumstances which have not been determined to the satisfaction of the philosophic world. Clay being a heterogeneous mixture, it by no means follows that its contractions are equable at different temperatures; and even were this ascertained, there is great doubt how far the means employed by Wedgwood did accurately estimate the degree of Fahrenheit at which his scale commences.

There is still another serious objection to the general use of such an instrument. It occurred to the ingenious inventor, that different portions of clay would possess different degrees of contractibility; and he endeavoured to secure uniformity, to a certain extent, by laying in a large stock of Cornish clay, which he hoped would supply innumerable pyrometric pieces of the same quality. It was found, however, that spontaneous changes take place in such clay, which render its indications liable to variation at distant intervals; or pieces, now formed of the same clay, will not give the same indication with pieces baked several years ago. Attempts were made to remedy this inconvenience by forming a clay of uniform quality of fixed proportions of silex and alumine. Fine Cornish clay yielded, on analysis, two parts of silex and three of alumine; and such a mixture made into a paste with $\frac{2}{5}$ths their weight of water, has been recommended for the fabrication of pyrometric pieces. The method detailed by Wedgwood should then be followed in moulding them. The paste is first to be rammed into a metallic mould 0.6 inch wide, 0.4 deep, and 1 inch long: they should be dried in the air, and when quite desiccated, Wedgwood gaged them in another mould exactly 0.5 of an inch wide, and of the form given in the figure. Before they are baked they will, of course, just enter the widest end of the scale, resting at 0°. When contracted by baking to $\frac{1}{5}$th of their bulk, they will pass to the 120°; and when reduced to $\frac{2}{5}$ths, they would pass to the 240°, or the extremity of the scale; but Mr. Wedgwood never did obtain a higher temperature than 160°. From these proportions each degree of Wedgwood's scale is equivalent to a contraction of $\frac{1}{600}$th part of the pyrometric piece.

The difficulty of obtaining clay of an uniform quality, and not liable to spontaneous change, has lately given rise to a suggestion of employing pyrometric pieces formed of Chinese agalmatolite; a suggestion of Mr. Sivright of Meggetland, well worthy of attention.*

A more formidable objection was started by some foreign chemists to Wedgwood's scale; one, indeed, that would have overturned the theory of the instrument. It was alleged, that the effect of a long continued, or often repeated, exposure to even *inferior degrees of heat*, would cause contraction of the clay, after it had undergone the action of a higher temperature. This point has been examined with much care by Guyton de Morveau, who has shown, in his valuable essay,† the inaccuracy of this opinion; although he contends that Wedgwood has greatly erred in the attempts to convert his scale into degrees of Fahrenheit's thermometer, as we shall immediately notice.

On the whole, the pyrometer of Wedgwood is an instrument well adapted to the purposes of the potter, or to convey some idea of the relative heat of furnaces; but we cannot regard the determination of the celebrated inventor as giving even a tolerable approximation to relative degrees of high temperatures by other scales. As, however, Mr. Wedgwood's tables of temperature are often quoted, we shall here subjoin them, with the corresponding degrees of Fahrenheit, according to his calculation.

---

* Edinb. Phil. Journal, vol. vi. p. 179.

† Annales de Chimie, vol. lxxiv. lxxviii. xc.

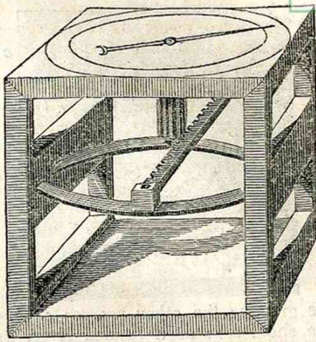
	W.		F.
Red heat in full day-light	0°	=	1077°
Enamel heat	6	=	1857
Brass melts	21	=	3807
Swedish copper melts	27	=	4587
Fine silver melts	28	=	4717
Settling heat of flint glass	29	=	4847
Fine gold melts	32	=	5237
Delft ware baked	41	=	6407
Working heat of plate glass	57	=	8487
Flint glass furnace, low heat	70	=	10,177
Cream coloured ware baked	86	=	12,257
Welding heat of iron, least	90	=	12,777
Ditto ditto greatest	95	=	13,427
Stone ware, baked	102	=	14,337
Derby China vitrefies	112	=	15,637
Flint glass furnace, high heat	114	=	15,897
Inferior Chinese porcelain softened	120	=	16,677
Bow porcelain vitrified	121	=	16,807
Plate glass furnace, greatest heat	124	=	17,197
Smith's forge, greatest heat	125	=	17,327
Cast iron begins to melt	130	=	17,977
Bristol porcelain vitrifies	135	=	18,627
Hessian crucible melted	150	=	20,577
Cast iron thoroughly melted	150	=	20,577
Chinese porcelain, best sort softened	156	=	21,557
Greatest heat of an air furnace eight inches in diameter; deduct soften Nankeen porcelain at all	160	=	21,877
Extremity of Wedgwood's scale	240	=	32,277

These results are rendered doubtful by the causes already noticed; and the experiments of Morveau and Daniell with pyrometers of platina lead to very different results.

14. The metallic thermometer of Regnier is described in a report of the French Institute for 1798.* The inventor had remarked, that when a thin metallic rule, resting on a table, is raised by the middle, it forms a segmental arc of which the *versed sine*, that is a line perpendicular to the chord, drawn to the centre of the arc, is twelve times longer than the space through which the extremity of the bar has moved; and, on this principle, he proposed to construct an instrument for noting variations of atmospheric temperature. The small models which he exhibited answered perfectly; but his intention was, to apply his invention to instruments on a larger scale for public use.

The instrument consists of two plates of yellow copper, two mètres long, fixed in an iron frame, in a bent position, with their concave surfaces toward each other, as in the sketch, *fig*. 20. On one is fixed a pinion of eight leaves, on an axis, the end of which supports an index to mark the temperature. To the centre of the other plate is attached a toothed rack, in the position of the versed sine of the curve, playing in the leaves of the pinion. When the plates are cooled they approach each other, when heated their centres recede; and the only circumstances of consequence in the position of the bars or plates are, that they should be at some little distance

Fig. 20.



from each other, and so bent that they cannot become parallel by any reduction of temperature to which they may be exposed. Regnier found, that two such bars, of two mètres in length, by a change of temperature equal to 60 centesimal degrees, changed the relative position of their centres, or *had a play* equal to 65 millimètres; but the correction for the expansion of the iron frame reduces this by ⅗; so that there remains about 26 millimètres for the real play of the centres of the bars; and if the frames, in public instruments of this sort, are made of stone, that change, by diminishing the expansibility of the frame, will increase that of the bars. Regnier gave a radius of 649 millimètres to his index; so that it will traverse over a circle of 1.298 mètres in diameter. The pinion has 8 leaves in a diameter of 27 millimètres; and these proportions are such, that a temperature of 60 degrees centesimal will nearly cause a whole revolution of the index round a dial 4.079 mètres in circumference. Hence each degree would be about 68 millimètres in size, or rather more than 2½ inches; and consequently might be distinctly seen at some distance.

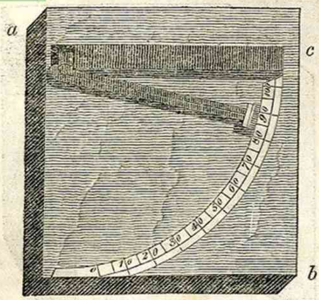
15. The platina pyrometer of Guyton de Morveau, *fig*. 21, was laid before the French Institute in 1804, and was designed to measure the heat of open fire-places and of furnaces.

Its basis is a small, yet solid plate *a*, *b* of highly baked porcelain, in which is a grove capable of containing a flat bar of platina *c*, 1.75 inch in length, 0.2 of an inch broad, and about 0.1 of an inch in thickness. One end of this

* Mémoires de l'Institut. Nationale, tom. ii. an. 7.

bar rests or abuts against the bottom of

Fig. 21.



the groove; the other presses against the short arm of a bended lever, the long arm of which, moving on a pivot, becomes the index of the instrument. The short arm of this lever is just one twentieth of the length of the long arm, which in the original instrument was equal to 1.8 inch; consequently the space moved over by the long arm will be twenty times as great as the motion caused in the short arm by the expansion of the bar.

A finely graduated arc of a circle, of which the index is a radius, is fixed on the porcelain; and each degree of this arc is subdivided into ten parts by a vernier on the extremity of the index itself, and thus the instrument is capable of indicating an expansion of $\frac{1}{3730}$th part of the radius. All these parts are of platina.

With this instrument Guyton made many experiments, the general result of which proves, that Wedgwood has greatly erred in assigning too high a temperature for the degrees of his scale, a result confirmed by the later experiments of Daniell. Guyton ascribes Wedgwood's error to his estimating the fusing point of *silver* much too high. It was by means of a pyrometric piece of fine silver that Wedgwood connected his scale with that of Fahrenheit; and an error with respect to that metal must viciate all the results. According to Morveau, the fusing point of silver ought to have been at 22° W. instead of 28°: and each degree, instead of being equivalent to 130° of F., ought to have been no more than 62°.5; while the commencement of his scale should have been at 517° F., instead of at 1077°.5.

There is some reason, however, to believe, that Morveau has stated a red heat in day rather too low; for thermometers of mercury and of oil can sustain a temperature of 517° F. without any luminousness even in the dark.

Morveau appears to have taken great pains to connect the scale of his pyrometer with the common thermometer; and he is probably nearer the truth than Wedgwood.*

His corrected table of Wedgwood's temperatures is as follows:—

	Wedg.		Fah.
Mercury boils	2°	=	642.75
Zinc melts	3	=	705.26
Antimony melts	7	=	955 23
Silver melts	22	=	1822.67
Copper melts	27	=	2205.18
Gold melts	32	=	2517.63
Iron welds	95	=	6508.88
Cast iron melts	130	=	8696.24
Porcelain melts	155	=	9633.68
Manganese melts	160	=	10517.12
Malleable iron melts	175	=	11454.56
Nickel melts	175	=	11454.56
Platina melts	175	=	11454.56

16. In 1803, Mr. James Crighton, of Glasgow, published a new "metallic thermometer," in which the unequal expansion of zinc and iron is the moving power. A bar is formed by uniting a plate of zinc, *fig.* 22, *c*, *d*, 8 inches long, 1

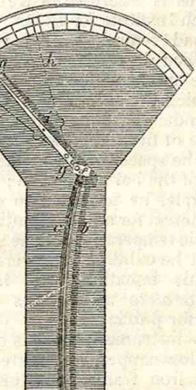


Fig. 22.

inch broad, and ¼ inch thick, to a plate of iron *a*, *b* of the same length. The lower extremity of the compound bar is firmly attached to a mahogany board at *e*, *e*; a pin *f* fixed to its upper end plays in the forked opening in the short arm of the index *g*, *g*. When the temperature is raised, the superior expan-

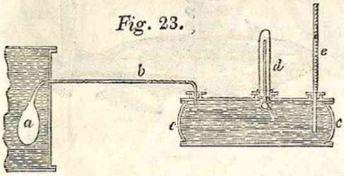
* Annales de Chimie, tom. lxxiv. lxxviii. xc.

sion of the zinc *c d* will bend the whole bar, as in the figure; and the index *g* will move along the graduated arc, from right to left, in proportion to the temperature. In order to convert it into a *register thermometer*, Crighton applied two slender hands *h, h* on the axis of the index: these lie below the index, and are pushed in opposite directions by the stud *i*, a contrivance seemingly borrowed from the instrument of Fitzgerald.

On the whole, the principle of this pyrometer is just; but it does not seem to possess any considerable advantages over several of those already noticed.

17. We have some doubts of the propriety of noticing a sort of *air pyrometer*, *fig*. 23, proposed by M. Schmidt

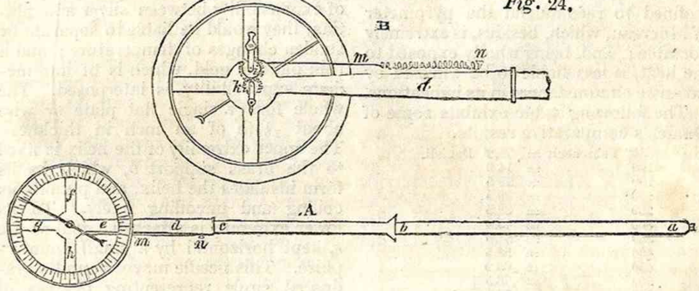
Fig. 23.



of Jasy in Moldavia.* It is so evidently a mere theoretic proposal, and is, besides, an expensive, clumsy, and probably not very accurate mode of ascertaining high temperatures. It consists of a bottle *a*, and narrow tube *b* of platina, the former to receive the impression of the heat, and the latter to convey the expanded air into *c c*, an air-tight cistern partially filled with water. The cover of the cistern is perforated by three holes; in one of which the end of the platina tube is cemented; in the second is fixed a glass tube *d*, containing a common thermometer; and in the third, a slender graduated tube *e*, which dips into the water in the cistern. The thermometer is for ascertaining the temperature of the included air of the cistern before the experiment; the graduated tube for ascertaining the temperature communicated to the platina bottle by the ascent of this water raised by the pressure of the expanded air on the surface of the fluid in the cistern. Any further description would be superfluous.

The pyrometer of Mr. Daniell (*fig*. 24) was first described in Brande's *Quarterly Journal*.* The moving power is a rod or wire of platina 10.2 inches in length, and 0.14 inch in diameter, fixed in a tube of blacklead ware *a*, *b*, *c*, by a flanch within and a nut and screw without the tube at *a*. This tube has a shoulder moulded on it at *b*, for the convenience of always inserting it into the furnace, or muffle, to the same depth. From the extremity of the pla-

Fig. 24.



tina rod at *b* proceeds a fine wire of the same metal, $\frac{1}{100}$ inch in diameter, which comes out of a brass ferrule *d*, and passes two or three times round the axis of the wheel *i*, B, *fig*. 24. It then bends back, and is attached to a slender spring *m n*, which is fixed by one end to the pin at *n*, on the outside of the ferrule.

The substitution of a silk string for that part of the platina wire lapped round the wheel, and connecting it with the spring, has rendered the motions of the index more sensible. The axis of *i* is = 0.062 inch, and the diameter of the wheel one inch: its teeth play in the teeth of another wheel just one-third of its diameter, by which the wheel *k* has three times the movement of *i*; and the index on the axis of *k*

* Nicholson's Journal, 8vo, series, vol. ii, 141.

