general view is shown in fig. 71, and a diagrammatic view of the essential parts is shown in fig. 72.

The galvanometer boom A turning about the axis B (see fig. 72) is depressed every minute or half-minute as desired on to an inked thread G, which is forced against the paper, leaving a small ink mark behind on the paper C. The ink on the thread is renewed by means of a simple winding mechanism. This method of recording gives rectangular co-ordinates, and entirely prevents the blotting or smudging of the record. The instrument can be made extremely sensitive.

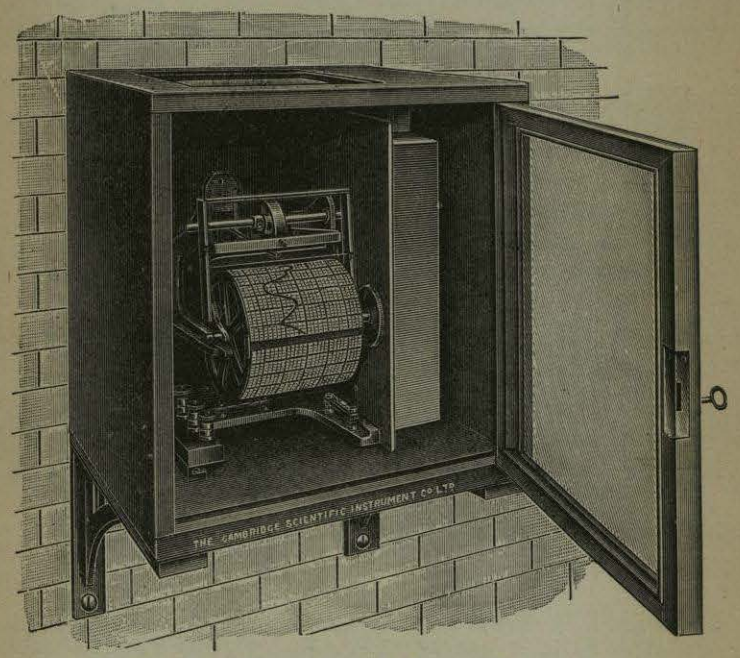

FIG. 71.—Patent Thread Recorder for recording temperatures.

The clockwork mechanism can be made to depress two or more galvanometer booms simultaneously, the various galvanometers being connected to different thermometers. The records obtained are entirely independent of each other, and the thermometers may be working over widely different ranges. If by any mishap one galvanometer or thermometer is damaged, the others are unaffected.

A scale for reading temperatures directly is fixed on the face of the chopper bar D, fig. 72.

The wires of the couple for furnace work are also threaded through double-drilled fire-clay tubes which serve to insulate them, and the whole is inserted in a covering sheath of gas or steam

barrel, the junction end of which is closed by a thin iron disc welded securely into the end. To the open end of the sheathing is fixed a head of cast metal, bored and tapped to fit the iron sheathing.

The cover of this head is made of ebonite, and carries the two terminals to which the wires of the couple are connected, and also the galvanometer leads.

3. For examining the thermal changes that take place during the cooling down of a piece of steel, which is a very important

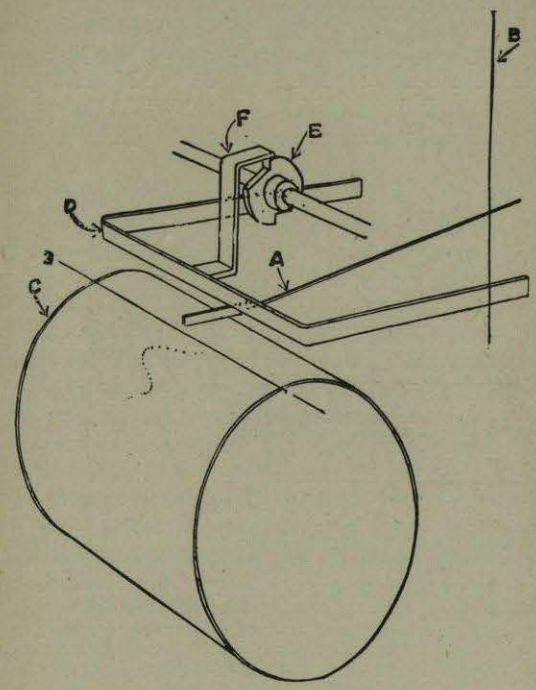

FIG. 72.—Essential parts of Thread Recorder.

matter, as by this means the correct temperature for subsequent thermal and mechanical treatment is ascertained, the differential method is used. This method was devised for use for the Alloys Research Committee[1] work, and has since proved of very great value in determining small thermal changes during the cooling down of metals and alloys.

