which occupies a portion of the tube shaped like the letter U, one extremity of the mercurial column being in contact with the alcohol already mentioned, while the other extremity is in contact with a second column of alcohol; and beyond this there is a small space occupied only with air, so as to leave room for the expansion of the liquids. When the alcohol in the bulb expands, it pushes the mercurial column before it, and when it contracts the mercurial column follows it. The extreme points reached by the two ends of the mercurial column are registered by a pair of light steel indices *c*, *d* (shown on an enlarged scale at K), which are pushed before the ends of the column, and then are held in their places by springs, which are just strong enough to prevent slipping, so that the indices do not follow the mercury in its retreat. One of the indices *d* registers the maximum and the other *c* the minimum temperature which has occurred since the instrument was last set. The setting consists in bringing the indices into contact with the ends of the mercurial column, and is usually effected by means of a magnet. This instrument is now, on account of its complexity, little used. It possesses, however, the advantages of being equally quick (or slow) in its action for maximum and minimum temperatures, which is an important property when these temperatures are made the foundation for the computation of the mean temperature of the interval, and of being better able than most of the self-registering thermometers to bear slight jolts without disturbance of the indices.

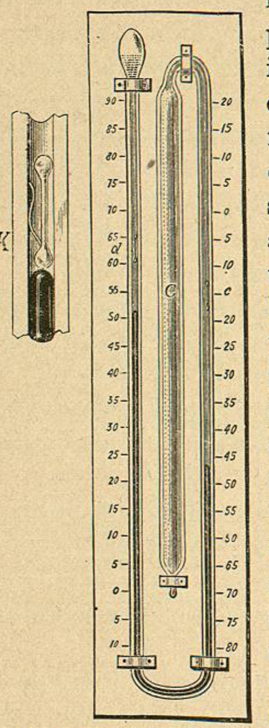

Fig. 11.—Six's Self-registering Thermometer.

Rutherford's self-registering thermometers are frequently mounted together on one frame, as in Fig. 12, but are nevertheless distinct instruments. His *minimum* thermometer, which is the only minimum thermometer in general use, has alcohol for its fluid, and is always placed with its tube horizontal, or nearly so. In the fluid column there is a small index *n* of glass or enamel, shaped like a dumb-bell.

When contraction occurs, the index, being wetted by the liquid, is drawn backwards by the contractile force of the liquid surface (see *Capillarity* in Part I.); but when expansion takes place the index remains stationary in the interior of the liquid. Hence the minimum temperature is indicated by the position of the

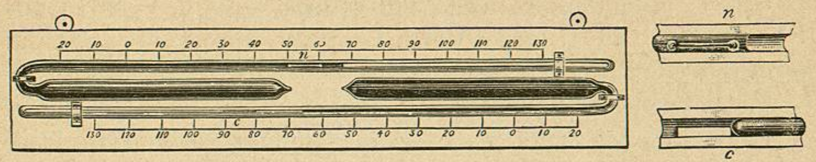

Fig. 12.—Rutherford's Maximum and Minimum Thermometers.

forward end of the index. The instrument is set by inclining it so as to let the index slide down to the end of the liquid column.

The only way in which this instrument is liable to derangement is by a portion of the spirit evaporating from the column and becoming condensed in the end of the tube, which usually terminates in a small bulb. When the portion thus detached is large, or when the column of spirit becomes broken into detached portions by rough usage in travelling, "let the thermometer be taken in the hand by the end farthest from the bulb, raised above the head, and then forcibly swung down towards the feet; the object being, on the principle of centrifugal force, to send down the detached portion of spirit till it unites with the column. A few throws or swinging strokes will generally be sufficient; after which the thermometer should be placed in a slanting position, to allow the rest of the spirit still adhering to the sides of the tube to drain down to the column. But another method must be adopted if the portion of spirit in the top of the tube be small. Heat should then be applied slowly and cautiously to the end of the tube where the detached portion of spirit is lodged; this being turned into vapour by the heat will condense on the surface of the unbroken column of spirit. Care should be taken that the heat is not too quickly applied. . . . The best and safest way to apply the requisite amount of heat, is to bring the end of the tube slowly down towards a minute flame from a gas-burner; or if gas is not to be had, a piece of heated metal will serve instead."[1]

Rutherford's *maximum* thermometer is a mercurial thermometer, with the stem placed horizontally, and with a steel index *c* in the tube, outside the mercurial column. When expansion occurs, the

[1] Buchan's *Handy Book of Meteorology*, p. 62.

index, not being wetted by the liquid, is forced forwards by the contractile force of the liquid surface (see *Capillarity* in Part I.); but when contraction takes place, the index remains stationary outside the liquid. Hence the maximum temperature is indicated by the position of the backward end of the index. The instrument is set by bringing the index into contact with the end of the liquid column, an operation which is usually effected by means of a magnet.