* Vol. xi. p. 309.

moves therefore three times round for every revolution of *i*. The action of the spiral spring *m* draws round the wheel *i* and the index, when the expansion of the platina rod permits it to act. The dial is divided into 360 degrees. By experiment, Daniell ascertained that each degree of his scale = 7 degrees of Fahrenheit's: and he has published an account of some well conducted experiments on the fusing points of some of the metals with this instrument, which very widely differ from the results obtained by Wedgwood, but nearly agree with those of Morveau. Mr. Daniell found, that after being exposed to high temperatures, the pyrometer did not fall to the point from which it set out; a circumstance which he attributes, with justice, to changes in the form of the tube induced by a high temperature. This is certainly an imperfection in the principle of the instrument; but if the degrees of heat be marked by the ascending series, its indications seem tolerably correct, and, although perhaps little to be depended on in nice investigations, it may become an useful instrument to manufacturers who make use of high temperatures. The tube should not be exposed to a naked fire, except it be of wood charcoal; because the foreign ingredients of fossil coal will adhere or incorporate with the blacklead ware of the tube. On these grounds we should feel more inclined to recommend the pyrometer of Morveau, which, besides, is extremely portable; and, being wholly exposed to the heat, is less liable to be affected by extrinsic circumstances in its indications.

The following table exhibits some of Daniell's comparative results.

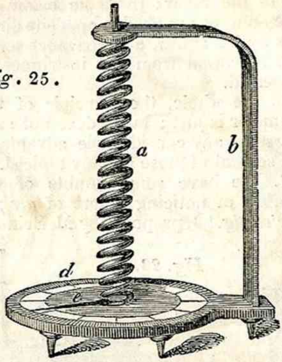
50° Fahrenheit	=	7°.2′ Daniell.
100	=	14 0
150	=	22.5
200	=	30.5
250	=	38.5
300	=	45.4
350	=	51.5
400	=	58.5
450	=	66.9
500	=	73 5
550	=	77.0
580	=	84.0

600° by calculation he estimates at 86°.4.

	D.	F.
Melting point of tin	63	441
——— bismuth	66	462
——— lead	87	609
Boiling point of mercury	92	644
Melting point of zinc	94	658
Red heat in full daylight	140	930
Heat of a parlour fire	163	1141
Melting point of brass	267	1869
——— silver	319	2233
——— copper	364	2548
——— gold	370	2590
——— cast iron	497	3479

18. Messrs. Breguet, the celebrated chronometer-makers, have lately constructed a most elegant and delicate pyrometer, or metalline thermometer, of which we give a figure. (See *fig.* 25.)

Fig. 25.



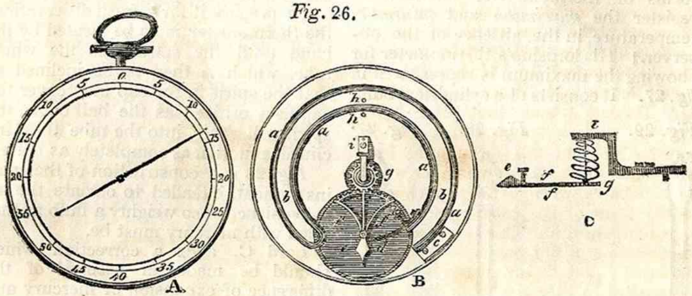
It consists of a helix formed of three metals of unequal expansibility. The exterior plate of this delicate helix is of silver, the interior of platina, and between them is one of gold. Two only are necessary to the perfect action of the instrument; but from the difference of expansibility between silver and platina, they would be liable to separate by sudden changes of temperature; and a thin plate of gold, which is of intermediate expansibility, is interposed. The whole form a single flat plate or wire about $\frac{1}{100}$th of an inch in thickness. The upper extremity of the helix is fixed to the brass support *b*, which by its form insulates the helix, and permits its coiling and uncoiling freely. To its lower extremity is attached a gold needle *e*, kept horizontal by a small counterpoise. This needle moves round a graduated circle representing degrees of the centigrade scale. When the ambient air is heated, the expansion of the metals carries round the needle in the direction of the coils of the helix, and a diminution of temperature moves it in the opposite direction by relaxing the coils. Experiment has proved that equal increments of temperature move the needle over equal spaces of the scale, so that it is comparable with other thermometers.

The sensibility of the instrument is represented as very great, when compared to a mercurial thermometer; and it is applicable to such purposes as ascertaining the temperature of a *vacuum*, which the mercurial thermometer is able to do less accurately, because of the dilatability of its bulb by the removal of pressure.

The height of the instrument, from which this description is drawn, is 3 inches, including the feet, which are half an inch; the diameter of the helix is rather less than $\frac{3}{10}$; and its length is $1\frac{1}{2}$; the diameter of the graduated circle is 2 inches inside, and its breadth $\frac{1}{4}$.

19. The instrument delineated in *fig.* 26, from one now before us, is a beautiful instrument of the same kind, the work of the Parisian artist, Frederick Houriet, which appears to be little known in this country. It is of the size of a thin ordinary watch, with a dial A divided according to the centigrade scale. The mechanism is covered by a thin plate of metal, which opens like a hunting watch; and the instrument is so delicate as to move, in less than a minute, after it is laid on the hand, at an ordinary temperature of 60° F.

Fig. 26.



The pyrometric piece is the bent compound bar *a*, *b*, *a*, *b*, composed of a plate of steel on the side *a*, and of another of brass on the side *b*, united together into one bar. The steel plate is $\frac{1}{30}$ inch in thickness, and the brass twice as much, forming a bar 9.5 inches in length, and about $\frac{1}{7}$ inch in depth. One extremity is firmly secured to the frame at *c:* the rest of it is free, bent up for the convenience of size, and secured against any accidental injury from rude handling by passing between two steel studs *h*, *h*. Its free extremity is terminated by a plate of steel *d* screwed to it, and projecting 0.3 inch beyond it, to press against the short arm *e* of the lever *f f*. The long arm of the lever ends in an arch-head with thirty teeth, that play in the teeth of a small wheel *g* with twenty-two teeth, which is fixed on the axis of the slender hand. The lengthening of the bar pushes the short arm of the lever, and the arch-head moves over a space proportional to the difference in length of the arms of the lever. How this motion is communicated in an increased ratio to the index is obvious from the construction. Under the cock *i*, which supports the common axis of the index, and *g*, is a spiral spring of flattened gold wire, intended to bring back the index when the contraction of the bar allows it, and to retain the piece *d* in contact with the short arm of the lever *e*. The instrument is adjusted by means of a steel screw *k* working in a small tube, which perforates the end piece *d*.

The whole instrument is most delicately made, and it accords in its indications with a mercurial centigrade thermometer, with which it has been carefully compared; forming one of the most elegant metalline thermometers hitherto described.

Chapter III.

History and Construction of Register Thermometers.

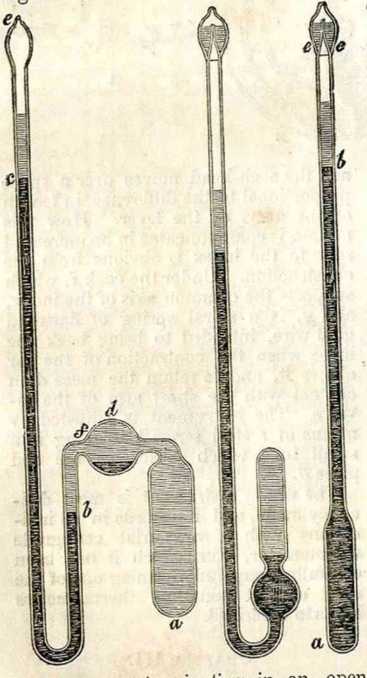
The original suggestion of a thermometer which could register its own indications in the absence of the observer, is due to the celebrated John Bernoulli, who describes such an instrument in a letter to Leibnitz;* and an instrument

* Leibnitzii et Bernoulli Commercium Philosoph. et Mathemat.

on nearly the same principle was constructed by Kraft:* but their contrivances are inferior to several others of a later period, and do not require a detailed notice. We shall therefore proceed to describe the most approved register thermometers.

1. Lord Charles Cavendish communicated to the Royal Society different forms of thermometers, intended to register the *maximum* and *minimum* temperature in the absence of the observer.† His lordship's thermometer for showing the maximum is represented in *fig*. 27. It consists of a cylindrical bulb,

Fig. 29. *Fig*. 28. *Fig*. 27.



and a stem terminating in an open capillary orifice, covered by a glass cap or ball *e* completely closing the thermometer. The bulb and part of the stem are filled with mercury, the rise and fall of which indicate the temperature in the usual way; above the mercury a portion of alcohol is introduced, sufficient to fill the rest of the tube and a small part of the cap. When the mercury rises it drives the spirit before it into the cap *e*, from which it cannot return while the instrument remains erect; and the deficiency of spirit in the tube, on the subsiding of the mercury, measured by a proper scale, will show how much the maximum rise of the thermometer exceeded its height at the time of the observation.

To prepare it for a fresh observation, the thermometer is to be heated by the hand until the spirit fills the whole tube, which is then to be inclined so that the spirit in the cap may cover the capillary orifice: as the ball cools, the spirit will drain into the tube thus inclined, and fill it as completely as before.

Fig. 28 is a construction of the same instrument, intended to obviate the inconvenience of so weighty a bulb as that filled with mercury must be.

Lord C. adds a correction which should be made on account of the difference of expansion of mercury and spirit, in computing the deficiency, if this be measured by the same scale as the ascent of the mercury: the degrees computed by the column of spirit will exceed those of the mercurial column by $\frac{1}{8}$ of a degree for every 10° of Fahrenheit of difference between them.

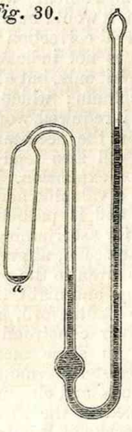
Fig. 29 is his lordship's minimum thermometer. Its bulb, $\frac{3}{4}$ of the ball *d*, and part of the leg *b*, are to be filled with spirit of wine; from *b* to *c* is occupied by a column of mercury, and about $\frac{1}{4}$ of *d* contains a portion of this fluid; a little alcohol is likewise introduced above the mercury before the orifice of the tube at *e* is closed in the usual manner. The mercury at *c* will, when furnished with a proper scale, indicate the present temperature in the ordinary way; but, when the spirit in the bulb contracts by cold, the mercury will rise in the short leg of the siphon from *b* into the ball *d*, from which it cannot get back into the tube *b*. This will therefore occasion a deficiency of mercury in that leg, which, measured by a proper scale attached to the short leg of the siphon, and subtracted from the present height of the mercury in the long leg, will show the lowest point to which the thermometer had fallen during the absence of the observer. To prevent the mercury falling in too large drops into the ball *d*, by which the delicacy of the instrument would be impaired, a solid but fine thread of glass passes through the short leg to the

* Van Swinden, Comparaison des Thermomètres.
† Phil. Trans. vol. l. for 1757.

narrow neck *f* of the ball *d*, by which the passage is still further contracted, so that the mercury trickles through in most minute division. The instrument is prepared for a new observation by being inclined so as to bring the mercury in *d* to cover the orifice at *f*; the bulb is then heated, and the mercury is expelled from the ball into the short leg of the siphon, until it be filled with that fluid.

Fig. 30 is another form of the last

Fig. 30.



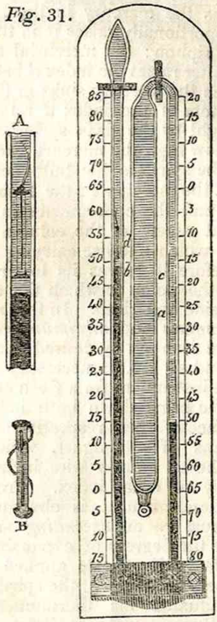
instrument, which has the advantage of being more easily adjusted, and is less liable, from slight motion, to have the mercury which has passed into *a* brought back into the tube.

These instruments are extremely ingenious contrivances; but there are some practical difficulties in their construction; and the minimum thermometer is rather liable to be broken from the size of the bulb, and the several bendings of the tube. Hence Lord C. Cavendish's thermometers never appear to have come into general use, although very well adapted for certain purposes, as for ascertaining the temperature of the ocean at great depths. It is therefore unnecessary here to notice the corrections pointed out by Mr. Cavendish in its applications to various purposes.

2. Next in point of time is the contrivance of Fitzgerald; which has been already noticed, as well as that of Crighton; for rendering their metallic thermometers indicators of the maxima and minima of temperature during the absence of the observer.

3. The Register Thermometer invented by Mr. James Six, of Colchester, was first described in the *Philosophical Transactions*,* and is represented in *fig.* 31. It is, in fact, a spirit of wine

Fig. 31.



thermometer, with a long cylindrical bulb, and a tube bent in the form of a siphon with parallel legs, and terminating in a small cavity. A portion of the two legs of the siphon from *a* to *b* is filled with mercury; the bulb, and the remainder of both legs of the siphon, as well as a small portion of the cavity, are filled with highly rectified alcohol. The double column of mercury is intended to give motion to the two indices *c*, *d*; the form of which is better seen at A. Each index consists of a bit of iron wire inclosed in a glass tube, which is capped at each extremity by a button of enamel. Their dimensions are such, that they would move freely in the tube, were it not for a thread of glass drawn from the upper cap of each, and inclined so as to press against one side of the tube, forming a delicate spring of sufficient power to

* Vol. lxxii.

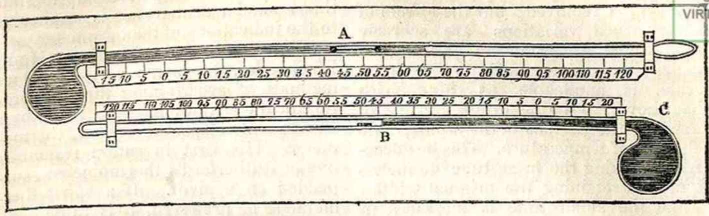
retain the attached index at any part of the tube, to which it is raised by the column of mercury. The action of the instrument will now be readily understood. When an increase of temperature expands the spirit in the bulb, it depresses the mercury in the limb *a*, and proportionally raises it in the limb *b* of the siphon: the mercurial column in the latter raises the index *d* before it; and when the mercury sinks in that leg, the bottom of the index *d*, retained at that height by the glass spring, will indicate how high the mercury had risen. When the spirit in the bulb contracts by cold, the mercury in the limb *b* descends, and the consequence is a proportional ascent of the column in the side *a*; which likewise carrying the index *c* before it, leaves its lower extremity at the point to which the column of that side had risen. In this manner the *maximum* and *minimum* temperatures are seen at any desired interval of time; and all that is necessary to prepare the instrument for a fresh observation is to bring down both indices to the surface of their respective columns by means of a magnet, which will act on the bit of iron wire included in the body of each index. From the above description, it is obvious, that there must be an *ascending* scale to measure the degrees of expansion in *b*, and a *descending* scale applied to *a* to mark the contraction of the spirit. Mr. Six graduated his thermometers by placing them in water at different temperatures, and marking on his scales the heights corresponding to every 5° of a standard mercurial thermometer immersed in the same liquid. This elegant invention has become a common instrument; and on account of the ease with which the glass spring of the index may be broken off, many instrument makers substitute a slender bristle, tied to the upper part of the index, and lapped round its body, as at B. This renders the spring less easily spoiled by the careless shifting of the index; but the hair, by being long steeped in spirit, is liable to have its elasticity destroyed; and a slender silver or platina wire would be preferable. The usual dimensions of the instrument are, a bulb from 6 to 16 inches in length, and from 0.2 to 0.3 inch in internal diameter; the siphon from the $\frac{1}{40}$ to the $\frac{1}{20}$ of an inch in width, and of a length proportioned to the size of the bulb; the indices about 1 inch long; the terminal expansion of the tube is, in most of the instruments now made, rather too small; in Six's original instrument, this part was a cylinder of 2 inches in length, by half an inch in diameter, to a bulb of 16 inches in length, and $\frac{6}{16}$ inch in internal diameter.