The method consists essentially in eliminating the general cooling effect during the observation, and noting any differences in temperature of the metal under examination and another metal of similar thermal capacity, but having no critical changes in the

[1] Alloys Research Committee, *Inst. Mech. Eng.*, 5th Report.

range of temperature used during the experiment. For this second metal a piece of nickel steel or platinum is generally used. For these observations two galvanometers are required, one connected with a simple thermo-couple in the usual way to indicate the temperatures, the second galvanometer being connected with a compound couple which only indicates any change of temperature in the two metals used. As these two metals are kept at the same temperature, the ray of light from the second galvanometer will only move when heat is given out or absorbed by critical changes taking place in the metal under examination. Arrangements can be made in the photographic

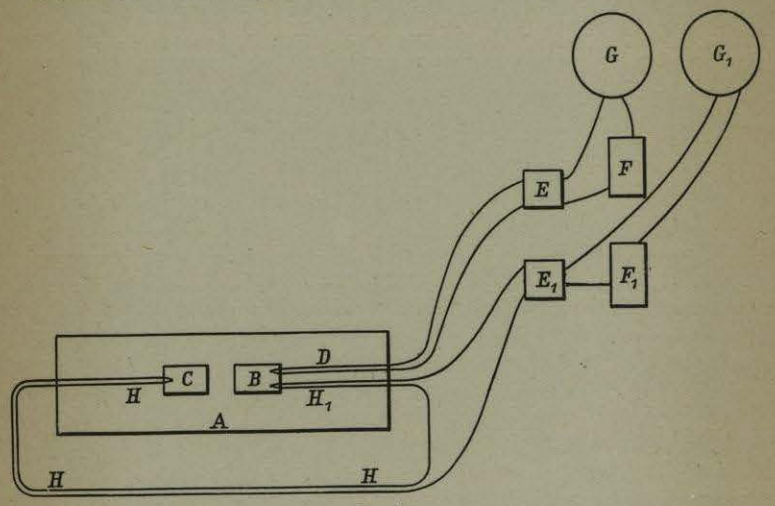

FIG. 73.

A Electric furnace.
B Steel under examination.
C Neutral metal; Ni-steel, or platinum.
D Thermo-couple for temperature.
E E_1 Cold-junctions.
F F_1 Resistance boxes.
G Galvanometer for temperature.
H H_1 Compound thermo-couple.
G_1 Differential galvanometer.

recorder to record the movements of the two galvanometers at the same time, or the readings may be obtained by lamp and scale arrangements.

In any case a curve can be obtained having as co-ordinates actual temperature and differences of temperature between the two metals, that is, heat given out, due to critical changes.

Fig. 73 is a diagram indicating the connections necessary for obtaining differential curves. A is a tube furnace containing an unglazed porcelain tube about 16 inches long and 1 inch in diameter, heated electrically by means of a coil of nickel wire or platinum foil carrying about 20 amperes. B is a cylinder of the steel under examination; it is bored with two holes, one for the

simple thermo-couple D which is connected through the cold-junction E and resistance box F to the galvanometer G, which records the temperature of the steel during heating or cooling. C is a cylinder of nickel steel, having no critical points at the temperatures used, or a cylinder of platinum bored with one hole and containing a thermo-couple H, one wire of which, say the platinum, passes through the cold-junction E_1 and the resistance box F_1 to the differential galvanometer G_1, the other wire, say the platinum-iridium, passes to H_1, where it forms with another platinum wire a second thermo-couple, which is placed in the second hole in the steel under examination; this platinum wire now passes through the cold-junction box E_1 to galvanometer G_1, thus completing the circuit. It will be seen that the thermal changes indicated by this galvanometer will be the algebraic sums of those of the metal B under examination and the neutral metal C.

For really accurate measurements in scientific research, the modification of the air thermometer devised by Deville and Troost may safely be adopted. With regard to it, modifications of the air thermometer in which glass bulbs were replaced by metal were adopted by Prinsep and others early in the last century. The great advance Deville and Troost made was the substitution of bulbs of porcelain for those of metal. The following is an outline of their experimental method:—

Their apparatus consists of a globular flask of Bayeux porcelain of 280 or 300 cubic centimetres capacity, with a neck 11 centimetres long and 4 millimetres in internal diameter. A quantity of iodine is put into the flask, and the neck is nearly closed by a small plug of porcelain, which lies loosely in the opening. When the flask is now exposed to a high temperature, the iodine is vaporised, and the greater part escapes by the neck, driving out at the same time nearly the whole of the air. After the flask has been exposed for about twenty minutes to the temperature that is to be measured, the flame of an oxyhydrogen blowpipe is allowed to play for an instant on the porcelain plug lying in the neck; the plug is thus melted, and closes the flask hermetically. When cold the flask is cleaned and carefully weighed; the end of the neck is broken under boiled water or mercury, and the flask is weighed together with the water or mercury which enters; it is then completely filled with water or mercury and weighed again; lastly, the flask is weighed when empty. From the weights thus obtained it is easy to calculate the capacity of the flask and the volume of the residual air, that is, air which has not been expelled by the iodine vapour. The first weighing gives directly the excess of weight of the flask, and iodine vapour over that of the empty flask. The

observations which require to be made in each experiment are the following:—

Temperature of the balance	$t°$
Pressure of the atmosphere	h millimetres
Excess of weight of sealed flask and iodine vapour at end of experiment over that of the empty flask	i grms.
Capacity of flask	v cubic centimetres
Residual air	a ,, ,,

