CHAPTER V.

PYROMETRY.

Pyrometry.—This term is applied to the measurement of high temperatures. It is not possible, it is true, to attain as accurate measurements of high temperatures as it is of low ones by the aid of thermometers; nevertheless, very precise determinations have been made, and, as the measurement of high temperatures is of great importance in metallurgy, some attention must be devoted to the principles on which pyrometry is based.

The author has elsewhere pointed out[1] that, notwithstanding the importance attached by early experimenters to the action of heat on metals, they had but little definite information respecting the relative degrees of intensity of heat; and their views were not inadequately expressed in the eighth century by Geber, who stated that great difficulties arose in conducting operations with the aid of heat, because heat cannot be measured, "*sed quoniam non est res ignis, quæ mensuari possit.*"[2] The name of Josiah Wedgwood is always associated with the early attempts to provide a practical method of pyrometry; but, although he wrote a thousand years after Geber, he seems to have merely changed the language of the latter, "heat cannot be measured," into a lament that there were no trustworthy instruments for effecting the measurement of "the higher degrees of heat, from a red heat up to the strongest that vessels made of clay can support."[3] He therefore devised a pyrometer which depended on the contraction that clay experiences when strongly heated. It is not necessary to give a history of pyrometry in this place; the author would merely point out that Wedgwood demonstrated the necessity for the accurate measurement of high temperatures, and that, from his time, the invention of more or less suitable instruments has proceeded rapidly.

[1] Lecture at the Royal Institution. *Nature*, vol. xlv., 1892, p. 534.

[2] From the edition of his *Summa Perfectionis Magisterii*, published in Venice, 1542, p. 28. (Additions have probably been made to Geber's original text.)

[3] *Phil. Trans. Roy. Soc.*, vol. lxxii., 1782, p. 305.

In the long interval between the work of Wedgwood and that of the late Sir William Siemens, such pyrometric appliances as were actually in industrial use depended mainly on what is known as the "method of mixtures,"—that is, upon the employment of a body, the specific heat of which was known, to transfer or carry heat from a furnace, or source of heat, to a measured volume of water, the rise in temperature of which was indicated by an ordinary thermometer. Pyrometers depending on the expansion of metallic strips or rods are also employed; but they may all be set aside with the general statement that, although they are useful in affording rough approximate measurements, they are useless for accurate pyrometry. It may be well to add that a noteworthy advance in thermometry was made a few years ago in Professor Ramsay's laboratory at University College by Messrs Baly and Chorley, who employ the fluid alloy of sodium and potassium, instead of the mercury of the ordinary thermometer; temperatures of 600° Centigrade may thus be measured by making the thermometers of very hard glass.

By introducing nitrogen into the stem of thermometers above the mercury they may be used up to 500°, and it may be added that glass thermometers filled with petrol may be used to measure temperatures as low as – 200° C.

Carl Barus[1] has given the following classification of the principles on which pyrometers have been constructed in an admirable treatise on the measurement of high temperatures:—

1. Dilatation of solids—
   (*a*) A single solid;
   (*b*) Two solids acting differentially.
2. Dilatation of liquids.
3. Dilatation of gases—
   (*a*) Expansion measured in volume, manometrically;
   (*b*) Expansion measured in pressures, manometrically;
   (*c*) Expansion measured in volume, by displacement.
4. Vapour tension.
5. Dissociation.
6. Fusion.
7. Ebullition.
8. Specific heat.
9. Heat conduction.
10. Heat radiation.
11. Viscosity—
    (*a*) of solids;
    (*b*) of liquids;
    (*c*) of gases.
12. Spectrophotometry and colour. Rotary polarisation.
13. Acoustics (wave-length).
14. Thermo-electrics.
15. Electrical resistance.
16. Magnetic moment.
17. Miscellaneous.

This classification shows that almost every thermal phenomenon has been utilised for pyrometry. It is especially necessary for the student to know what appliances afford a means of estimating high temperatures with sufficient accuracy for the ordinary purposes of a metallurgical works, and are at the same time

[1] *Bulletin of the United States Geological Survey*, No. 54, Washington, 1889. This contains an exhaustive bibliography of pyrometry.

sufficiently durable to withstand rough usage. For delicate investigations there are several instruments that can safely be adopted. These will be described subsequently.