The chief defect of Six's thermometer arises, as in most other contrivances of this sort, from the unequal expansion of the spirit, and the introduction of two liquids of very different expansibility in the instrument; while, from the construction, it would be difficult to apply any general correction to its indications. It does not indicate the expansion of the spirit only, but also that of the mercurial column; which, where nice observation is required, would be of some moment; and the necessary friction of the indices will also tend to diminish the effect of expansion. Yet this instrument is a valuable addition to meteorology; and is probably the most convenient for ascertaining the temperature of the ocean, at great depths, of any hitherto given to the public.

4. The day and night thermometers of Dr. John Rutherford, from the simplicity of their construction, and low price, have in some measure superseded the register thermometer of Six. This ingenious and elegant device was first published in the Transactions of the Royal Society of Edinburgh,* and is represented in *fig.* 32; where A represents a spirit, and B a mercurial thermometer, each provided with its own scale, placed horizontally on the same piece of box wood or ivory. B contains, as an index, a bit of steel wire, which is pushed before the mercury, and is left in that situation to mark how high the temperature had been. A contains a glass index half an inch long, with a small knob at each end; it lies in the spirit, which can freely pass beyond it when expanded by heat; when contracted by cold, from the attraction between spirit and glass, the last film of the column of spirit is enabled to overcome the slight friction of the index on the inside of the tube, and to carry it back towards the bulb. This attraction is so considerable, that although the index will move freely up and down in the spirit, on inclining the instrument, it will rest on the last film, and require several smart concussions given to the thermometer, to make it

* Edin. Phil. Trans. vol. iii.

Fig. 32.

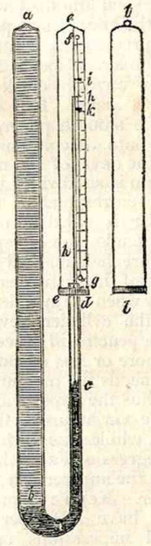


escape into the empty part of the tube. From the position of both thermometers it is obvious, that to bring both indices to the surface of the respective fluids, it is only necessary to incline the instrument toward C; and it is thus prepared for a fresh observation.

The accuracy of Rutherford's thermometers depends on the ease with which they are constructed, and the application of a due correction for the inequalities of expansion between them; this can be more readily accomplished than with Six's thermometer; because the indications of each fluid are independent of each other. The discrepancies between both thermometers have been carefully examined by De Luc,* and more lately by De Wildt, of Hanover;† the results will be given in the sixth chapter, from which the correction can be applied. Such a correction will render them applicable to the nicest meteorological observations of maxima and minima. For more ordinary purposes they are very convenient, as not being easily deranged, and being adjusted, for each observation, with the utmost facility.

5. In the *Transactions* of the same society,‡ we find another register thermometer, by Mr. Alexander Keith, a gentleman of great mechanical invention, and long an active member of that society. It is represented in our *fig*. 33; where *a b* is a glass tube, 14 inches long, and ¾ inch in calibre, sealed at the top, and below communicating with a bent tube *b*, *d*, 7 inches long, and 0.4 inches in diameter, open at the top, where it is cemented to a metallic plate *e*, which supports the ivory scale *e*, *e*, 6½ inches long. From *a* to *b*, the tube is filled with highly rectified alcohol, and from *b* to *c* with mercury. At *c* is a conical float of ivory or glass, resting on the surface of the quicksilver, and

Fig. 33.



supporting a kneed wire *h*, intended for moving two indices of black silk *i*, *k*, that slide along the fine gold wire *g*, *f*, as will be readily seen from the figure.

To prepare the instrument for observation, the indices are drawn, by means of a crooked wire prepared for the purpose, till they touch each side of the knee of the *float wire*. It is obvious that, as the heat alters the dimensions of the column of spirit in *a*, *b*, the mercury will rise or fall in the small tube, and the float swimming on the surface of the mercury will raise or depress the knee *h*, which will move the indices accordingly on the wire *g*, *f*. The instrument is defended from wind or rain by the glass case *l*, *l*, which, by means of its metal collar, fits tight on *e*, and is only removed to adjust the indices.

This instrument, it is true, is influ-

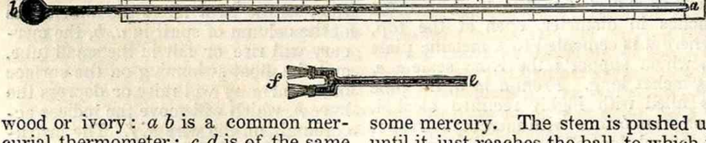
* Recherches sur les Mod. de l'Atmosphère.
† Jameson's Edin. Phil. Journal for October, 1826.
‡ Edin. Phil. Trans. vol. iv.

enced by atmospheric pressure, when its cover is removed; but the effects of barometrical variations are scarcely appreciable except in an air thermometer; and when made on a large scale, is applicable, as Mr. Keith has shown, to the important purpose of marking the *periods* of the atmospheric changes of temperature. This he effected by making the large tube 40 inches long, but retaining the original width; while the small tube is increased in diameter, but not in length. The float *c* is enlarged, and the float wire carries, instead of the knee, a soft pencil, which is made to press lightly against a hollow vertical cylinder, 7 inches long and 5 in diameter, moved by clock-work, once round in 31 days. This cylinder is covered with smooth paper, ruled longitudinally into 31 columns, to correspond to the days of the month; and every column is subdivided into 6 equal parts, each corresponding to 4 hours. The cylinder is ruled across into 100 divisions, intended to correspond to the 100° of Fahrenheit marked on the ordinary scale of the instrument, which is unnecessary when the cylinder is applied. Thus, as the cylinder revolves, the point of the pencil will trace a line on the paper more or less deviating from a horizontal line, as the mercury rises and falls; and thus the paper will present a *chart* of the variations of the thermometer for a whole month, the value of which, in degrees of Fahrenheit, will be indicated by the numbers on the margin of the paper. Keith recommends the observer to have a copper plate for giving ruled impressions on smooth paper, to be applied monthly to the cylinder; and these, bound up together, will present tabular views of the fluctuations of the thermometer for every month. It is hardly necessary to state that a similar contrivance is applicable to the indications of the barometer.

6. We are indebted to Mr. Henry Home Blackadder, for some very ingenious methods of ascertaining the temperature of the air, at any given hour, by a subsequent inspection of a thermometer. His first invention resembles one of Rutherford's thermometers, suspended on a pivot. If a spirit thermometer be preferred, it is to be hung vertically and inverted, so that the index may rest on the last film of the liquid. Suppose that we desire to know the temperature at 5 o'clock, A. M., a lever connected with a clock is applied, so as to bring the thermometer to a horizontal position at that hour; and, at the same time, the motion causes the bulb of the thermometer to approach some source of heat a little higher than that of the air; as, for instance, a small lamp, by which the spirit would rise beyond the now horizontal index, leaving it at the point to which the spirit had contracted before the reclination of the instrument. When a mercurial thermometer is employed, the instrument is also hung vertically, but with its bulb lowermost; and the index, therefore, resting on the mercury. It is brought to a horizontal position by the same means as the other thermometer; and then its bulb, coming into contact with a camel-hair pencil, kept continually moist with water, is cooled so as to cause the mercury to shrink, and leave the index at the height of the column while the instrument was in the upright position.

By a subsequent improvement he has contrived to dispense with the index altogether. This modification is seen in *fig.* 34, where two thermometers are placed parallel on the same piece of box wood or ivory: *a b* is a common mercurial thermometer; *c d* is of the same size, but is not hermetically sealed. The end of its stem is ground flat, and is introduced into the neck of a small ball at *e*; which, as well as the stem, contains some mercury. The stem is pushed up until it just reaches the ball, to which it is cemented by colourless varnish.

Fig. 34.

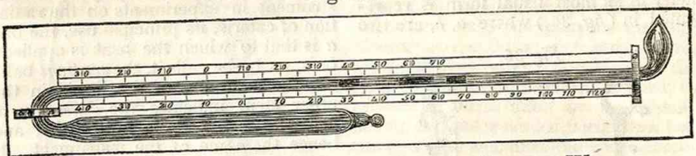


When these thermometers are in the upright position, the globule of mercury in *e* covers the orifice of the tube; and on applying the heat of the hand to *d*, the mercury in the stem joins that in the ball; and the stem will remain filled with the mercury while the instrument is vertical: but when it is brought into a horizontal position by the machinery above mentioned, and the bulbs approximated to the pencils *e f*, suspended over them for that purpose, and supplied with liquid through the channels in them, the mercury in the ball will leave the orifice of the stem, and that in the latter will descend, as represented in the figure; and its subsequent contraction is marked by an inverted scale; which, with the indications of the other thermometer, will enable us to ascertain the temperature at the moment of the reclination of the instrument. Thus, as both instruments are equal, if the same diminution of temperature has sunk *a b* to 50°, and has produced a contraction of 10° in *e d;* it is evident the sum of both numbers will show the degree at which the common thermometer stood at the moment of the change of position; which in this case has been 60°.

This idea is most ingenious, and is said in practice to work exceedingly well. It promises to be useful in meteorological investigations, although not so complete as the register thermometer of Keith, which continues to note its own indications for a whole month; while that requires to be readjusted for each observation.

7. We shall conclude this chapter by a notice of another register thermometer invented by Dr. Traill, and seen in *fig.* 35. It is a single spirit thermometer,

Fig. 35.



in which a column of mercury $\frac{1}{3}$ of an inch in length is introduced: at each end of this column lies an index of fine steel wire, gilded by means of a galvanic circuit, to prevent oxidation in the spirit. An inspection of the figure will show how the variations of bulk of the spirit in the bulb will move the column of mercury; and by this the indices are pushed in opposite directions, but will remain at the lowest and highest points to which they are driven by the mercury. The difference between the two scales will be the length of the mercurial column. The indices are brought in contact with the mercury by a magnet.

This thermometer has the advantage of giving the *maxima* and *minima* by the changes in volume of a single fluid; for the expansion of so short a column of mercury is quite inappreciable. The defect of this construction is the liability of the mercury to separate by sudden motions of the instrument. This is least likely to happen when the mercurial column is short and the calibre of the tube is minute; and it is to admit of a fine tube that gilded steel wire is preferred to an index coated with glass.

Chapter IV.

Differential Thermometers, and their Modifications.

Thermometers of this kind are not affected by general changes of temperature in the surrounding medium; but are delicate indicators of partial changes affecting one of their balls. Some of the forms of the air thermometer described by Van Helmont, bear a general resemblance to the instrument known by the name of *differential thermometer:* but they were rudely constructed, without a fixed scale, and unsusceptible of accuracy, or of application to the delicate investigations required by modern experimental philosophy. We are indebted to the ingenuity of Professor Leslie of Edinburgh for a perfect differential thermometer, and its application to some very important purposes.

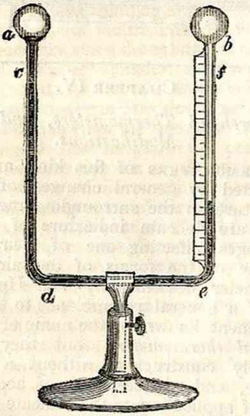
In January 1800, he published a description of a new *hygrometer* and *photometer*,* of which the principle depends on the difference in the volume of air contained in two equal balls of glass, connected by a tube bent in the

* Nicholson's Journal, 4to, vol. iii. p. 461.

form of a letter U, when the balls are unequally heated. This difference is measured by the motion of a coloured liquid contained in the bent tube. "In ordinary cases," says Leslie, "the intermediate liquor would continue stationary; for the air in both balls having the same temperature, and, consequently, the same elasticity, the opposite pressures would exactly counteract each other;" but if one ball becomes colder than the other, "it is manifest that the liquor would be pushed towards it by the superior elasticity of the air included in the other." This is the principle which suggested to him the

1. *Differential Thermometer*, used with so much skill and ingenuity in those delicate investigations *on heat*, with which he was occupied from the above period, until the publication of his work early in 1804. The differential thermometer in its most usual form is represented in (*fig*. 36,) where *a*, *b*, are two

Fig 36.



equal glass spherules, connected by the tube *c*, *d*, *e*, *f*, slightly dilated just below the ball *a*, and at *e*, and partially filled with a coloured liquid, as represented in the figure. The dilatation below *a*, is intended as a reservoir of liquid; and that at *e*, for the more easy adjustment of the liquor to the commencement of the scale, by passing bubbles of air from one ball to the other. The liquid recommended by Leslie,* after many trials, is strong sulphuric acid, tinged by carmine. The scale he adopts, is *millesimal*, from the freezing to the boiling point of water; or 10 degrees of it are equal to one of the scale of Celsius. The instrument is cemented to a wooden foot, either immediately, or is furnished with a sliding stem to adapt it to different heights. Each leg of the instrument is usually from 3 to 6 inches in length, and the balls are from 2 to 4 inches apart. The calibre of the stem *e*, *f*, is from the 1-50th to 1-60th of an inch; that of the rest of the syphon a little larger.

When exposed in a room, or in the open air, the differential thermometer remains stationary at 0°, whatever may be the temperature of the ambient air; but if one of its balls be more heated than the other, the unequal expansion of the included air puts the coloured fluid in motion. In employing this instrument in experiments on the radiation of caloric, its principal use, the ball *a* is that to which the heat is applied; or is, as Leslie calls it, the *sentient* ball; and the mounting of the liquid in the other stem indicates the *difference* of elasticity of the air in both balls, and hence the name of the instrument. It owes to its insensibility to general changes of temperature, its peculiar fitness for measuring the influence of radiation.

The theory of the instrument supposes that *gases expand uniformly with equal increments of temperature:* this is, perhaps, not strictly true; yet, as Leslie remarks, it is so nearly correct, that, in the limited range of the instrument, the irregularity from that cause is quite inappreciable.

It is worthy of remark, that, a few weeks after the publication of Mr. Leslie's "Inquiry," a part of the "Philosophical Transactions" of London appeared, which contained a set of experiments almost similar to many of his, and a description of an instrument, in principle precisely similar to his differential thermometer. This was

2. *Rumford's Thermoscope.*

It consisted also of two horizontal balls, united by a syphon; and the only difference from Leslie's thermometer is, that the scale is attached to the horizontal part of the tube (which is the longest portion); and the coloured liquid is a bubble moving to and fro, when the balls are unequally heated, in the horizontal part of the tube. Rumford pro-

* Experimental Inquiry, p. 417, 1804.

fesses to have borrowed the idea of the thermoscope from Leslie's hygrometer; but the latter has roundly charged him with a more direct plagiarism from the *differential thermometer;* to which accusation we do not recollect that any satisfactory answer has been published.