In order to be able to calculate the exact temperature at which the flask was sealed the following constants are necessary:—

Weight of 1 c.c. air at 0° and 760 mm. pressure	= 0·001293 grm.
Density of iodine vapour referred to air as unity	= 8·716
Coefficient of expansion of air for 1° C. . .	= 0·00366
Coefficient of cubical expansion of the porcelain for 1° C.	= 0·0000108

The required temperature may then be calculated in the following manner:—

Let $I_w = \left(\frac{(v-a)0{\cdot}001293}{(1+0{\cdot}00366\,i)}\frac{h}{760}+i\right)$ be the total weight of iodine vapour contained in the flask at the moment of sealing; then

$$\frac{I_w}{0{\cdot}001293\times 8{\cdot}716}\frac{(1+0{\cdot}00366\,T)\,760}{h}=I_v$$

will be the volume of the vapour at the same moment; but

$$I_v+\frac{a(1+0{\cdot}00366\,T)\,760}{(1+0{\cdot}00366\,t)}\frac{}{h}=v(1+0{\cdot}0000108\,T),$$

and from this equation, in which T, the temperature required, is the only unknown quantity, its value is easily found.

Owing to the belief that the molecule of iodine undergoes dissociation at high temperatures, this method has been modified, atmospheric air being used in place of iodine.

Barus has devised a form of appliance which he considers to be superior to that used by Deville for determining the boiling-points of metals. As shown in fig. 74, it consists of a glazed tube of porcelain d, passed through a hole in the base of a crucible a. The zinc or other metal whose boiling-point is to be determined is shown at k. In this case a thermo-couple is used as a pyrometer, and it is inserted into the porcelain tube d. A reducing atmosphere of gas may be introduced through the tube h. The whole is enclosed in a Fletcher gas furnace F. Gas enters through A, and the products of combustion escape at D.

The question naturally arises—How far may the indications

afforded by the air thermometer be trusted? Are the degrees indicated by it at a white-heat comparable with the degrees of the ordinary thermometer? The author believes that the laws of Boyle and of Charles will probably hold good at the high temperatures of ordinary furnaces; and, further, the evidence as to temperature indicated by the air thermometer does not rest upon the expansion of a single gas, as the porcelain bulb may be filled with nitrogen, oxygen, or carbonic anhydride. The question as to the degree of confidence which may be reposed in the numerical values of high temperatures is, however, so important that the author would refer to the following experiment of Carl Barus, who has devoted years of patient work to pyrometric investigations. Fig. 75 shows the arrangement adopted by him for comparing directly the air thermometer with the thermo-junction.[1] The latter is inserted in a tubulure extending to the centre of the bulb e, and the disposition of the various parts of the apparatus

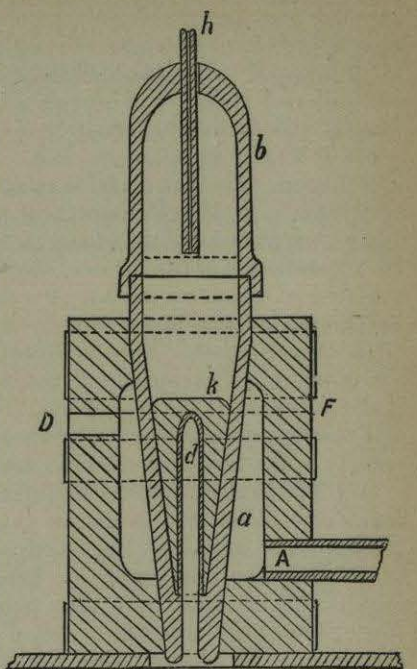

FIG. 74.

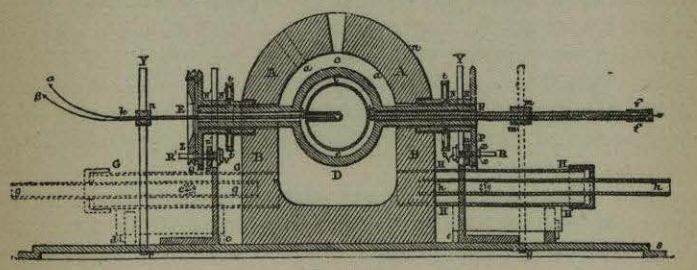

FIG. 75.

is as follows. The walls of a cylindrical furnace B B are covered with a hemispherical dome A A. The furnace is heated by gas, introduced through the burners G G, H H; compressed air enter-

[1] *Bulletin United States Geological Survey*, No. 54, Washington, 1889.