This thermometer is liable to get out of order after a few years' use, by chemical action upon the surface of the index, which causes it to become wetted by the mercury, and thus renders the instrument useless.

Phillips' maximum thermometer (invented by Professor Phillips, the eminent geologist, and made by Casella) is recommended for use in the official *Instructions for Taking Meteorological Observations*, drawn up by Sir Henry James for the use of the Royal Engineers. It is a mercurial thermometer not deprived of air. It has an exceed-

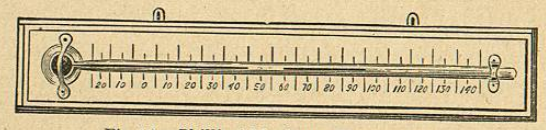

Fig. 13.—Phillips' Maximum Thermometer.

ingly fine bore, and the mercurial column is broken by the insertion of a small portion of air. The instrument is set by reducing this portion of air to the smallest dimensions which it can be made to assume, and is placed in a horizontal position. When the mercury expands, it pushes forwards this intervening air and the detached column of mercury beyond it; but when contraction takes place the intervening air expands, and the detached column remains unmoved.

The detached column is not easily shaken out of its place, and when the bore of the tube is made sufficiently narrow the instrument may even be used in a vertical position, a property which is often of great service.

In Negretti and Zambra's maximum thermometer (Fig. 14), which is employed at the Royal Observatory, Greenwich, there is an obstruction in the bent part of the tube, near the bulb, which barely leaves room for the mercury to pass when forced up by expansion, and is sufficient to prevent it from returning when the bulb cools.

The objection chiefly urged against this thermometer is the extreme mobility of the detached column, which renders it very liable to

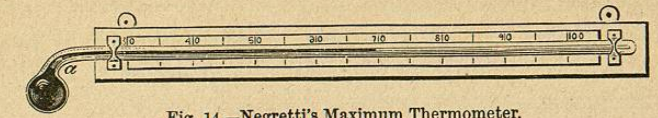

Fig. 14.—Negretti's Maximum Thermometer.

accidental displacement; but in the hands of a skilful observer this is of no moment. Dr. Balfour Stewart (*Elementary Treatise on Heat*, p. 20, 21), says:—"When used, the stem of this instrument ought to be inclined downwards. . . . It does not matter if the column past the obstruction go down to the bottom of the tube; for when the instrument is read, it is gently tilted up until this detached column flows back to the obstruction, where it is arrested, and the end of the column will then denote the maximum temperature. In resetting the instrument, it is necessary to shake the detached column past the obstruction in order to fill up the vacancy left by the contraction of the fluid after the maximum had been reached."

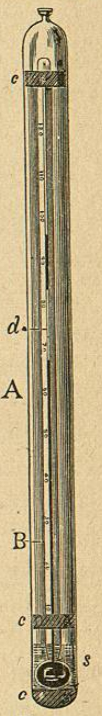

Fig. 15. Thomson's Protected Thermometer.

Deep-sea and Well Thermometers.—Self-registering thermometers intended for observing at great depths in water should be inclosed in an outer case of glass hermetically sealed, the intervening space being occupied wholly or partly by air, so that the pressure outside may not be transmitted to the thermometer. A thermometer not thus protected gives too high a reading, because the compression of the bulb forces the liquid up the tube. The instrument represented in Fig. 15 was designed by Lord Kelvin for the Committee on Underground Temperature appointed by the British Association. A is the protecting case, B the Phillips' thermometer inclosed in it, and supported by three pieces of cork *ccc*. A small quantity of spirit *s* occupies the lower part of the case; *d* is the air-bubble characteristic of Phillips' thermometer, and serving to separate one portion of the mercurial column from the rest. In the figure this air-bubble is represented as expanded by the descent of the lower portion of mercury, while the upper portion remains suspended by adhesion. This instrument has been found to register correctly even under a pressure of 2½ tons to the square inch.