The differential thermometer has undergone several alterations of form to adapt it to particular purposes as an air thermometer. One of the most common is seen at *fig.* 37, where the ball *b* is cemented to the tube, after the introduction of the liquid, as in the old air thermometer, but this form has been rendered more elegant and convenient by the modification of *Dr. De Butts of Baltimore,* (See *fig.* 38,) in which no cement is necessary; for the stem and both balls are united by the blow-pipe. These instruments are to be either fixed perpendicularly on a stand, or suspended. The liquid is contained in the lower ball, and the heat is applied to the upper one; so that the stem is provided with a *descending scale.*

Fig. 38.

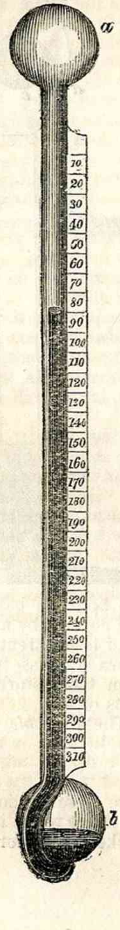
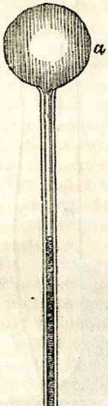


Fig. 37.

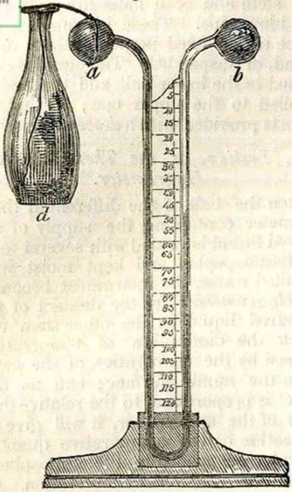


3. *Leslie's, or the Thermometric Hygrometer.*

When the ball of the differential thermometer containing the supply of coloured liquid is coated with several folds of tissue paper, and kept moist with distilled water, the instrument becomes an *Hygrometer:* for the descent of the coloured liquid in the other stem will mark the diminution of temperature caused by the evaporation of the water from the humid surface; and as this effect is proportional to the relative dryness of the ambient air, it will give an indication of the comparative quantity of water suspended in the atmosphere, at the different times of observation. In most cases, two minutes are sufficient to produce the full effect on the instrument; and the included liquid then becomes stationary, until the whole moisture is exhaled from the ball. The drier the ambient air is, the more rapidly will the evaporation go on; and the cold produced will be greater. When the air is nearly saturated with moisture, the evaporation goes on slowly; the cold produced is moderate, because the ball regains a large portion of its lost heat from surrounding bodies; and the degree of refrigeration of the ball is an index of the dryness of the air. Could we ascertain with precision the capacity of air for moisture, at different temperatures, this hygrometer would likewise afford a measure of the absolute quantity of water suspended in the air. The most approved form of the instrument, according to Leslie, is seen in *fig.* 39. The balls are parallel, and bent from each other; *a* is covered smoothly with several folds of tissue paper, which is to be kept continually moistened with pure water, drawn from the vase *d*, by the capillary attraction of a few fibres of silk. In order to obviate any inequality from the disturbing effect of light, the ball *b* is formed of pale blue glass; and the *papered* ball is covered with thin Persian silk of the same hue.

Should the water become frozen on the ball, this hygrometer will still act; for evaporation goes on from the sur-

Fig. 39.



face of ice, in proportion to the dryness of the air. Mr. Leslie estimates, that when the ball is moist, air, at the temperature of the ball, will take up moisture equal to the sixteen thousandth part of its weight, for each degree of his hygrometer; and as ice in melting, requires 1-7th of the caloric consumed, in converting water into vapour, when the papered ball is frozen, the hygrometer will sink more than when wet by 1° in 7°; and hence in the frozen state, we must increase the value of the degrees 1-7th: so that each of them will correspond to an absorption of moisture, equal to one-fourteen thousandth part of the weight of the air.

When this hygrometer stands at 15°, the air feels damp; from 30° to 40°, we reckon it dry; from 50° to 60°, very dry; and from 70° upwards, we should call it intensely dry. A room will feel uncomfortable, and would probably be unwholesome, if the instrument in it did not reach 30°.* In thick fogs it keeps almost at the beginning of the scale. In winter, in our climate, it ranges from 5° to 15°; in summer often from 15° to 55°; and sometimes attains to 80° or 90°. The greatest degree of dryness ever noticed by Leslie, was at Paris in the month of September, when the hygrometer indicated 120°.

* Leslie "On the Relations of Air, Heat, and Moisture," p. 70.

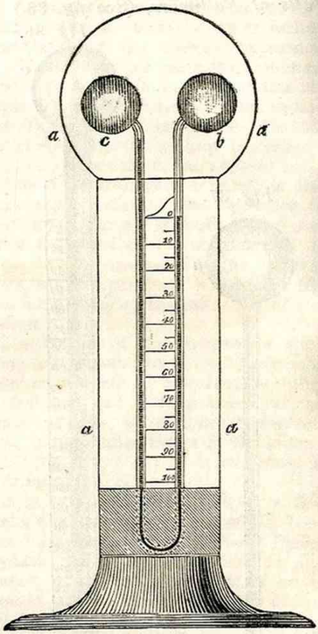
The thermometric hygrometer is of two forms; the *stationary*, (*fig.* 39,) and the *portable*, which resembles the instrument delineated in (*fig.* 41), without its glass shade. This last form is defended by a wooden case which screws over it, to fit it for the pocket.

4. *Leslie's Photometer*.

This elegant instrument is the differential thermometer, covered by a case of transparent glass, and having one of its balls either painted black, or, what is better, formed of black glass enamel.

The *Stationary* Photometer (*fig.* 40)

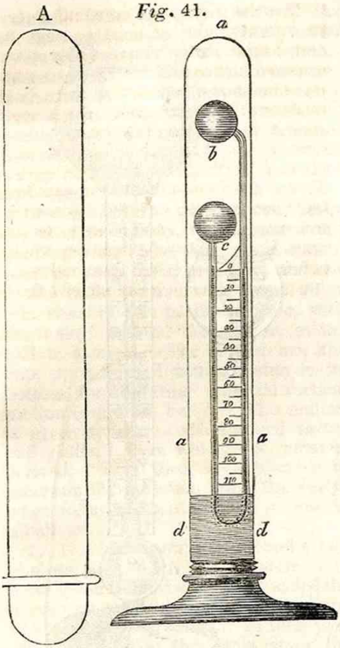
Fig. 40



has both its balls at the same height, and covered by a spherical shell of the most transparent glass; which, with the annexed glass tube, defend the balls from the disturbing influence of currents of air.

The *Portable* Photometer (*fig.* 41) has the balls in the same vertical line, in order to admit a turned tube of wood A, of the same form as its cover *a*, *a*, to screw on the brass collar *d*, as a defence to the instrument when in the pocket; and for further convenience

A *Fig.* 41.



the socket is made to unscrew from the sole of the instrument. The ball, *b*, is of black, or deep reddish-brown enamel, while *c* is as diaphanous as possible. The graduation, and other parts of the photometer, are on the same scale and construction as in the differential thermometer.

Dr. Franklin, and others, had remarked the superior power which dark colours possessed of absorbing the calorific influence of the sun's rays; and Dr. Watson, afterwards Bishop of Llandaff, had, in 1773, observed, that when a thermometer, having its ball blackened, was exposed to the sun's light, it rose 10° higher than it had previously done in a similar situation. The researches of Mr. Leslie put this fact in a more striking point of view, and led to the invention of this instrument.

The theory of the photometer hangs on the supposition, that the intensity of light emitted from any body, is always proportional to the temperature excited by its incidence on the blackened ball. This is probably true with regard to the undecomposed rays of the sun, in which the caloric and the light, if different kinds of matter, are intimately blended; but there is strong reason to suspect, that light emitted by terrestrial bodies is not always proportional to the concomitant temperature. Thus the intense splendour of phosphorus burning in oxygen gas, gives out far less heat than the comparatively dull combustion of hydrogen in the same gas; and we have found this photometer often more affected by the emanations from a fire so dull, that not a single letter could be discerned in a well-printed page, than by the degree of daylight, by which we could read the same print with pleasure and facility. It is differently affected too by light of different colours, where their illuminating property appears the same; and the experiments of Herschel, Englefield, and others, show that the maximum of heat in the solar beam, decomposed by the prism, by no means corresponds with the illumination, but is even altogether beyond the margin of the spectrum.*

As a measure, however, of the intensity of undecomposed solar light, it appears to support the character it receives from the inventor.—" The photometer," says he, " exhibits distinctly the progress of illumination from the morning's dawn to the full vigour of noon, and thence its gradual decline till evening spreads her sober mantle. It marks the growth of light from the winter solstice to the height of summer, and its subsequent decay through the dusky shades of autumn; and also enables us to compare, with numerical accuracy, the brightness of different countries—the brilliant sky of Italy, for instance, with the murky air of Holland."

The direct impression of the sun's rays at noon, about the summer solstice, in this country, equals from 90° to 100° of this instrument; and at midwinter, the force of the solar beams is from 25° to 28°. The indirect light, from a summer's sky, at noon, is from 30° to 40°; in winter, it is from 10° to 15°. In the most gloomy weather, in summer, the photometer rarely indicates less than 10° at noon; but in winter it sometimes barely exceeds a single degree.

The observations on the light of day with this instrument should always be made in the open air; and the direct

* Herschel, Phil. Trans. 1800; Englefield, Journ. Roy. Institution, vol. i.

effect of the sun's rays noticed, as well as the indirect reflection from the sky.

5. *Pyroscope.*

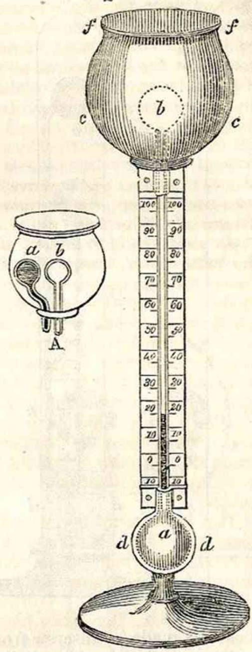
When one ball of the differential thermometer is smoothly covered with thick silver leaf, or inclosed in a polished sphere of silver, and the other ball is naked, it forms the *pyroscope;* an instrument intended by its inventor, Mr. Leslie, to measure the intensity of heat radiating from a fire into a room, or the frigorific influence from a cold body. A figure is unnecessary, as the instrument is usually made either like the differential thermometer, like that represented in (*fig.* 37,) or the hygrometer, (*fig.* 39.) The theory of its construction and application is, that all the rays incident on the metallic surface, are returned from it; while those that reach the transparent ball expand the air within it, and depress the coloured liquid in the stem. In this way the comparative radiation from various bodies may be ascertained; and it is so delicate an instrument, that in a warm room it will be visibly affected by a pitcher of cold water, at the distance of a few inches.

6. The *Æthrioscope of Leslie* is another modification of the differential thermometer which we shall here notice. One of its most usual forms is given in *fig.* 42; and is what the inventor calls the *Pendant Æthrioscope.* The ball *a* of the thermometer is inclosed within a brass sphere, *d, d,* without touching it; and for the convenience of adjustment, this sphere may be unscrewed in the middle. The other ball, *b*, which is about one half the diameter of the first, is in the centre of an oblong spheroidal cup, *c, c,* which may be covered by a top that fits on at *f, f.* The coloured liquid in the stem is supported by capillary attraction in the dilated extremity of the tube, where it joins the ball *a.* The brass work is highly polished, and the inside of the spheroidal cup is well gilt.*

This very elegant instrument is intended, in the language of Mr. Leslie, "to indicate the *cold pulses* emanating from the sky;" or, in other words, to give a comparative idea of the radiation proceeding from the surface of the earth toward the region of perpetual congelation in the atmosphere. The brass coverings defend both balls from the influence of the sun's rays, or

* Edin. Phil. Trans., vol. viii.

Fig. 42.



other adventitious sources of heat; and when the ball *b* is cooled by radiation toward the heavens, the air within it contracts, and the elasticity of that within *a*, forces up the liquid in the stem, the height of which marks the intensity of the radiation.

When the cover is on, the liquid remains at 0°; but when it is removed, and the instrument presented to a clear sky, either by night or by day, it instantly begins to rise, and continues to mount until the ball *b* has sustained the greatest diminution of temperature, which radiation at that time can produce.†

The circumstances which favour radiation from the surface of the earth toward the sky, namely, a clear and calm atmosphere, are admirably pointed out by Dr. Wells, in his excellent Essay on *Dew:* and this instrument becomes a

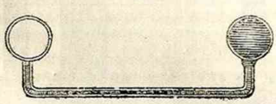
† Leslie appears to have been led to this invention by some of his own experiments on radiant caloric; but it is proper to state, that Dr. Wollaston had shown, that when a delicate thermometer, in the focus of a concave metallic mirror, is presented to the sky, cold is indicated.

valuable indicator of the state of the air favourable to the deposition of that interesting meteor. Such is its extreme delicacy, that, when rising, its progress is checked by the smallest cloud sailing over it; and it may be kept in a state of oscillation, by being alternately stretched beyond the edge of a parasol, and drawn within its shade, when the sky is clear and serene.

Besides the forms given above, Leslie describes two others, the *Standard* and the *Sectorial*. The first has the stem bent up as in the hygrometer, and one of the balls covered with silver leaf or gilt, near the side of the cup *c*, *c*, with the naked ball in the centre, as the balls *a*, *b*, in A. The second has the cup, *c*, *c*, formed with a notch in its bottom, for admitting a partial vertical motion round the ball *b*. The motion is given by means of a toothed sector and pinion; from which the name is derived. This form is applicable to ascertain the radiation from the earth, when we ascend a mountain, or rise in a balloon.

7. The differential hygrometer and photometer would have come into more general use had they indicated the maximum and minimum between any two times of observation. In their present construction they only show the state of the atmosphere at the moment of observation, and, therefore, require an attention which few have leisure or inclination to bestow on meteorological observations. To render them more extensively useful the following alteration is suggested, by which they are brought nearly to the thermoscope of Rumford in form. The tubes connecting the balls have the upright part of their stems shortened, and the horizontal part extended: instead of a coloured fluid filling the stems, there is a short column of mercury introduced into the horizontal part of the stem; the motion of which, towards either ball, carries before it a piece of steel wire, which constitutes the index of maximum and of minimum change during the absence of the observer. This construction will be readily understood from the figure 43, which represents the register hygrometer. A double scale lies along the horizontal part of the instrument. When the indices are adjusted for a fresh observation, they are brought by a magnet to each extremity of the little column of mercury.*

Fig. 43.



Chapter V.

Of some peculiar Applications of the Thermometer.