ing by the inner tubes *g g* and *h h*. The inlets for the gas are *c c'*. The furnace can be heated to a high temperature with ease; but in order to equalise the heat, Barus employs an internal globular "muffle," E C D F. It consists of two hemispheres of fire-clay, provided with lateral tubes, which pass through the walls of the furnace. The two hemispheres are held together by the iron collars N N, N N'. The outer edges of these collars P P' are flanged, and fit into the grooves of two friction rollers Q Q', of which R R' are the respective axes. There are adjusting screws at V V', *u u'*, *t t'*. The muffle is rotated by a belt pulley screwed on to the flange P'. The air thermometer is shown in position, *f f k i e*, supported by the clamp *m m*. A similar clamp *n n*, on the opposite side of the furnace, supports the thermo-junction *k k*, the wires of which are shown at $\alpha\beta$. It will be observed that the thermo-junction passes directly into the re-entering tubulure of the porcelain bulb; but the wires must not touch the walls of the tubulure. The capacity of the bulb *e* is about 300 c.c. The muffle is turned at the rate of about fifty revolutions per minute; and this speed, which is probably needlessly high, ensures uniformity in the temperature of the furnace.

It will be evident that the arrangements briefly described above enable the indications of the air thermometer and the thermo-junction to be compared, and full details of the experiments will be found in the monograph by Barus. The results of recent work in this direction have been published by the author[1] and also by Stansfield.[2] It will be found[3] that if the results of the experiments be plotted with the electro-motive force of the thermo-junction (in micro-volts) as abscissæ, and the temperatures, indicated by the air thermometer, as ordinates, the several observations coincide very nearly with a straight line; and singularly valuable information is thus afforded as to the trustworthy character of the respective methods. The general conclusion would appear to be—that the thermo-junction, the use of which is very simple, may replace the air thermometer, which, as arranged for accurate work, involves the employment of cumbersome apparatus and much tedious calculation, and is, in fact, about the last piece of apparatus that should be offered to engineers with a view to the measurement of temperatures in the ordinary course of work.

An air thermometer in a form adapted for industrial use has, however, been devised by Prof. Wiborgh of Stockholm,[4] who measures the pressure exerted by the expansion of a known volume of air when forced into a porcelain bulb raised to the temperature which it is required to determine. Another form

[1] Alloys Research, 4th Reports, *Inst. Mech. Eng.*
[2] *Philosophical Magazine*, July 1898.
[3] *Bulletin U.S. Geological Survey*, No. 54, Washington, 1889.
[4] *Journal of the Iron and Steel Institute*, 1888, vol. ii. p. 110.

has recently been patented by Prof. H. L. Callendar,[1] who has so modified the differential air thermometer as to enable the degrees of temperature to be read directly on a graduated tube.

The Uehling Pneumatic Pyrometer[2] is much used in large iron and steel works in America, and has been adopted in this country to a considerable extent for taking the temperature of the blast. This pyrometer is based on the laws governing the flow of air through small apertures, and the principle may be illustrated by fig. 76.

The chamber C has an inlet aperture A and an outlet aperture B, and a uniform suction is created in the chamber C' by the steam aspirator D. Air will be drawn into chamber C' creating

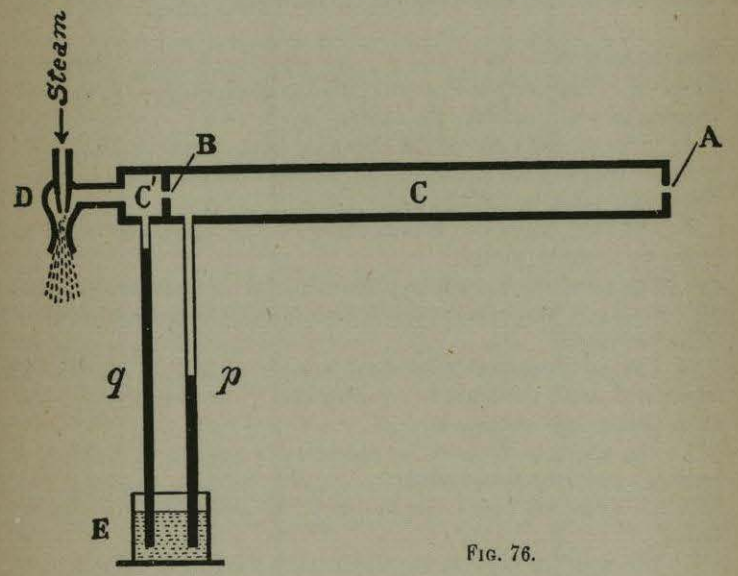

FIG. 76.

a suction in C, which in turn causes air to enter through A. The velocity at which the air flows through A depends upon the suction in C, and the velocity at which it flows through B depends upon the excess of suction in C' over that in C, that is, the effective suction in C'.