The use of the spirit *s* is to bring the bulb more quickly to the temperature of the surrounding medium.

Another instrument, designed, like the foregoing, for observations in wells and borings, is *Walferdin's maximum thermometer* (Fig. 16). Its tube terminates above in a fine point opening into a cavity of considerable size, which contains a sufficient quantity of mercury to cover the point when the instrument is inverted. The instrument is set by placing it in this inverted position and warming the bulb until the mercury in the stem reaches the point and becomes connected with the mercury in the cavity. The bulb is then cooled to a temperature lower than that which is to be observed; and during the operation of cooling, mercury enters the tube so as always to keep it full. The instrument is then lowered in the erect position into the bore where observations are to be made, and when the temperature of the mercury rises a portion of it overflows from the tube. To ascertain the maximum temperature which has been experienced, the instrument may be immersed in a bath of known temperature, less than that of the boring, and the amount of void space in the upper part of the tube will indicate the excess of the maximum temperature experienced above that of the bath.

Fig. 16.

If the tube is not graduated, the maximum temperature can be ascertained by gradually raising the temperature of the bath till the tube is just full.

If the tube is graduated, the graduations can in strictness only indicate true degrees for some one standard temperature of setting, since the length of a true degree is proportional to the quantity of mercury in the bulb and tube; but a difference of a few degrees in the temperature of setting is immaterial, since 10° Cent. would only alter the length of a degree by about one six-hundredth part.

13. **Thermograph.**—A continuous automatic record of the indications of a thermometer can be obtained by means of photography, and this plan is now adopted at numerous observatories. The following description relates to the Royal Observatory, Greenwich. A sheet of sensitized paper is mounted on a vertical cylinder just behind the mercurial column, which is also vertical, and is protected from the action of light by a cover of blackened zinc, with the exception of a narrow vertical strip just behind the mercurial column. A strong beam of light from a lamp or gas flame is concentrated by a cylindric

lens, so that if the thermometer were empty of mercury a bright vertical line of light would be thrown on the paper. As this beam of light is intercepted by the mercury in the tube, which for this purpose is made broad and flat, only the portion of the paper above the top of the mercurial column receives the light, and is photographically affected. The cylinder is made to revolve slowly by clock-work, and if the mercury stood always at the same height, the boundary between the discoloured and the unaffected parts of the paper would be straight and horizontal, in consequence of the horizontal motion of the paper itself. In reality, the rising and falling of the mercury, combined with the horizontal motion of the paper, causes the line of separation to be curved or wavy, and the height of the curve above a certain datum-line is a measure of the temperature at each instant of the day.[1] The whole apparatus is called a *thermograph*, and apparatus of a similar character is employed for obtaining a continuous photographic record of the indications of the barometer[2] and magnetic instruments.

14. **Metallic Thermometers.**—Thermometers have sometimes been constructed of solid metals. Breguet's thermometer, for example (Fig. 17), consists of a helix carrying at its lower end a horizontal needle which traverses a dial. The helix is composed of three metallic strips, of silver, gold, and platinum, soldered together so as to form a single ribbon. The silver, which is the most expansible, is placed in the interior of the helix; the platinum, which is the least expansible, on the exterior; and the gold serves to connect them. When the temperature rises, the helix unwinds and produces a deflection of the needle; when the temperature falls, the helix winds up and deflects the needle in the opposite direction.

Fig. 18 represents another dial-thermometer, in which the thermometric portion is a double strip composed of steel and brass, bent into the form of a nearly complete circle, as shown by the dotted lines in the figure. One extremity is fixed, the other is jointed to the

[1] Strictly speaking, the temperatures corresponding to the various points of the curve are not read off by reference to a single datum-line, but to a number of datum-lines which represent the shadows of a set of horizontal wires stretched across the tube of the thermometer at each degree, a broader wire being placed at the decades, and also at 32°, 52°, and 72°.