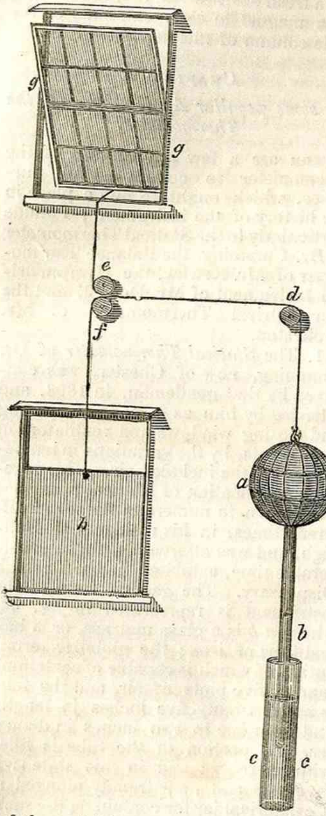
There are a few applications of the thermometer to certain useful purposes, which ought to find a place in the history of the instrument; I allude particularly to the Statical Thermometer of Dr. Cumming, the Balance Thermometer of Mr. Kewley, the Hygrometrical Instrument of Mr. Daniell, and the Barometrical Thermometer of Mr. Wollaston.

1. The *Statical Thermometer* of Dr. Cumming, now of Chester, was contrived by that gentleman, in 1808, and intended by him as a mode of opening and closing windows and ventilators in apartments, by the variations in temperature of the included air. This ingenious application of statical principles was shown to numerous friends at different times, in his residence at Denbigh, and was afterwards, for a considerable time, exhibited in the Denbigh Dispensary. The general form of the instrument is represented in *fig.* 44, where *a b* is a glass matrass, or a ball and tube of iron; the globular termination of which is capable of containing four or five pints of air, and the tube is about twenty-five inches in length, and from one to two inches in diameter. A portion of the tube is filled with mercury; and in this state it is inverted, and its extremity plunged in a cylindrical jar for containing the same fluid. The ball is covered by a net of strong cord, or of wire, which forms a ring at the top, for the suspension of the ball and tube. From this ring passes a cord over the pulley, *d*; and it may either pass upward under the pulley, *e*, to be attached to the frame of a swing window, as shown at *g*; or downwards over the pulley *f*, to be fixed to the ventilator *h*. When the heat of the apartment expands the air in the ball, it depresses the mercurial column in the tube, *b*; by which the whole instrument

* This instrument acts rather slowly, and the motion of the indices is not quite smooth; but it appears capable of supplying a desideratum in meteorological observations—a register hygrometer.

becomes as much lighter as the weight of the mercury expelled from the tube,

Fig. 44.

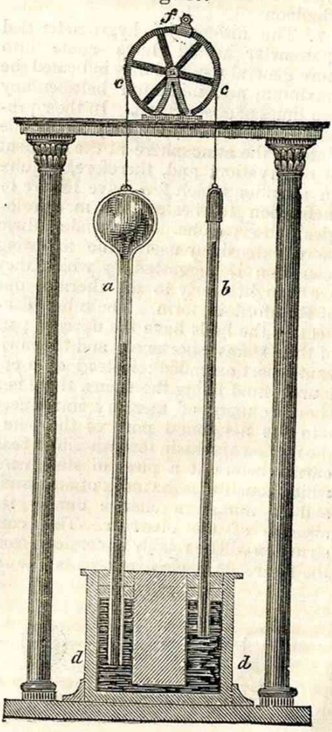


and the weight at the top of the window, or of the ventilator, opens these apertures which were kept shut by the weight of the statical tube and ball. On the other hand, when the cooling of the air in the chamber causes the contraction of the air included in the ball, the pressure of the atmosphere forces the mercury into the tube, which thus becomes so much heavier; and as it descends, it drags with it the window frame, or ventilator, attached to it.

This simple and very ingenious contrivance is applicable to hot-houses, rooms, and apartments of every description, that are liable to considerable changes of temperature; and it possesses considerable powers: for in a tube two inches in diameter, every inch in the rise or fall of the mercury is equivalent to a moving power of about one pound. It is liable to be slightly altered also by changes in atmospheric pressure.

Dr. Cummings's attention was drawn to the importance of regulated temperature in the treatment of disease, whether in public institutions or in private practice, and the contrivance above noticed was the method by which he endeavoured to obtain this important object: but he soon perceived that the principle was applicable to various meteorological purposes; and the instrument has, in his hands, undergone successive modifications and improvements, until it has become the basis of a thermometer, hygrometer, and photometer, capable of registering their own indications, by the aid of clock-work, at any given time. Details of these different contrivances would lead us into too

Fig. 45.



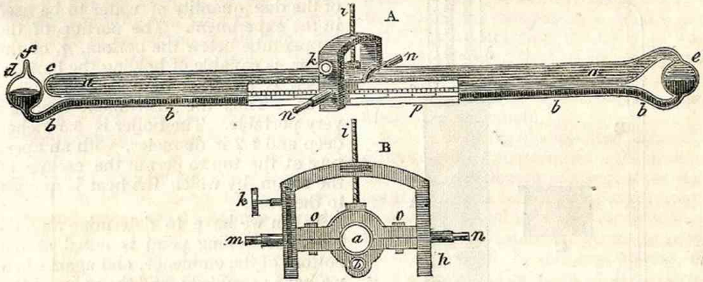
wide a field; but it may be proper to state, that finished drawings of them all have been in the possession of a distinguished member of the Meteorological Society of London for upwards of four years. The principle of them will be readily understood from the preceding figure, (*fig.* 45,) in which *a* represents an air thermometer; *b* a barometer, suspended from the opposite side of the wheel *c c*, to compensate the influence of variations in atmospheric pressure on the instrument; *d d* is a siphon-cistern, in both sides of which the mercury will always remain on the same level; *f* is an index, to which a pencil may be fixed, for tracing the variations of the instrument on a plate revolving by means of clock-work.

The portions of the tubes which dip into the mercury should be of equal substance; and the tube of the air-thermometer should be a cylinder capable of containing twice as much mercury as the corresponding portion of the barometer which counterpoises it. A small correction may be required for the varying immersion of the tubes, produced by the oscillations of the instrument. This must be determined by experiment, and allowed for in the graduation of the scale.

2. The *Balance Thermometer* of Mr. Kewley is a contrivance for a similar purpose, and is represented in *fig.* 46, A.

This instrument is the subject of a patent, the date of which is 1816. It

Fig. 46.



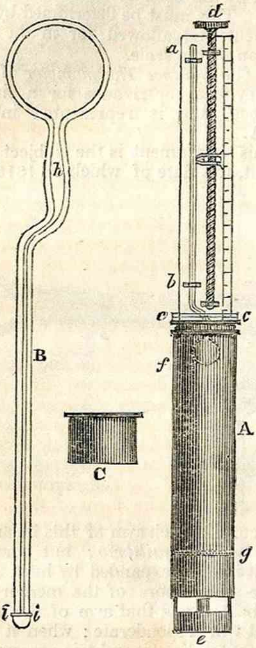
consists of a tube of glass, *a*, *a*, closed at *c*, and terminating at *e* in a ball, which communicates with another tube of smaller diameter, which also terminates in a ball at *d*, having a communication with the external air at *f*. The tube *a*, *a*, and one half of the ball, *e*, are filled with spirit, or any light easily expansible fluid. The other tube, from *e* to *d*, is filled with mercury. The whole is suspended in the iron frame, *h*, *i*, *k*, *m*, B, by means of two clamping pieces, which are adjusted to the tubes by the screws, *o*, *o*. The centre of gravity is suitably adjusted by means of the milled nut, sunk in the transverse part of the frame, and receiving the screw, *i*; in order that the whole may librate on the knife edges, *m*, *n*, destined to rest on surfaces resembling the suspension frame of a common balance. A brass scale, *p*, is moved by the nut, *k*, on the arbor of which is a pinion playing in the *teeth* of the plate, *p*.

It is obvious, that by adjusting the mercury in each arm of this balance, it will be in *æquilibrio;* but when the spirit in *a* is expanded by heat, it will force some more of the mercury into the ball, *d*, and that arm of the instrument will preponderate; when it again contracts, the atmospheric pressure will cause the mercury to resume its original situation.

The instrument may be used as a thermometer, by ascertaining at what temperature it is in equilibrio, and when either end preponderates, finding how much is necessary to restore the balance by the motion of the brass plate, *p;* but its chief value arises from its applicability to shut and open doors or windows, according to the temperature of the apartment; in which case, a lever, or tooth-wheel, is fixed on one of its centres of oscillation. It is almost needless to remark, that the whole may be constructed of iron, and of any convenient size. In point of simplicity and cheapness, however, it is inferior to that proposed by Dr. Cumming, which preceded it in date; although until now no detailed account of that invention has been published.

3. The *Barometrical Thermometer* of the Rev. F. Wollaston is seen in *fig.* 47, A. It is a thermometer with a

Fig. 47.



large bulb, devised for the measurement of altitudes, by observing the temperature at which liquids boil on different elevations;* on the principle first pointed out by Fahrenheit,† that the boiling of a fluid varies with the pressure of the atmosphere. Cavallo first applied this principle to the measurement of heights,‡ and the instrument proposed by Mr. Wollaston is intended to facilitate this method.

The bulb of the mercurial thermometer he proposed to use, is one inch in diameter, with a dilatation *h*, as seen in B, and ending in a capillary tube, five inches long, which is not closed in the usual manner, but, after being broken off smoothly, is sealed by a little cap of glass, as at *i*, *i*. The scale is 4.15 inches long, divided into 100 parts, and may be subdivided by a vernier into 1000 parts; giving 241 parts to each inch of the scale; and to facilitate observation, these are read off by a small lens jointed to the index, but not represented in our figure. The index is moved by a micrometer screw, *d*. The thermometer is supported by means of stuffing between two circular plates of metal, *c*, *c*, through which it passes, and which are tightened by screwing them together. They form a metallic collar, that may be screwed by either end into the top of the copper boiler, *f*, *g*, which becomes the case of the thermometer on inverting it; and then the bulb is protected by a copper cap C, which also serves as a measure of the due quantity of water to be used in the experiment. The portion of the copper tube below the bottom, *g*, of the boiler, is capable of holding the lamp, *e*, which is attached to it by two sliding wires. Thus the instrument becomes very portable. The boiler is 5.5 inches deep and 1.2 in diameter, with an aperture at the top to permit the escape of the steam, by which the heat is applied to the bulb.

When we have to determine an altitude, the boiling point is noted at the bottom of the eminence, and again when we have ascended; and the value of the difference between those points on the scale having been ascertained by experiment, we can estimate the height ascended, provided no change has, in the mean time, taken place in the barometrical pressure; or these points may be simultaneously found by two observers. The only correction required is, for the specific gravity of air at different temperatures, which may be found by General Roy's tables. The use of the dilatation, *h*, is to receive the expanded mercury, before it arrives at the boiling point: and the small cap, *i*, *i*, is intended to receive a globule of mercury, to be detached occasionally from the column in the stem, when it is wished to alter the range of the scale to suit various altitudes. The method of separating this globule is, to elevate the mercury, by heating the bulb until the thread of metal may be shaken over the flat end of the capillary tube; and when we wish to join the globule again to the thread, the two portions of mercury are brought into contact by heat, and then as the in-

* Phil. Trans. for 1817.
† Phil. Trans. vol. xxxii.
‡ Phil. Trans. vol. lxvi.

strument, held in the vertical position, cools, the globule will follow the thread into the stem.

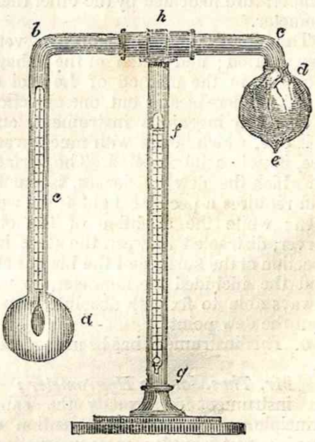
This instrument is of great delicacy; being capable of showing a difference of altitude of not more than three feet; but, unfortunately, although not very bulky, it is not very portable, from the liability of the stem to be broken by the weight of the bulb, even from the usual jolting of a carriage; an accident which happened thrice to the writer of this, within one month. From this circumstance, and its price, it is not likely to supersede the barometer in geological surveys.

4. M. Le Roi was the first who suggested the temperature at which dew begins to be deposited as a method of ascertaining the moisture of the air. De Luc has the merit of having proved that the quantity and force of vapour in a vacuum of any given dimensions, are equal to its force and quantity, in an equal volume of air, at the same temperature; or that the force and quantity of vapour in the air are dependant on its temperature.* This was confirmed by Mr. J. Dalton,† who investigated the force of vapour, at every temperature, from 0° to above 212° Fahrenheit, and expressed this force by the height of the mercurial column, which it could support in a Torricellian tube. These results are given in a tabular form, and are thus easily applied to hygrometric purposes. Dalton finds the *dew point*, like Le Roi, by pouring *cold* water into a glass, and marking the temperature at which it just ceases to cause the deposition of dew on the sides of the glass, in the open air. This is the point at which, in an air of that temperature, dew would just begin to be formed. From this fact he is able to infer, not only the force exerted by the vapour, but its quantity in a perpendicular column of the whole atmosphere, and the force of evaporation at the time of observation.

Thus, if the *dew point* be 45°, the force of vapour in Dalton's table = 0.316 of an inch of the mercurial column, or the one-ninety fifth of the whole atmospheric pressure; or, if the specific gravity of steam be 0.70, the weight of the steam or vapour in a given volume of air will be the one hundred and thirty-sixth part of the whole. Now, as the force of a *whole atmosphere of steam*, at the surface of the earth, would be the weight of a perpendicular column of it, and as in a mixed atmosphere of steam and air, the force exerted by each is as their relative weights, it follows, that when the dew point is 45°, the whole superincumbent column of vapour in the atmosphere, being equal to the one-ninety-fifth of the whole atmospheric pressure, will be equivalent to a pressure of 4.30 inches of water; or the vapour, if condensed, would afford that depth of water. From these data, Dalton has shown how we can find the force of evaporation at a given time: for the quantity of water evaporated from a given surface is proportional to the maximum force of vapour at the temperature of that surface; it being understood that the vapour is still in contact with a surface of water. Hence, if we have the dew point 45°, while the temperature of the air is 50°, by subtracting the force of vapour at 45° from that of 50°, we shall obtain the force of the evaporation at that time—thus, .375—.316=.059, the force of evaporation.

5. It is on this principle that *Daniell's Hygrometer* is constructed; the invention of a gentleman distinguished for his meritorious labours in meteorology. It was published in 1820, along with a meteorological table, and seems to have been suggested by the cryophorus of Wollaston.‡ The form of the instrument is seen, as last improved by Mr. Daniell, in (*fig.* 48.) The ball *a* is of

Fig. 48.



* Recherches sur les Modifications de l'Atmosphère.
† Manchester Memoirs, vol. v. 535.—vol. i. new series, p. 252.