As the suction in C increases, the effective suction in C' must decrease, and hence the velocity at which air flows in through A increases and the velocity at which air flows out through B decreases, until the velocity of flow through both apertures becomes equal. When this occurs no further change of suction in C will take place. Air is expanded by heat, and the higher the

[1] *Proceedings of the Royal Society*, 1892, vol. l. p. 247.
[2] This account is taken from the excellent description by Mr Harrison in *Journ. Iron and Steel Inst.*, 1904, i. p. 124.

temperature the greater will be its volume and the smaller will be the quantity drawn through a given aperture by the same suction after it has been reduced again to normal temperature. If, therefore, the atmospheric air before entering A is heated and again cooled to some lower temperature, say 100° C., before passing through B, less air will enter through A than is drawn out through B, hence the suction in C must increase and the effective suction in C′ decrease, therefore the velocity of air through A will increase and that through B will decrease, until again the same quantity of air flows through each aperture.

Thus, every change in temperature of the air entering through A will cause a corresponding change in suction in C, and these changes in suction will truly represent the changes in temperature of the air entering A. Two manometer tubes *p* and *q* communicate respectively with C and C′, the lower ends being immersed in water. The column in *p* will indicate the suction in C′, and the column in *q* will indicate the suction in C.

In order to make use of the above principle in the construction of an instrument for measuring high temperatures, the following conditions must be fulfilled:—

1. The air must be drawn through the apertures with a perfectly uniform suction.

2. The aperture A must be placed in such a position that the air entering it will have acquired the same temperature as that to be measured.

3. The parts exposed to the heat must be made of a material which will resist the highest temperature to be determined, and at the same time will not scale.

4. The aperture B must be placed in a medium of perfectly constant and fixed temperature.

5. All apertures must remain perfectly clean and free from scale.

6. The chamber C must be absolutely air-tight, so that no air can enter except through A.

The complete pyrometer is shown diagrammatically in fig. 77.

Fig. 78 is taken from a photograph, and shows a portable fire tube and a Steinbart recording gauge. In fig. 77, H is the suction regulator which provides uniform suction, and works on the principle of sucking air through a constant column of water, and by keeping the water-levels in H and N at constant heights a perfectly uniform suction is obtained. The interior of the fire tube and pipe is shown in *e*, *f*, *g*, *h*, *i*; (figs. 77A and 77) the aperture A is made at the end of a small closed platinum tube *e*, enclosed in an outer tube of the same material *d*, so that the aperture is within a very small distance of the tube *d* which protects it. These platinum tubes are brazed into drawn copper tubes *c* and *f*, which are cooled by the water jacket F. Atmospheric air enters by connection *b*, which opens into the space

between the inner and outer tubes and finds its way to aperture

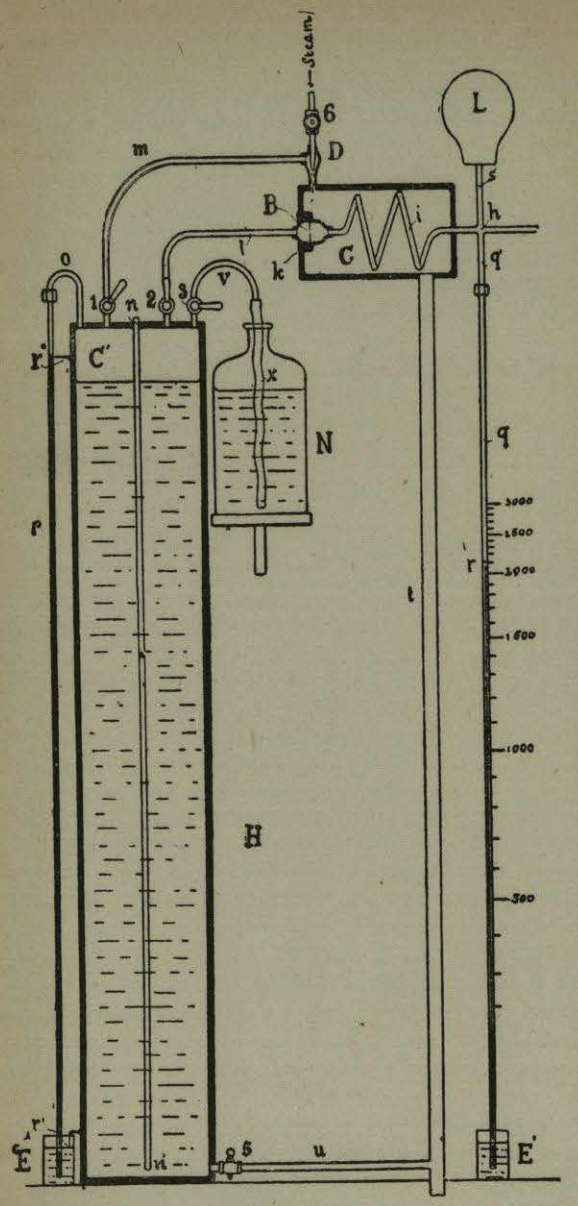

Fig. 77.