Mr R. S. Whipple, who has contributed much to the progress of technical pyrometry, has given the following very useful table of types of thermometers in general use.[1]

TYPES OF THERMOMETERS IN GENERAL USE.

	Principle.	Type.	Range in Degrees C.
Expansion . .	Those depending on the change in volume or length of a body with temperature.	Gas . . . . . Mercury, Jena glass, and nitrogen . . . Glass and spirit or petrol Unequal expansion of metal rods . . . Contraction of porcelain .	0 to 1,000 − 40 ,, 500 − 200 ,, +40 0 ,, 500 0 ,, 1,800
Transpiration and Viscosity . .	Those depending on the flow of gases through capillary tubes or small apertures.	The Uehling . . .	0 to 1,600
Thermo-electric . .	Those depending on the E.M.F. developed by the difference in temperature of two similar thermo-electric junctions opposed to one another.	Galvanometric . . . Potentiometric . .	0 to 1,600 0 ,, 1,600
Electric Resistance	Those utilising the increase in electric resistance of a wire with temperature.	Direct reading on indicator or bridge and galvanometer . .	0 to 1,200
Radiation . .	Those depending on the heat radiated by hot bodies.	Thermo-couple in focus of mirror . . . Bolometer . . .	0 to 10,000 0 ,, 10,000
Optical . . .	Those utilising the change in the brightness or in the wave-length of the light emitted by an incandescent body.	Photometric comparison . Incandescent filament in telescope . . . Nicol with quartz and analyser . . .	0 to 2,000 0 ,, 2,000 0 ,, 2,000
Calorimetric . .	Those depending on the specific heat of a body raised to a high temperature.	Copper or platinum ball with water vessel . .	0 to 1,500
Fusion . .	Those depending on the unequal fusibility of various metals or earthenware blocks of varied composition.	Alloys, etc., of various fusibilities . . .	0 to 1,980

[1] *Proc. Western Soc. of Engineers, Chicago*, vol. xii., No. 2.

The simplest methods are undoubtedly grouped in class 6 of Barus' "fusion." For instance, the insertion of a fragment of metal of known melting-point in the locality whose temperature is to be tested will often afford at once the required information. Thus the temperature of the hot blast may be capable of melting a rod of lead (melting-point 327°), though it may fail to melt a similar rod of zinc (melting-point 419°). A strip of pure silver will just melt at a temperature at which zinc boils, and this has been accurately determined as being 961°; and it follows, therefore, that a temperature which will just melt pure silver is somewhere near 960°.

This method of "fusion" has been greatly improved by Dr H. Seger of Berlin, who has devised and manufactured a series of cones which are known as "Seger Cones," and which consist of truncated pyramidal-shaped bodies, composed of a graduated mixture of aluminium silicates, which soften and fuse at definite temperatures, and by the aid of which it is possible to determine the approximate temperatures of furnaces and of heated spaces. The following table gives the numbers of the series used in practice, together with the approximate temperature at which they fuse.[1]

No.	Temp. in Degrees C.	No.	Temp. in Degrees C.	No.	Temp. in Degrees C
022	590	03	1090	17	1470
021	620	02	1110	18	1490
020	650	01	1130	19	1510
019	680	1	1150	20	1530
018	710	2	1170	21	1550
017	740	3	1190	22	1570
016	770	4	1210	23	1590
015	800	5	1230	24	1610
014	830	6	1250	25	1630
013	860	7	1270	26	1650
012	890	8	1290	27	1670
011	920	9	1310	28	1690
010	950	10	1330	29	1710
09	970	11	1350	30	1730
08	990	12	1370	31	1750
07	1010	13	1390	32	1770
06	1030	14	1410	33	1790
05	1050	15	1430	34	1810
04	1070	16	1450	35	1830
				36	1850

It must be remembered that the above figures are only an approximation to the true temperatures, but this approximation is sufficiently accurate for numerous industries or operations. By

[1] *Journ. Iron. and Steel Inst.*, 1904, No. 1, p. 117.

standardising a number of intermediate cones by means of the thermo-electric pyrometer, and by definitely determining the softening points of the most readily fusible and of the most refractory cones respectively, and adjusting the remainder by interpolation, a series is obtained which, assuming the incremental variations to be correctly expressible as constants, will at least furnish a useful indication of temperature.