‡ Quarterly Journal of Science, vol. viii. 299—see also vol. ix. &c.

black glass, about one and a quarter inch in diameter, and is connected with a ball *d* of the same size, by a bent tube one-eighth of an inch in diameter. A portion of sulphuric æther, sufficient to fill three-fourths of the ball *a*, is introduced; a small mercurial thermometer, with a pyriform bulb, is fixed in the limb *a b*, the atmospheric air is expelled as completely as possible; and the whole is sealed at *e*. The ball *d* is covered with muslin; the whole is supported on a brass stand *f, g*, on which is another delicate mercurial thermometer. The tube can be removed from the spring tube *h;* and the whole, together with a phial of æther, packed neatly in a box, that goes easily into the pocket. The method in which the dew point is indicated by this instrument, is as follows:—The æther is all brought into the ball *a*, by inclining the tube; the balls are placed perpendicularly; the temperature of the ambient air is now noted; æther is poured from a dropping tube that fits the mouth of the small phial, on the muslin cover of *d;* and, the cold produced by its evaporation, causing a condensation of the elastic æthereal vapour within the ball, produces a rapid evaporation from *a*, by which the temperature of the thermometer in it sinks; and when the black ball is thus cooled to the dew point, a film of condensed vapour, like a ring, surrounds the ball. If the thermometer be at that instant noticed, we obtain the true dew point of air at the temperature indicated by the other thermometer.

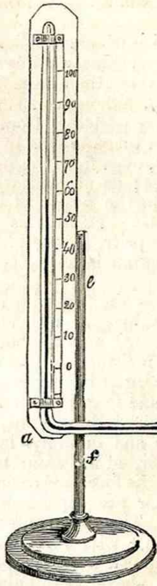
The observation is made in a very short period; and much of the labour required in the method of Le Roi is saved. There seems but one objection to this very ingenious instrument, and it is one, which, even with much practice, is not easily obviated. The surface on which the dew condenses, is small, and requires a peculiar light to be well seen; while the attention of the observer, distracted between the close inspection of the surface of the black ball, and the included thermometer, is not always able to fix with absolute precision the dew point.

6. This instrument has been modified in

Mr. Thos. Jones's Hygrometer;

an instrument on exactly the same principle as the original invention of Daniell, but simpler in construction, more compact, and less expensive. It is seen in *fig.* 49, consisting of a delicate mercurial thermometer, with its tube at *a, b*, bent so as to bring its cylindrical ball *c*, parallel with, and at a little distance from, its stem. The bulb is one inch long, and is terminated by a flattened surface *d*, of black glass, which projects a little beyond the sides of the bulb. The bulb below the flattened surface is covered with black silk. The instrument is supported on the wire *e f*, which is attached to the scale by a pivot, that allows the black surface to be inclined to the light, and the whole, with a phial of æther, are contained in a small case. *

Fig. 49.



When used, the temperature of the air is first noted; then æther is poured on the silk cover of the bulb; and the condensation of the dew is seen on the black extremity of the bulb.

The difficulty of marking the incipient condensation on these instruments is the same; and it has produced various modifications of the instrument.

7. Dr. Cumming, of Chester, finds that the dew point is most conspicuously shown, by inclosing the bulb of a delicate thermometer, covered by a sponge, in a tube of planished tinned iron, silver, or platina. When the sponge is moist-

* Phil. Trans. for 1826, part ii. p. 23.

ened with any very evaporable fluid, such as æther or alcohol, and a stream of air blown through the tube, a more rapid and more conspicuous deposition of dew takes place on the surface of the metallic tube, than we ever recollect to have observed in similar experiments.

Fig. 50 is Dr. Cumming's hygrometer fitted to a portable air-syringe, by which a current of air is produced through the tube B B. The bulb of the delicate thermometer within it is surrounded with fine sponge, to retain the evaporable fluid; the tube B B is of highly polished metal, with an aperture in its upper part covered with a glass tube, for the inspection of the thermometer, as represented in the figure.

Fig. 50.

Chapter VI.

On the Imperfections common to all Instruments for the Indication of Heat.

1. The terms *thermometer* and *pyrometer* might lead to the supposition, that the instruments so designated were actual indicators of the quantity of *caloric* contained in those bodies to which they are applied; but a single experiment is sufficient to show that this view is erroneous. If we place equal quantities of water and of snow, both at temperature 32°, in a room at 60°, the temperature of the water will, as indicated by the thermometer, after some time, rise considerably; but the effect of the heat on the ice will only be to melt it partially, while its temperature remains steadily at 32°. Here we have *caloric* received by the ice which does not affect the thermometer.

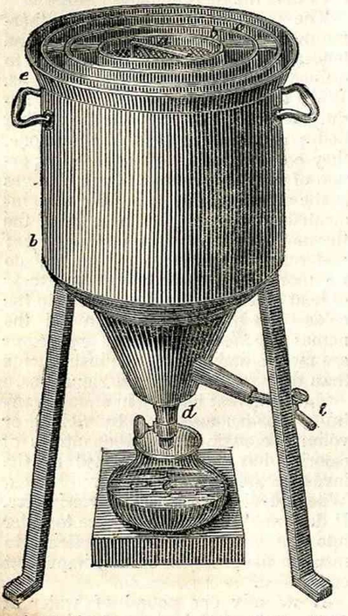
The principle upon which the thermometer and the pyrometer act is, the tendency which heat or *caloric* has to diffuse itself among contiguous bodies. When applied to a hot body, they acquire a portion of the heat from that body; and when applied to a cold one, they communicate to that body a portion of their own caloric. These changes in the quantity of its own caloric are indicated by changes in the bulk of the thermometric fluid, or pyrometric piece; and such instruments, therefore, do no more than show a certain excess of heat given out by the hottest to the coldest body. On this ground the names of *thermoscope* and *pyroscope* are more suitable for such instruments than their more common designations.

That different bodies, in equal quantities, whether measured by weight or volume, contain unequal quantities of caloric, has been established by the investigations of Boerhaave, Black, Wilcke, Irvine, Crawford, Lavoisier, &c. It does not belong to this place to enter into this subject, but it is sufficient to mention the grounds for this important conclusion.

If we mix one pound of water at 212°, and as much water at 32°, when due precautions are employed to mix them without loss of heat or the addition of extraneous temperature, the thermometer plunged in the mixture will indicate very nearly 122°, or the arithmetical mean between the extremes; which proves that equal quantities of the *same body* contain quantities of caloric proportional to their temperature. If, however, we mix a pound of mercury with a pound of water, at different temperatures, when the mercury is the hottest, the temperature of the mixture will be greatly *below* the mean; and when the water is the hottest body, the mixture will be greatly *above* the mean temperature. A series of such experiments have shown that the same quantity of caloric which can raise the temperature of water only 4°, will raise that of mercury 112°. If this be the case at every temperature, which is most probable, the *quantity of caloric* in water is to that in an equal weight of mercury, at the same temperature, as 112 : 4 = 28 : 1.

Besides this method of finding out the comparative quantity of caloric in bodies, there is another founded on the fact, that ice in melting absorbs an uniform quantity of caloric. Professor Wilcke, of Copenhagen, first conceived the idea of employing the melting of ice or snow, for the purpose of ascertaining the comparative quantity of caloric in different bodies; and this method was improved in the hands of Lavoisier and Laplace, by the invention of the *Calorimeter*.

It consists of two vessels of tinned iron, and a wire cage, which are fitted so that one may be inserted within the other, leaving a cavity between the sides of each. (See *fig*. 51.) The wire-cage,



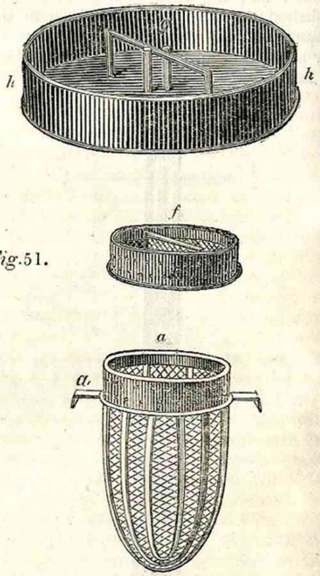


Fig.51.

a, is the innermost; and is destined to receive the heated body, the subject of experiment. The space between it and the second vessel, *b*, is to be filled with pounded ice, or snow, as well as the perforated cover, *f*, of the cage *a*. It is the melting of this snow which affords the indication of the comparative quantity of caloric in the bodies submitted to experiment; it rests on a wire sieve, at the bottom of the cylinder *b*, and is received at the orifice of the pipe *d*. To guard against the effects of external temperature, the cavity between the vessel *b*, and the exterior one, is filled also with pounded ice or snow; the general lid *h*, of the whole being also covered with snow, and its edges resting in a groove *e*, lined with the same material, the interior of the instrument is defended from all direct access of external temperature. The two tubes, *g*, in the lid, are for the introduction of thermometers; but during experiments those tubes are shut up, to prevent the access of currents of air through the calorimeter. The water collected between the outer and second vessel may be drawn off by the pipe *i*. Experiments of this kind should be made in a room at a temperature of 32°. Before commencing the experiment, the snow is saturated with moisture by its melting, to obviate as much as possible the error from not collecting the whole of the water.

The indications of this instrument,

from the cause just alluded to, and the impossibility of altogether obviating the effects of currents of air through it, during experiments, are not susceptible of such accuracy as the more simple method of mixture; although this also is liable to lead to erroneous conclusions, from the difficulty of obtaining the true result of the effect of the different mixtures.

2. There is an obvious source of error in the indications of all instruments employed to measure temperature, in as much as the apparent changes in the volume of the thermometric substance are not the real augmentation or diminution of bulk it undergoes. The glass of the thermometer, and the frame of the pyrometer, are also expanded and contracted by changes of temperature; so that our instruments only show the *excess of the expansions* of the thermometric fluid, or pyrometric bar over those of the glass and frame; by which the true indications are diminished.

From the extreme nicety of some of the investigations in which the mercurial thermometer is employed, a comparative ratio of the expansions of mercury and glass has been most diligently sought after by De Luc, Ramsden, Roy, and others. From their investigations it has been ascertained that all solids and liquids vary in their rate of expansion; but that the expansibility of glass depends so much on the manufacture of that article, and varies so much in the different kinds, that no general equation as a correction for this source of error can be of practical utility. Even the form of the glass rod is material. Roy gives the expansion of a glass tube = 0.0046569th; of a solid glass rod = 0.0096944th, in passing from the freezing to the boiling point of water.*

An important series of experiments by Lavoisier and Laplace have been published by Biot,† from which it appears that of twenty-three solids tried, glass was the least expansible of them all.

The length of different glass rods, which at 32° Fahrenheit = 1.00000000, at 212° Fahrenheit is augmented as follows:

Glass of St. Gobain	1.00089089	$=\frac{1}{1122}$
Glass tube, without lead	1.00087572	$=\frac{1}{1142}$
Ditto	1.00089760	$=\frac{1}{1114}$
Ditto	1.00091751	$=\frac{1}{1090}$
French glass, with lead ...	1.00087199	$=\frac{1}{1147}$
English flint glass	1.00081166	$=\frac{1}{1248}$

* Phil. Trans., vol. lxxv.

† Traité de Physique, t. ii. 158.

This will show the impossibility of any general correction being applied; and the adoption of any formulæ for this purpose would be an affectation of accuracy, of which, unfortunately, the subject is incapable. If, however, such formula is considered desirable, it may easily be constructed from the experiments of De Luc on glass tubes‡ at different temperatures, which, reduced to the scale of Fahrenheit, are,

Temp.		Bulk.	Temp.		Bulk.
32°	=	100000	150°	=	100044
50	=	100006	167	=	100056
70	=	100014	190	=	100069
100	=	100023	212	=	100083
120	=	100032			

3. Another error of some magnitude is produced by the inequalities of the expansions of the same substances by equal increments of temperature.

If we could consider expansion simply as the effect of the application of heat, equal increments of temperature should produce equal rates of increase of volume; but the expansion is the *resultant*, in solids and in liquids, of two opposite forces—of the repulsive energy of caloric opposed by the cohesion of the particles of matter; and, accordingly, it not only differs in the different kinds of solid and liquid matter, but in the same body at different temperatures. As might be expected from this view, it must be in an increasing ratio with the temperature; because the force of cohesion must diminish with the distance of the particles of matter.

In aëriform bodies, the force of cohesion does not exist; and we might infer that equal increments of heat would produce equal expansions, in all gases, at all temperatures. In gases, the ratio might even be expected to decrease, in a minute but inappreciable degree, with the temperature; because the increased distance of the particles will tend to diminish the repulsive energy.

Experiment in these particulars accords with theory. The ratio of expansion in solids and liquids is found to be an *increasing* one, as the temperature is augmented, and is very different in each substance; while in the gases, it is not only equable in the same gas, but equal in all.

The manner in which an increasing

‡ Recherches, t. i.

ratio of expansion must affect thermometers and pyrometers, graduated on the principle of equal degrees between two fixed points, is obvious; and it early became an object of solicitude. Drs. Halley and Brooke Taylor devised the method of investigation—namely, by mixing together equal weights of water at different ascertained temperatures, and finding how much the thermometer, plunged in that mixture, differed from the mean temperature. From not sufficiently attending to the various requisites to obviate error, they did not arrive at the true conclusion. We owe to De Luc the more successful investigation of this problem; by a train of nice experiments, in which he endeavoured to guard against the sources of error arising from the cooling effect of the vessel containing the mixture, and of the escape of vapour, he proved that the different thermometric fluids do not expand in a uniform ratio to the quantities of caloric applied; but follow an increasing rate as their temperature is raised. Mercury he found to be the most regular in its expansions; yet it also showed very sensible deviations. When equal weights of water at 32° and 212° were mixed, the mercurial thermometer did not indicate the mean temperature 122°, but only 119°; an oil thermometer, in the same experiment, stood no higher than 117°, and one of spirit of wine at 108°; while, with a thermometer filled with water, the temperature of the mixture appeared only to be 75°. His experiments showed the great superiority of the mercurial over the alcoholic thermometer; but this superiority, it probably owes, as Mr. John Dalton has remarked, in a great measure to the distance of the ordinary range of temperature, from the freezing and boiling point of mercury; for the experiments of De Luc show that the irregularities of all fluids are much augmented about the points of their consolidation and passing into vapour.

From the usual method of graduating the mercurial thermometer from two fixed points only, the error from inequality of expansion will be greatest at the mean between the two points; when, according to De Luc, it amounts to about 3° Fahrenheit below the real temperature. In the following table are given the result of De Luc's researches, on the two fluids chiefly used for thermometers—mercury and alcohol. In the first column are the indications of the mercurial thermometer, according to De Luc's or Reaumur's scale; in the second, the indications of the alcoholic thermometer at the corresponding temperatures; and in the third, are, what ought to be, the real temperatures as discovered by experiment.