A. The fire-tube is held by a sneck in the water-cooled jacket F, which is continuously fed by water which enters at *y* and

escapes at *z*. This water-jacket is screwed into a flange bolted on to the blast or gas main, and protects those parts of the fire-tube which would otherwise be injured by heat. It will thus be seen that by fixing the fire-tube in such a position that the platinum point is in the hot blast or gas, the temperature of which it is desired to measure, the air between the two platinum tubes will acquire that temperature before it enters the aperture A.

The aperture B (fig. 77) is made in a small dished platinum plate, which is held between knife-edge spigot joints in a small brass casting located within a chamber C, and in connection with a copper coiled pipe *i*, which is kept at a temperature of 100° C. by means of the steam from the aspirator D. The air, before entering the fire-tube, is filtered by passing through a 2-inch diameter pipe filled with cotton-wool I (fig. 77A). The steam aspirator D (fig. 77) sucks air through the tube *m* out of the chamber C′, and produces a suction in C′ which is shown by the manometer tube *p*. With a constant suction in C′, and cocks 2 and 4 open, air will enter the filter I, where it is purified, and passes through *b* to the fire-tube. It flows in the annular space between the two tubes *c* and *f*, and as it reaches the point of the platinum fire-tube *d*, which protrudes beyond the water-jacket, it acquires the temperature surrounding it which is to be measured, and passes in through the aperture A at that temperature. It then passes through the pipe *e*, *f*, *g*, *h* into the coil *i*, where it assumes the temperature of 100° C., at which it passes through the aperture B, thence by the pipe *l* into the chamber C′, from which it is drawn by the aspirator D through *m*, and discharged with the exhaust steam and water to the atmosphere again. The branch pipes S and *q′* connect respectively to the recording gauge and the manometer tube *q*, which is placed on a graduated temperature scale. This pyrometer is made in either single or double form; in the latter, one temperature and suction regulator and one aspirator serve for two fire-tubes.

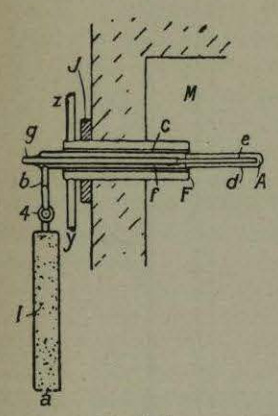

FIG. 77A.

A Steinbart Recording Gauge is generally used in connection with this pneumatic pyrometer. This gauge is shown in fig. 79, and consists of a vertical glass cylinder containing mercury, in which floats a glass bell having attached to it a rod with a properly adjusted balance weight.

To this hanging rod is attached a small horseshoe magnet carrying a pen supplied with ink. A small bar of soft iron is

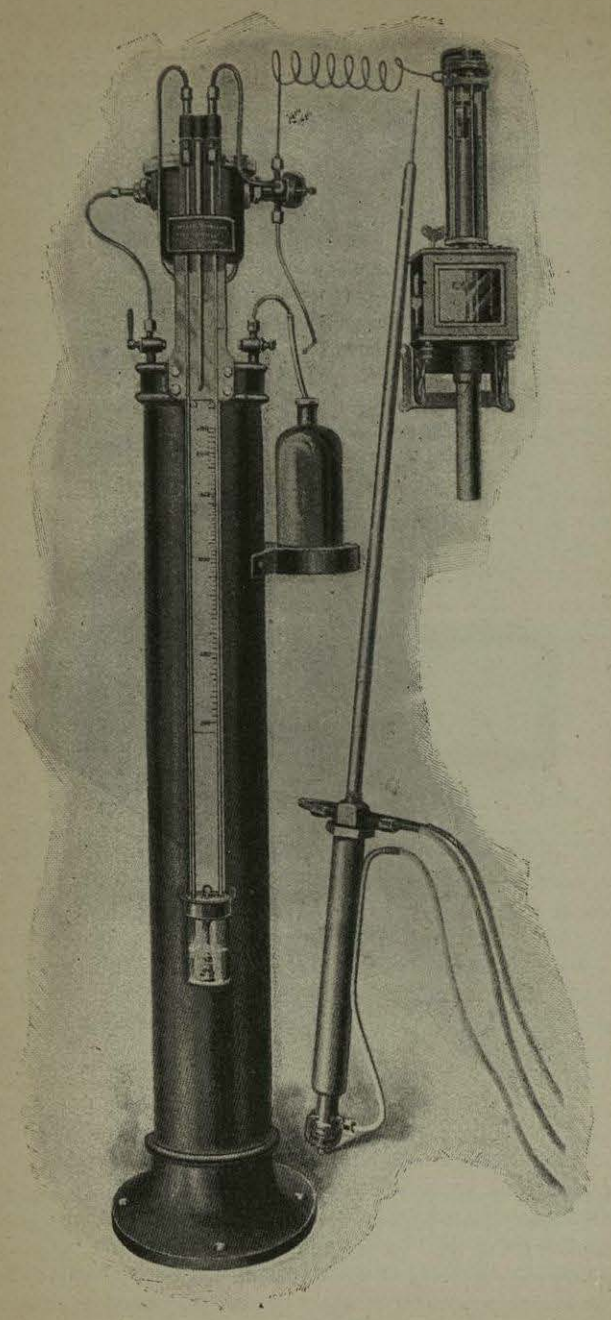

FIG. 78.

placed so as to draw the pen against a continuous strip of paper moved slowly past it by clockwork.