In order to give long degrees, the bulb of the thermometer is made very large—eight inches long, and ·4 of an inch in internal diameter.—(*Greenwich Observations*, 1847.)

[2] See *Photographic Registration* in Part I.

shorter arm of a lever, whose longer arm carries a toothed sector. This latter works into a pinion, to which the needle is attached.

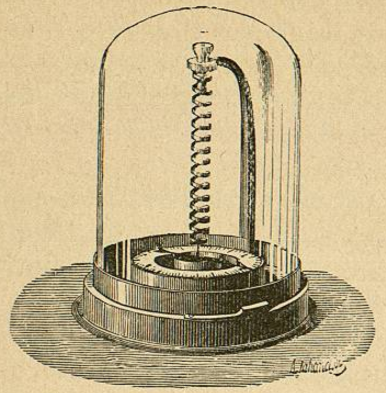

Fig. 17.—Breguet's Thermometer.

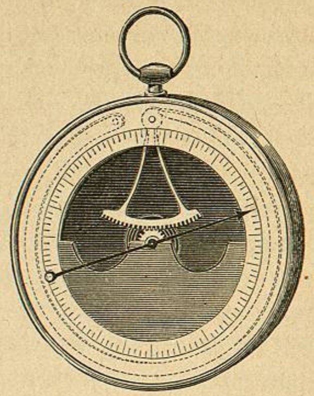

Fig. 18.—Metallic Thermometer.

Immisch's thermometer, which is extremely portable and convenient, contains a crescent-shaped thin metallic vessel (Fig. 19) filled with a highly expansible liquid. With rise of temperature, the horns A B of the crescent are further separated by the expansive force of the liquid, and the movement is transmitted to a hand which travels round a dial.

It may be remarked that dial-thermometers are very well adapted for indicating maximum and minimum temperatures, it being only necessary to place on opposite sides of the needle a pair of movable indices, which could be pushed in either direction according to the variations of temperature.

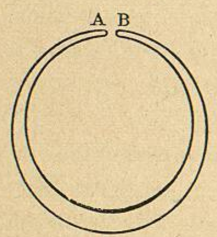

Fig. 19.

Generally speaking, metallic thermometers offer great facilities for automatic registration.

In Secchi's meteorograph, for example, the temperature is indicated and registered by the expansion of a long strip of brass (about 17 metres long) kept constantly stretched by a suitable weight; this expansion is rendered sensible by a system of levers connected with the tracing point. The thermograph of Hasler and Escher consists of a steel and a brass band connected together and rolled into the form of a spiral. The movable extremity of the spiral, by acting upon a projecting arm, produces rotation of a steel axis which carries the tracer.

15. Pyrometers.—Metallic thermometers can generally be employed for measuring higher temperatures than a mercurial thermometer could bear; but there is great difficulty in constructing any instrument to measure temperatures as high as those of furnaces. Instruments intended for this purpose are called pyrometers.

Wedgwood, the famous potter, invented an apparatus of this kind, consisting of a gauge for measuring the contraction experienced by a piece of baked clay when placed in a furnace; and Brongniart introduced into the porcelain manufactory at Sèvres the instrument represented in Fig. 20, consisting of an iron bar lying in a groove in a porcelain slab, with one end abutting against the bottom of the groove, and the other projecting through the side of the furnace, where it gave motion to an indicator.

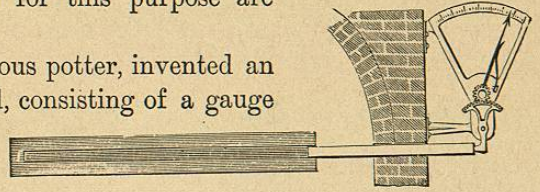

Fig. 20.—Brongniart's Pyrometer.

Neither of these instruments has, however, been found to furnish consistent indications, and the only instrument that is now relied on for the measurement of very high temperatures is the air-thermometer.

Of late years much attention has been given to the measurement of temperature by an electrical method depending on the fact that the resistance of a metal to the passage of a current of electricity increases with the temperature. Platinum is the metal usually selected for this purpose, and the instrument employed is called the *platinum pyrometer*, or the *electrical pyrometer*.