Mercurial Ther.	Alcohol Ther.	Real Tem.
80	80.0	80.0
75	73.8	75.28
70	67.8	70.56
65	61.9	65.77
60	56.2	60.96
55	50.7	56.15
50	47.3	51.26
45	40.2	46.37
40	35.1	41.40
35	30.3	36.40
30	25.6	31.32
25	21.0	26.22
20	16.5	21.12
15	12.2	15.94
10	7.9	10.74
5	3.9	5.43
0	0.0	0.0

There is reason to believe, however, that De Luc states the irregularity of the mercurial thermometer too high. Dr. Crawford investigated this point with great care, and concluded, that when the difference of temperature of the two portions of fluid did not exceed 100° F., the average deviations of the mercurial thermometer were not above 0.25 of a degree. De Luc himself allows, that the result of the mixtures must be inaccurate, if the *capacity* of the water operated on is changed during the experiment. In mixing together hot and cold water, the probability is, that the diminished volume of the mixture causes a diminution of capacity; and, consequently, an *increase* of temperature, beyond what is due to the heat of the two portions mixed together. By exposing a mercurial thermometer in a vessel, in which the included air was exposed to the frigorific influence of melting snow, and the heat of watery vapour at 212°, he found that it indicated 121°, or only a single degree less than the arithmetical mean.* From comparison with air thermometers, Gay Lussac inferred that the mercurial thermometer was equable in its expansions,

* Experiments on Animal Heat.

between the freezing and the boiling point of water.* Petit and Dulong have investigated the subject, by a comparison with the air thermometer, and with the expansions of a pyrometer of very infusible metals (platina and copper) which appear, by the experiments of Lavoisier and Laplace, to be very equable in their expansions, below the boiling point of water. They found that the irregularity in mercury increases with the temperature; and would even appear to be greater than the rise of the mercurial thermometer indicates, were not the increasing expansion of the mercury diminished by the increasing ratio of the dilatation of the glass itself.† Hence the source of error in thermometers arising from the expansion of the glass, is rather advantageous than detrimental to their accuracy.

The difference between the indications of the alcoholic and mercurial thermometers, as lately ascertained by Dr. De Wildt, do not materially differ from the determinations of De Luc; and having been obtained for every 5° of Reaumur's scale, apparently with much care, we give the result as a table of correction for Rutherford's thermometers; for which purpose they were intended by the author.

Mercury.	Spirit.	Mercury.	Spirit
−45° =	−28°.50	+20°...	+16°.48
40	25 .92	25	20 .97
35	23 .19	30	25 .60
30	20 .32	35	30 .38
25	17 .30	40	35 .31
20	14 .13	45	40 .38
15	10 .82	50	45 .60
10	7 .36	55	50 .97
5	3 .75	60	56 .48
0	0 .00	65	62 .14
+5	+ 3 .90	70	67 .95
10	7 .95	75	73 .90
15	12 .14	80	80‡.00

The indications of air thermometers were at one time supposed liable to uncertainty, from the inequalities of their expansion. Guyton and Prieur imagined that they progressively expanded in a greater ratio than the temperature,§ but this has been proved to be erroneous; and the mistake probably arose

* Annales de Chimie, t. xliii.
† Annales de Chimie et Physique, t. ii. p. 240.
‡ Jameson's Edin. Phil. Journal, Oct. 1826, and Kastner Archiv fur die Gesammte Natural, Decem. 1825.
§ Journal de l'Ecole Polytechnique.

from their neglecting the effect of hygrometric water in the gases. General Roy* found that their expansion followed a ratio, *decreasing* with the elevation of temperature; and the same result was obtained by Mr. Dalton,† Dr. Murray,‡ Gay Lussac,§ and Petit and Dulong;|| but there is reason to conclude that this apparently decreasing ratio in the expansion of gases is owing to the error caused by the unequable expansions of the mercury in the thermometer, and the dilatation of the bulb of that instrument; and philosophers now agree to consider the expansions of gases equable and equal, as before stated; especially as the decreasing ratio disappears, if we apply De Luc's correction of the real mean between 32° and 212°.

From the foregoing observations, we may conclude, that the air thermometer requires no correction of its indications; that the accuracy of the mercurial thermometer is not materially affected by the inequalities of the expansions of the mercury, in ordinary ranges of temperature; that the expansion of alcohol is pretty uniform, until about 30° R. or 100° F.: above that point its expansions become more irregular; but it has the advantage over every other liquid, of marking the lowest degrees of natural or artificial cold hitherto observed.

The irregularities affecting pyrometers, except from alteration in the size of the substances supporting the bars, are extremely minute. The experiments of De Luc and Roy would lead to the conclusion, that the expansibility of solids is not quite equable. Roy thinks that this slight irregularity may be apparent rather than real; but Lavoisier and Laplace state, that the expansions of solids keep pace with those of the mercurial thermometer, from the freezing to the boiling point of water; and Petit and Dulong assert, that the expansion of metals is progressive above 212° F.

These irregularities, if they exist, are so minute, as not, in any ordinary practical purpose, to affect the indications of pyrometers; and at high temperatures extreme accuracy is seldom of much consequence.

The differences arising from two pyrometers of different materials may be corrected by Table IV. in the appendix

* Phil. Trans. vol. lxvii.
† Manchester Memoirs, vol. v. p. 599.
‡ Edin. Phil. Trans. § Ann. de Chim. t. xliii.
|| Annales de Chim. et Phys. t. ii.

of the results obtained in 1782, by Lavoisier and Laplace, lately recovered by Biot. Each substance at 32° F. = 1.00000000.

There is one precaution in graduating thermometers, which will render any irregularities of little consequence; that is, in forming the scale, not to rest satisfied with only two fixed points, and *equally dividing* the intervening space; but to obtain intermediate points by means of mixtures, or by comparison with a standard instrument so formed; and by the shortness of the intervals adapting the scale to inequalities in the bore of the tube, or to the less important irregularities just now considered.

APPENDIX.

No. I.—TABLES OF CORRESPONDENCE OF THE DIFFERENT THERMOMETRICAL SCALES.

(From Dr. Murray's *System of Chemistry*).

TABLE FOR THE CENTIGRADE THERMOMETER.

Centigrade.	Reaumur's.	Fahrenheit's.	Centigrade.	Reaumur's.	Fahrenheit's.	Centigrade.	Reaumur's.	Fahrenheit's.
100	80.	212.	53	42.4	127.4	6	4.8	42.8
99	79.2	210.2	52	41.6	125.6	5	4.	41.
98	78.4	208.4	51	40.8	123.8	4	3.2	39.2
97	77.6	206.6	50	40.	122.	3	2.4	37.4
96	76.8	204.8	49	39.2	120.2	2	1.6	35.6
95	76.	203.	48	38.4	118.4	1	0.8	33.8
94	75.2	201.2	47	37.6	116.6	0	0.	32.
93	74.4	199.4	46	36.8	114.8	−1	−0.8	30.2
92	73.6	197.6	45	36.	113.	−2	−1.6	28.4
91	72.8	195.8	44	35.2	111.2	−3	−2.4	26.6
90	72.	194.	43	34.4	109.4	−4	−3.2	24.8
89	71.2	192.2	42	33.6	107.6	−5	−4.	23.
88	70.4	190.4	41	32.8	105.8	−6	−4.8	21.2
87	69.6	188.6	40	32.	104.	−7	−5.6	19.4
86	68.8	186.8	39	31.2	102.2	−8	−6.4	17.6
85	68.	185.	38	30.4	100.4	−9	−7.2	15.8
84	67.2	183.2	37	29.6	98.6	−10	−8.	14.
83	66.4	181.4	36	28.8	96.8	−11	−8.8	12.2
82	65.6	179.6	35	28.	95.	−12	9.6	10.4
81	64.8	177.8	34	27.2	93.2	−13	−10.4	8.6
80	64.	176.	33	26.4	91.4	−14	−11.2	6.8
79	63.2	174.2	32	25.6	89.6	−15	−12.	5.
78	62.4	172.4	31	24.8	87.8	−16	−12.8	3.2
77	61.6	170.6	30	24.	86.	−17	−13.6	1.4
76	60.8	168.8	29	23.2	84.2	−18	−14.4	−0.4
75	60.	167.	28	22.4	82.4	−19	−15.2	−2.2
74	59.2	165.2	27	21.6	80.6	−20	−16.	−4.
73	58.4	163.4	26	20.8	78.8	−21	−16.8	−5.8
72	57.6	161.6	25	20.	77.	−22	−17.6	−7.6
71	56.8	159.8	24	19.2	75.2	−23	−18.4	−9.4
70	56.	158.	23	18.4	73.4	−24	−19.2	−11.2
69	55.2	156.2	22	17.6	71.6	−25	−20.	−13.
68	54.4	154.4	21	16.8	69.8	−26	−20.8	−14.8
67	53.6	152.6	20	16.	68.	−27	−21.6	−16.6
66	52.8	150.8	19	15.2	66.2	−28	−22.4	−18.4
65	52.	149.	18	14.4	64.4	−29	−23.2	−20.2
64	51.2	147.2	17	13.6	62.6	−30	−24.	−22.
63	50.4	145.4	16	12.8	60.8	−31	−24.8	−23.8
62	49.6	143.6	15	12.	59.	−32	−25.6	−25.6
61	48.8	141.8	14	11.2	57.2	−33	−26.4	−27.4
60	48.	140.	13	10.4	55.4	−34	−27.2	−29.2
59	47.2	138.2	12	9.6	53.6	−35	−28.	−31.
58	46.4	136.4	11	8.8	51.8	−36	−28.8	−32.8
57	45.6	134.6	10	8.	50.	−37	−29.6	−34.6
56	44.8	132.8	9	7.2	48.2	−38	−30.4	−36.4
55	44.	131.	8	6.4	46.4	−39	−31.2	−38.2
54	43.2	129.2	7	5.6	44.6	−40	−32.	−40.

TABLE FOR REAUMUR'S THERMOMETER.

Reaumur's	Centigrade.	Fahrenheit's.	Reaumur's	Centigrade.	Fahrenheit's.	Reaumur's.	Centigrade.	Fahrenheit's.
80	100.	212.	42	52.5	126.5	4	5.	41.
79	98.75	209.75	41	51.25	124.25	3	3.75	38.75
78	97.5	207.5	40	50.	122.	2	2.5	36.5
77	96.25	205.25	39	48.75	119.75	1	1.25	34.25
76	95.	203.	38	47.5	117.5	–0	0	32.
75	93.75	200.75	37	46.25	115.25	–1	–1.25	29.75
74	92.5	198.5	36	45.	113.	–2	–2.5	27.5
73	91.25	196.25	35	43.75	110.75	–3	–3.75	25.25
72	90.	194.	34	42.5	108.5	–4	–5.	23.
71	88.75	191.75	33	41.25	106.25	–5	–6.25	20.75
70	87.5	189.5	32	40.	104.	–6	–7.5	18.5
69	86.25	187.25	31	38.75	101.75	–7	–8.75	16.25
68	85.	185.	30	37.5	99.5	–8	–10.	14.
67	83.75	182.75	29	36.25	97.25	–9	–11.25	11.75
66	82.5	180.5	28	35.	95.	–10	–12.5	9.5
65	81.25	178.25	27	33.75	92.75	–11	–13.75	7.25
64	80.	176.	26	32.5	90.5	–12	–15.	5.
63	78.75	173.75	25	31.25	88.25	–13	–16.25	2.75
62	77.5	171.5	24	30.	86.	–14	–17.5	0.5
61	76.25	169.25	23	28.75	83.75	–15	–18.75	–1.75
60	75.	167.	22	27.5	81.5	–16	–20.	–4.
59	73.75	164.75	21	26.25	79.25	–17	–21.25	–6.25
58	72.5	162.5	20	25.	77.	–18	–22.5	–8.5
57	71.25	160.25	19	23.75	74.75	–19	–23.75	–10.75
56	70.	158.	18	22.5	72.5	–20	–25.	–13.
55	68.75	155.75	17	21.25	70.25	–21	–26.25	–15.25
54	67.5	153.5	16	20.	68.	–22	–27.5	–17.5
53	66.25	151.25	15	18.75	65.75	–23	–28.75	–19.75
52	65.	149.	14	17.5	63.5	–24	–30.	–22.
51	63.75	146.75	13	16.25	61.25	–25	–31.25	–24.25
50	62.5	144.5	12	15.	59.	–26	–32.5	–26.5
49	61.25	142.25	11	13.75	56.75	–27	–33.75	–28.75
48	60.	140.	10	12.5	54.5	–28	–35.	–31.
47	58.75	137.75	9	11.25	52.25	–29	–36.25	–33.25
46	57.5	135.5	8	10.	50.	–30	–37.5	–35.5
45	56.25	133.25	7	8.75	47.75	–31	–38.75	–37.75
44	55.	131.	6	7.5	45.5	–32	–40.	–40.
43	53.75	128.75	5	6.25	43.25	–33	–41.25	–42.25

TABLE FOR FAHRENHEIT'S THERMOMETER.*

Fahrenheit's.	Reaumur's.	Centigrade.	Fahrenheit's.	Reaumur's.	Centigrade.	Fahrenheit's.	Reaumur's.	Centigrade.
212	80.00	100.00	170	61.33	76.66	128	42.66	53.33
211	79.55	99.44	169	60.88	76.11	127	42.22	52.77
210	79.11	98.88	168	60.44	75.55	126	41.77	52.22
209	78.66	98.33	167	60.00	75.00	125	41.33	51.66
208	78.22	97.77	166	59.55	74.44	124	40.88	51.11
207	77.77	97.22	165	59.11	73.88	123	40.44	50.55
206	77.33	96.66	164	58.66	73.33	122	40.00	50.00
205	76.88	96.11	163	58.22	72.22	121	39.55	49.44
204	76.44	95.55	162	57.77	72.77	120	39.11	48.88
203	76.00	95.00	161	57.33	71.66	119	38.66	48.33
202	75.55	94.44	160	56.88	71.11	118	38.22	47.77
201	75.11	93.88	159	56.44	70.55	117	37.77	47.22
200	74.66	93.33	158	56.00	70.00	116	37.33	46.66
199	74.22	92.77	157	55.55	69.44	115	36.88	46.11
198	73.77	92.22	156	55.11	68.88	114	36.44	45.55
197	73.33	91.66	155	54.66	68.33	113	36.00	45.00
196	72.88	91.11	154	54.22	67.77	112	35.55	44.44
195	72.44	90.55	153	53.77	67.22	111	35.11	43.88
194	72.00	90.00	152	53.33	66.66	110	34.66	43.33
193	71.55	89.44	151	52.88	66.11	109	34.22	42.77
192	71.11	88.88	150	52.44	65.55	108	33.77	42.22
191	70.66	88.33	149	52.00	65.00	107	33.33	41.66
190	70.22	87.77	148	51.55	64.44	106	32.88	41.11
189	69.77	87.22	147	51.11	63.88	105	32.44	40.55
188	69.33	86.66	146	50.66	63.33	104	32.00	40.00
187	68.88	86.11	145	50.22	62.77	103	31.55	39.44
186	68.44	85.55	144	49.77	62.22	102	31.11	38.88
185	68.00	85.00	143	49.33	61.66	101	30.66	38.33
184	67.55	84.44	142	48.88	61.11	100	30.22	37.77
183	67.11	83.88	141	48.44	60.55	99	29.77	37.22
182	66.66	83.33	140	48.00	60.00	98	29.33	36.66
181	66.22	82.77	139	47.55	59.44	97	28.88	36.11
180	65.77	82.22	138	47.11	58.88	96	28.44	35.55
179	65.33	81.66	137	46.66	58.33	95	28.00	35.00
178	64.88	81.11	136	46.22	57.77	94	27.55	34.44
177	64.44	80.55	135	45.77	57.22	93	27.11	33.88
176	64.00	80.00	134	45.33	56.66	92	26.66	33.33
175	63.55	79.44	133	44.44	56.11	91	26.22	32.77
174	62.11	78.88	132	44.55	55.55	90	25.77	32.22
173	62.66	78.33	131	44.00	55.00	89	25.33	31.66
172	62.22	77.77	130	43.55	54.44	88	24.88	31.11
171	61.77	77.22	129	43.11	53.88	87	24.44	30.55

* All the decimals in this Table are circulating decimals.