The paper is previously printed with vertical time division lines, and before it reaches the pen it is rolled between two rollers,

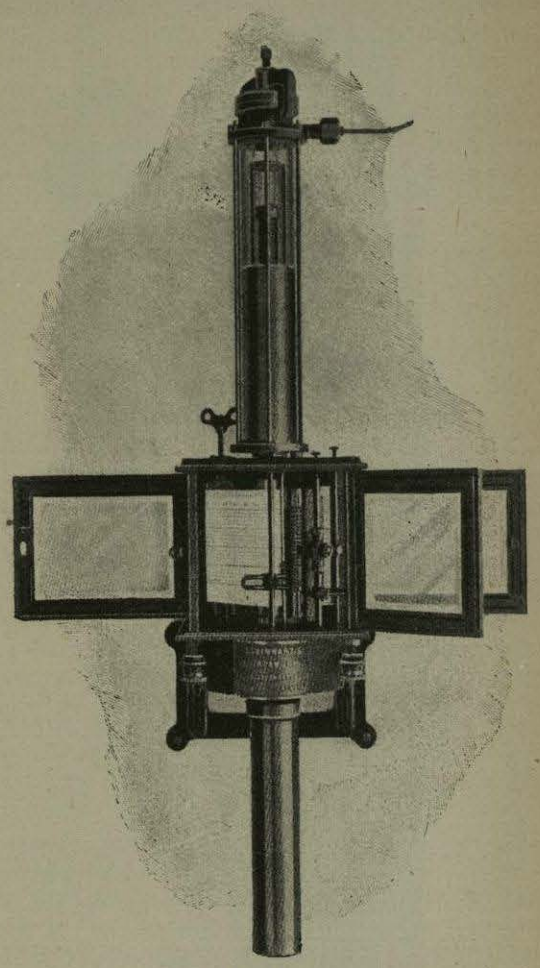

Fig. 79.

one a plain one and the other having on it a series of flanges carefully spaced, which print the horizontal temperature division lines on the paper as it passes, ink being applied by a pad revolving against it. The paper, after passing the pen, winds automatically on to a spring receiving roller, which can be released and the record examined at any time without interfering with the operation of the gauge. An eight-day clock gives motion to the paper.

Atmospheric pressure is admitted inside the glass float, and the upper part of the inside of the glass cylinder referred to is in connection with the air-pipe from the fire-tube to the regulator, so that the same amount of tension or suction is applied in this glass cylinder as in the air-pipe. This suction lifts the glass float more and more out of the mercury in which it floats as the suction increases, and allows it to fall as it decreases, and the hanging rod, with its attached magnet and pen, rises or falls with it, and thus a line is traced upon the paper, which, being moved by the clockwork, takes various forms as the suction varies, which is a true index of the variations of the temperatures being measured. The pen is set to the temperature line corresponding to the temperature being registered by the regulator, and when once correctly set will continue to rise and fall with variations in temperature. The record paper is usually cut off every twenty-four hours; the last seven hours are always in view. This recorder is very accurate and extremely sensitive, and is very little affected by vibrations. The pneumatic pyrometer is reliable up to 2500° F. (1425° C.), and temperatures up to 3000° F. (1650° C.) can be measured by it. By its intelligent use the attendant is able to keep the temperature within a few degrees of the heat ordered by the manager, and the latter can always know whether his instructions have been carried out or not.

Optical Pyrometry.

In conducting researches, the thermo-junction possesses, in the author's opinion, many advantages; but, unfortunately, its use involves appliances which are not sufficiently simple to be entrusted to ordinary workmen; and, as Prof. Le Chatelier has pointed out, the use of the thermo-electric pyrometer is only possible in works where the manager or some other responsible person has a taste for scientific investigation, and devotes himself personally to it. In this country such cases are now numerous, and the author would cite as an instance the Clarence Works, where Sir Lowthian Bell established a system of electrical pyrometry in connection with the hot-blast mains, each of which may, in turn, be placed in pyrometric communication with a central office.

A less complicated but still trustworthy instrument of moderate accuracy was much needed, and Le Chatelier supplied it. The eye of the workman again becomes the pyrometer, but it is supplemented by an instrument which enables him to record the intensity of the radiations emitted by a glowing body; so that the old method of judging temperature by the appearance of the mass is rendered comparatively accurate, and the familiar indications of "redness," "bright redness," and "whiteness" are subjected to

direct measurement. Optical pyrometry is not new, but its history, which would include references to the honoured names of Pouillet, Ed. Becquerel, Crova, and Violle, is far too complex to be dealt with in this work.