16. Differential Thermometer.—Leslie of Edinburgh invented, in the beginning of the present century, the instrument shown in Fig. 21, for detecting small differences of temperature. A column of sulphuric acid, coloured red, stands in the two branches of a bent tube, the extremities of which terminate in two equal bulbs containing air. When both globes are at the same temperature, whatever that temperature may be, the liquid, if the instrument is in order, stands at the same height in both branches. This height is marked zero on both scales. When there is a difference of temperature between them, the expansion of the air in the warmer bulb produces a depression of the liquid on that side and an equal elevation on the other side.

The differential thermometer is an instrument of great sensibility, and enabled Leslie to conduct some important investigations on the subject of the radiation of heat. It is now, however, superseded by the thermo-pile invented by Melloni. This latter instrument will be

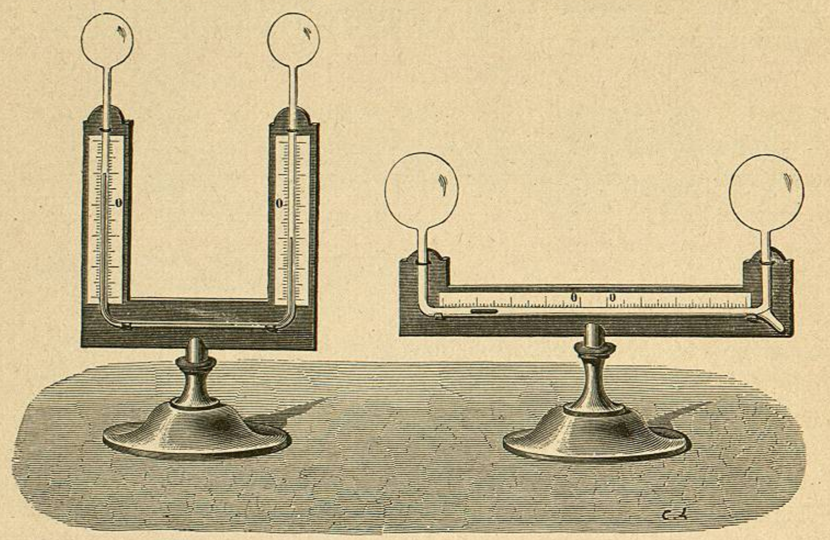

Fig. 21.—Leslie's Differential Thermometer. Fig. 22.—Rumford's Thermoscope.

described in another portion of this work. Rumford's thermoscope (Fig. 22) is analogous to Leslie's differential thermometer. It differs from it in having the horizontal part much longer, and the vertical branches shorter. In the horizontal tube is an alcohol index, which, when the two globes are at the same temperature, occupies exactly the middle.

CHAPTER II.

MATHEMATICS OF EXPANSION.

17. **Expansion. Factor of Expansion.**—When a body expands from volume V to volume $V+v$, the ratio $\frac{v}{V}$ is called the *expansion of volume* or the *cubical expansion* of the body.

In like manner if the length, breadth, or thickness of a body increases from L to $L+l$, the ratio $\frac{l}{L}$ is called the *linear expansion.*

The ratio $\frac{V+v}{V}$ will be called, in this treatise, the *factor of cubical expansion*, and the ratio $\frac{L+l}{L}$ the *factor of linear expansion.* In each case the factor of expansion is *unity plus the expansion.*

Similar definitions apply to expansion of area or superficial expansion; but it is seldom necessary to consider this element in thermal discussions.

18. **Relation between Linear and Cubical Expansion.**—If a cube, whose edge is the unit length, expands equally in all directions, the length of each edge will become $1+l$, where l is the linear expansion; and the volume of the cube will become $(1+l)^3$ or $1+3l+3l^2+l^3$.

In the case of the thermal expansion of solid bodies l is always very small, so that l^2 and l^3 can be neglected, and the expansion of volume is therefore $3l$; that is to say, the *cubical expansion is three times the linear expansion.* This is illustrated geometrically by Fig. 23, which represents a unit cube with a plate of thickness l and therefore of volume l applied to each of three faces; the total volume added being therefore $3l$.

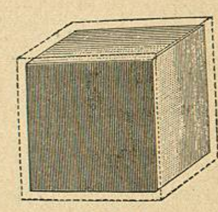

Fig. 23.

Similar reasoning shows that *the superficial expansion* is *double the linear expansion.*