TABLE FOR FAHRENHEIT'S THERMOMETER CONTINUED.

Fahrenheit's.	Reaumur's.	Centigrade.	Fahrenheit's	Reaumur's.	Centigrade.	Fahrenheit's.	Reaumur's.	Centigrade.
86	24.00	30.00	43	4.88	6.11	0	−14.22	−17.77
85	23.55	29.44	42	4.44	5.55	−1	−14.66	−18.33
84	23.11	28.88	41	4.00	5.00	−2	−15.11	−18.88
83	22.66	28.33	40	3.55	4.44	−3	−15.55	−19.44
82	22.22	27.77	39	3.11	3.88	−4	−16.00	−20.00
81	21.77	27.22	38	2.66	3.33	−5	−16.44	−20.55
80	21.33	26.66	37	2.22	2.77	−6	−16.88	−21.11
79	20.88	26.11	36	1.77	2.22	−7	−17.33	−21.66
78	20.44	25.55	35	1.33	1.66	−8	−17.77	−22.22
77	20.00	25.00	34	0.88	1.11	−9	−18.22	−22.77
76	19.55	24.44	33	0.44	0.55	−10	−18.66	−23.33
75	19.11	23.88	32	0.	0.	−11	−19.11	−23.88
74	18.66	23.33	31	−0.44	−0.55	−12	−19.55	−24.44
73	18.22	22.77	30	−0.88	−1.11	−13	−20.00	−25.00
72	17.77	22.22	29	−1.33	−1.66	−14	−20.44	−25.55
71	17.33	21.66	28	−1.77	−2.22	−15	−20.88	−26.11
70	16.88	21.11	27	−2.22	−2.77	−16	−21.33	−26.66
69	16.44	20.55	26	−2.66	−3.33	−17	−21.77	−27.22
68	16.00	20.00	25	−3.11	−3.88	−18	−22.22	−27.77
67	15.55	19.44	24	−3.55	−4.44	−19	−22.66	−28.33
66	15.11	18.88	23	−4.00	−5.00	−20	−23.11	−28.88
65	14.66	18.33	22	−4.44	−5.55	−21	−23.55	−29.44
64	14.22	17.77	21	−4.88	−6.11	−22	−24.00	−30.00
63	13.77	17.22	20	−5.33	−6.66	−23	−24.44	30.55
62	13.33	16.66	19	−5.77	−7.22	−24	−24.88	−31.11
61	12.88	16.11	18	−6.22	−7.77	−25	−25.33	−31.66
60	12.44	15.55	17	−6.66	−8.33	−26	−25.77	−32.22
59	12.00	15.00	16	−7.11	−8.88	−27	−26.22	32.77
58	11.55	14.44	15	−7.55	−9.44	−28	−26.66	33.33
57	11.11	13.88	14	−8.00	−10.00	−29	−27.11	−33.88
56	10.66	13.33	13	−8.44	−10.55	−30	−27.55	−34.44
55	10.22	12.77	12	−8.88	−11.11	−31	−28.00	−35.00
54	9.77	12.22	11	−9.33	−11.66	−32	−28.44	−35.55
53	9.33	11.66	10	−9.77	−12.22	−33	−28.88	−36.11
52	8.88	11.11	9	−10.22	−12.77	−34	−29.33	−36.66
51	8.44	10.55	8	−10.66	−13.33	−35	−29.77	−37.22
50	8.00	10.00	7	−11.11	−13.88	−36	−30.22	−37.77
49	7.55	9.44	6	−11.55	−14.44	−37	−30.66	−38.33
48	7.11	8.88	5	−12.00	−15.00	−38	−31.11	−38.88
47	6.66	8.33	4	−12.44	−15.55	−39	−31.55	39.44
46	6.22	7.77	3	−12.88	−16.11	−40	−32.00	−40.00
45	5.77	7.22	2	−13.33	−16.66			
44	5.33	6.66	1	−13.77	−17.22			

No. II.—TABLES OF EXPANSIONS OF BODIES BY HEAT.

I. TABLE OF EXPANSIONS ACCORDING TO SMEATON.

SUBSTANCES.	DILATATION FOR A LENGTH EQUAL TO UNITY.	
	In decimal fractions.	In vulgar fractions.
Blistered steel	0.00115000	$\frac{1}{870}$
Tempered steel	0.00122500	$\frac{1}{816}$
Bismuth	0.00139167	$\frac{1}{719}$
Copper hammered	0.00170000	$\frac{1}{588}$
Copper 8 parts with 1 of tin	0.00181667	$\frac{1}{550}$
Cast brass	0.00187500	$\frac{1}{533}$
Brass, 16 parts with 1 of tin	0.00190833	$\frac{1}{524}$
Fine pewter	0.00228333	$\frac{1}{438}$
Grain tin	0.00248333	$\frac{1}{403}$
Iron	0.00125833	$\frac{1}{795}$
Brass wire	0.00193333	$\frac{1}{517}$
Speculum metal	0.00193333	$\frac{1}{517}$
Lead	0.00286667	$\frac{1}{349}$
Antimony	0.00108333	$\frac{1}{923}$
Lead 2 parts with 1 of tin	0.00250533	$\frac{1}{390}$
Copper 2 parts with 1 of zinc	0.00205833	$\frac{1}{486}$
White glass (barometer tube,)	0.00083333	$\frac{1}{1175}$
Zinc	0.00294167	$\frac{1}{340}$
Zinc hammered	0.00310833	$\frac{1}{322}$
Zinc 8 parts with 1 of tin	0.00269167	$\frac{1}{372}$

II. TABLE OF EXPANSIONS ACCORDING TO ROY.

SUBSTANCES.	FOR A LENGTH EQUAL TO UNITY.	
	In decimal fractions.	In vulgar fractions.
Steel rod	0.00114450	$\frac{1}{874}$
Brass scale, Hamburgh	0.00185550	$\frac{1}{539}$
Brass plate rod, English	0.00189296	$\frac{1}{528}$
Brass plate trough, English	0.00189450	$\frac{1}{528}$
Cast Iron prism	0.00111000	$\frac{1}{901}$
Glass tube	0.00077550	$\frac{1}{1289}$
Glass rod	0.00080833	$\frac{1}{1237}$

III. TABLE OF EXPANSIONS ACCORDING TO TROUGHTON.

SUBSTANCES.	LINEAR DILATATIONS FROM THE TEMPERATURE OF FREEZING TO BOILING WATER.	
	In decimal fractions.	In vulgar fractions.
Steel	0.0011899	$\frac{1}{840}$
Silver	0.0020826	$\frac{1}{480}$
Copper	0.0019188	$\frac{1}{521}$
Iron Wire	0.0014401	$\frac{1}{694}$
Platina	0.00099218	$\frac{1}{1008}$
Palladium (according to Wollaston)	0.0010000	$\frac{1}{1000}$

IV. TABLE OF THE LINEAR DILATATION OF DIFFERENT SUBSTANCES FROM THE TEMPERATURE OF FREEZING TO THAT OF BOILING WATER, ACCORDING TO THE EXPERIMENTS OF LAVOISIER AND LAPLACE.

SUBSTANCES.	DILATATION FOR A LENGTH EQUAL TO UNITY.	
	In decimal fractions.	In vulgar fractions.
	At 212°	
Glass of St. Gobain	0.00089089	$\frac{1}{1122}$
Glass tube without lead	0.00087572	$\frac{1}{1142}$
Ditto	0.00089760	$\frac{1}{1114}$
Ditto	0.00091751	$\frac{1}{1090}$
English Flint Glass	0.00081166	$\frac{1}{1248}$
French glass with lead	0.00087199	$\frac{1}{1147}$
Copper	0.00172244	$\frac{1}{581}$
Ditto	0.00171222	$\frac{1}{584}$
Brass	0.00186671	$\frac{1}{535}$
Ditto	0.00188971	$\frac{1}{529}$
Hammered Iron	0.00122045	$\frac{1}{819}$
Iron Wire	0.00123504	$\frac{1}{812}$
Hard Steel	0.00107875	$\frac{1}{927}$
Soft Steel	0.00107956	$\frac{1}{926}$
Tempered Steel	0.00123956	$\frac{1}{807}$
Lead	0.00284836	$\frac{1}{351}$
Malacca Tin	0.00193765	$\frac{1}{516}$
Cornish Tin	0.00217298	$\frac{1}{462}$
Cupelled Silver	0.00192974	$\frac{1}{518}$
Parisian Standard Silver	0.00190868	$\frac{1}{524}$
Pure Gold	0.00146606	$\frac{1}{682}$
Parisian Standard Ditto not softened	0.00155155	$\frac{1}{645}$
Ditto, softened	0.00151361	$\frac{1}{611}$

V. TABLE OF THE EXPANSIONS OF LIQUIDS.

The expansions in this table were determined by Mr. Dalton. They are equal to what would be produced by an elevation of temperature from the freezing to the boiling point of water; the volume at the former being 1.

Mercury	.0200 = $\frac{1}{50}$
Water	.0466 = $\frac{1}{21.5}$
Water saturated with salt	.0500 = $\frac{1}{20}$
Sulphuric acid	.0600 = $\frac{1}{17}$
Muriatic acid	.0600 = $\frac{1}{17}$
Oil of turpentine	.0700 = $\frac{1}{14}$
Æther	.0700 = $\frac{1}{14}$
Fixed oils	.0800 = $\frac{1}{12.5}$
Alcohol	.0110 = $\frac{1}{9}$
Nitric acid	.0110 = $\frac{1}{9}$

No. III.

TABLE OF REMARKABLE TEMPERATURES ACCORDING TO FAHRENHEIT'S SCALE.

Iron red hot in the twilight	° 884
Heat of a common fire (Irvine)	790
Iron bright red in the dark	752
Zinc melts	700
Quicksilver boils (Irvine)	672
———— (Dalton)	660
———— (Crichton)	655
Linseed oil boils	600
Lead melts (Guyton, Irvine)	594
Sulphuric Acid boils (Dalton)	590
The surface of polished Steel acquires a deep blue colour	580
Oil of Turpentine boils	560
Phosphorus boils	554
Bismuth melts (Irvine)	476
The surface of polished steel acquires a pale straw colour	460
Tin melts (Crichton, Irvine)	442
A Compound of equal parts of Tin and Bismuth melts	283
Nitric Acid boils	242
Sulphur melts	226
A saturated Solution of Salt boils	218
Water boils, (the barometer being at 30 inches); also a Compound of 5 of Bismuth, 3 of Tin, and 2 of Lead, melts	212
A Compound of 3 of Tin, 5 of Lead, and 8 of Bismuth, melts	210
Alcohol boils	174
Bees' Wax melts	142
Spermaceti melts	133
Phosphorus melts	100
Æther boils	98
Medium Temperature of the Globe	50
Ice melts	32
Milk freezes	30
Vinegar freezes at about	28
Strong Wine freezes at about	20
A Mixture of 1 part of Alcohol, and 3 parts of Water, freezes	7
A Mixture of Alcohol and Water in equal parts, freezes	7
A Mixture of 2 parts of Alcohol and 1 of Water, freezes	11
Melting point of Quicksilver (Cavendish)	39
Liquid Ammonia crystallizes (Vauquelin)	42
Nitric Acid, spec. gr. about 1.42, freezes (Cavendish)	45
Sulphuric Æther congeals (Vauquelin)	47
Natural Temperature observed at Hudson's Bay	50
Ammoniacal Gas condenses into a liquid (Guyton)	54
Nitrous Acid freezes (Vauquelin)	56
Cold produced from diluted Sulphuric Acid and Snow, the materials being at the temperature of 57	78½
Greatest Artificial Cold yet measured (Walker)	91

ADDENDA ET CORRIGENDA.

Page 6. The description of the *fig.* 7, in the text, is taken from the Memoirs of the Academy of Sciences. It is probable that in the construction of the instrument, Amontons employed a tube of narrow calibre, to enable the included air to support the mercurial column. The proportion between the tube and ball may be inferred from what is stated of the expansion of the whole, by the heat of boiling water.

P. 10. In the beginning of the paragraph, just after the first set of formulæ, there is an error which requires correction. Instead of *these formulæ applying to all degrees above the freezing point,* read, "these formulæ apply to all degrees above the zero of each scale;"

P. 14. The notation employed by De Luc requires some explanation. y denotes the height of the barometer *in sixteenths of a Parisian line;* T the height of a thermometer, plunged in boiling water, above the melting point of ice, in hundredths of a degree of De Luc's scale; and a the constant quantity 10387, which Horsley thinks, from some of De Luc's experiments, should have been 10369; but in his investigations he retains the first number, as probably adopted on good grounds.

The logarithms used by De Luc are the tables of Briggs, in which the seven figures of the tables, as well as the indices, are reckoned integers; or he considers the *eighth* figure in the place of units: but it is most convenient to reckon all the figures after the index as decimals, and the formulæ will be $\frac{99\times 100}{2} Log.\ y-a=T$; or $\frac{\quad}{99\times 50}\ Log.\ y-a=T$.

P. 15. In the second column of the table, 29. should be opposite to .95, *instead of* .39.

The terms *lower* and *higher*, in the third column of the same table, are so in the original paper; but the directions will be more plain, if the reader will recollect, that where *lower* is indicated, the correction is "to be subtracted;" and when *higher* is used, the correction is "to be added."

P. 23, *Col.* 1. The action of the pinions in Ferguson's Pyrometer is ill expressed in the text; and the reader is requested to substitute for the member of the sentence commencing with "*and the bar, &c.*" in the 14th line, the following—"and as the bar k has fifteen teeth to one inch, it is obvious that when k moves one inch, the pinion l will have made one revolution and a quarter, and the pinion p will have moved $100\times 1\frac{1}{4}$, or 125 times round."

P. 29. In Wedgwood's table, *Col.* 1, line 27, for *deduct*, read, "did not."

In the same page, *Col.* 2, the radius of Regnier's instrument should have been 649 millimètres, its diameter 1.298 mètres, and its circumference 4.079 mètres.