Mr Crova[1] actually employed his spectro-pyrometer for industrial work, and measured the temperature of certain furnaces at the Creusot Works.

Le Chatelier's[2] photometric instrument is shown in figs. 80 and 81, and in its construction he has utilised the photometer of M. Cornu. The author was indebted either to Le Chatelier's published papers, or to descriptons which he furnished, for the details respecting the nstrument which will now be given. The light from a standard flame, or lamp L, burning amylic acetate, is reflected to the eye of the observer by the mirror M, while the light from the incandescent body also passes to his eye through a red glass in the eyepiece G; this renders the radiations nearly monochromatic. There is an adjustable orifice at O by which the amount of light admitted from the luminous body can be regulated. In order that intensities, which may often vary from 1 to 1,000,000, may be compared, absorbent glasses are employed; and these glasses are superposed at O′ and E, in greater or less number, as may be necessary. P is a counterpoise, to equalise the weight of the other parts of the appliance. The luminous object, the temperature of which has to be determined, may be focussed by sliding the tube A′; and in order to measure the intensity of its radiations with this instrument, the procedure is as follows:—The position of the mirror M, fig. 81, must be regulated by three screws at C, fig. 80, so that the luminous image of the lamp and that of the object

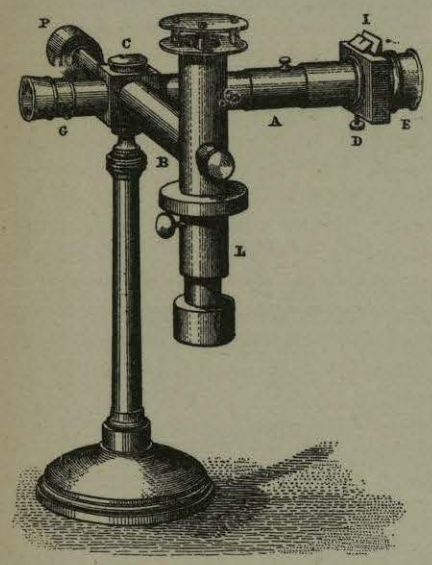

FIG. 80.

[1] *Comptes Rendus*, vol. lxxxvii., 1878, pp. 322 and 979; *ibid.*, vol. xc., 1880, p. 252; *ibid.*, vol. xcii., 1881, pp. 36 and 707; *ibid.*, vol. cxiv., 1892, p. 941.

[2] *Comptes Rendus*, vol. cxiv., 1892, p. 214; *l'Industrie Électrique*, No. 7, 1892, p. 147, where the formulæ given in this paper will be found.

to be measured are brought into juxtaposition, being divided by the edge of the mirror.

The photometer depends upon the adjustment to the same brightness of two images, one being that of the flame of a standard lamp, and the other that of the object whose temperature is to be determined. The adjustment is made by means of a diaphragm formed of two plates, each with V-shaped notches opposite to one another. The two plates can be moved past one another by turning a milled head D, fig. 80, and in this way a square aperture of variable size is formed, which, being placed in front of the object-glass O of the telescope, controls the amount of light admitted from the luminous object.

A divided scale I is attached to one half of the diaphragm and a pointer to the other, and this gives directly a linear measurement n of the aperture.

Let n' be a measurement when the image of an object of unit brightness (a candle flame, for instance) is matched to that of the standard lamp, and n the measurement when another object is matched in place of the candle. Since the eyepiece has a red glass within it, only red rays pass to the eye for measurement, and the intensity, I, of these red rays emitted by the second object, as compared with those from the candle, will be given by the equation

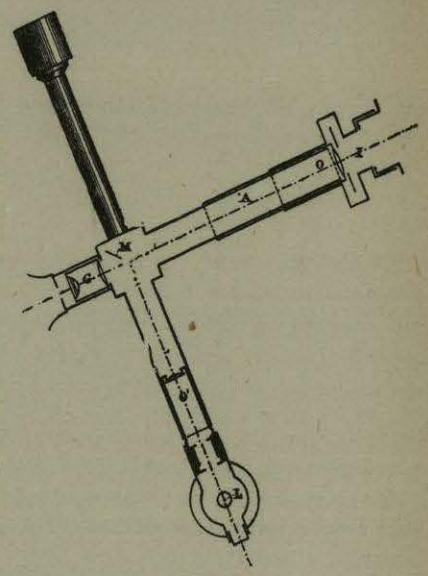

FIG. 81.

$$I = \left(\frac{n'}{n}\right)^2.$$

But if the two objects are not at equal distances from the instrument, the intensity will be apparently less for the more distant one, in the ratio $\left(\frac{f}{f'}\right)^2$, where f and f' are the focal lengths (given on the tube A) of the two objects; hence—

$$I = \left(\frac{n'}{n}\right) \times \left(\frac{f}{f'}\right)^2.$$