In practice, a number of cones are placed in the furnace, ranging over perhaps 8 or 10 numbers in sequence. At the end of the experiment the cones will be found to be variously affected, some having completely collapsed, while others are hardly altered.

The temperature is taken to be that at which a particular cone in the series appears to present a mean degree of fusing.

The cones are made up of mixtures in various proportions of quartz, kaolin, white marble, and felspar, the raw materials used for glazes at the Royal Berlin Factory.

Many appliances, notably the Siemens Water Pyrometer, may be purchased, the action of which depends upon the method of mixtures (No. 8 in Barus' scheme). This is shown in cross section in fig. 63, and consists of a cylindrical copper vessel provided with a handle and containing a smaller copper vessel. An air-space *a* separates the two vessels, and a layer of felt surrounds the inner one in order to retard the exchange of temperature with the surroundings. The capacity of the inner vessel is a little over one pint.

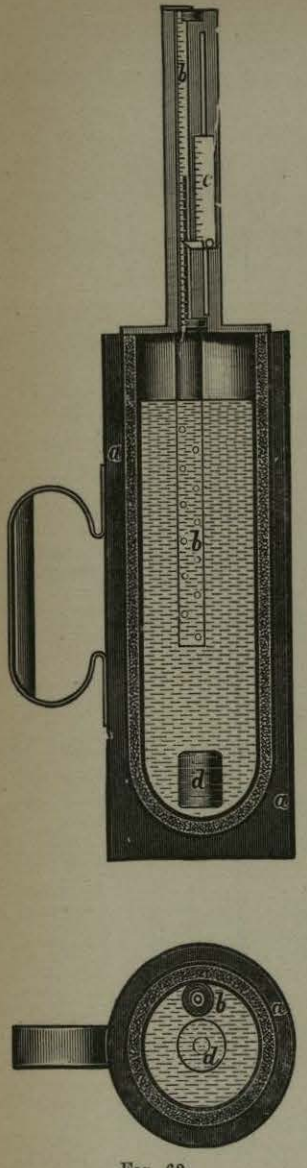


Fig. 63.

A mercury thermometer *b* is fixed close to the wall of the inner vessel, its lower part being protected by a perforated brass tube, whilst the upper

part projects above the vessel, and is divided as usual on the stem into degrees.

At the side of the thermometer there is a small brass scale *c*, which slides up and down, on which the high temperatures are marked; on a level with the zero division of the brass scale a small pointer is fixed, which traverses the scale of the thermometer. Small cylinders *d*, of either nickel, copper, iron, or platinum, which are so adjusted that their heat capacity at ordinary temperature is equal to one-fiftieth of that of the copper vessel containing one pint of water, are used. As, however, the specific heat of metals increases with the temperature, allowance is made on the brass sliding scales, which are divided according to the metal of which the cylinders are composed.

The water pyrometer is used in the following manner:—

Exactly one pint of clean water is poured into the copper vessel, and the pyrometer is left for a few minutes to allow the thermometer to attain the temperature of the water. The brass scale *c* is then set with its pointer opposite the temperature of the water, as shown by the thermometer. Meanwhile one of the metal cylinders has been exposed to the high temperature which is to be measured, and, after allowing sufficient time for it to acquire that temperature, it is rapidly withdrawn and carefully dropped into the pyrometer vessel. The temperature of the water then rises, and when the mercury of the thermometer has become stationary, the degrees are read off, as well as those on the brass scale opposite the top of the mercury.

The sum of these two values gives the temperature of the heated space in which the metal cylinder has been placed. With cylinders of iron or copper, temperatures up to 1000° C. or 1800° F. can be measured, and with cylinders of platinum temperatures up to 1500° C. or 2700° F.

For ordinary furnace work either copper or wrought-iron cylinders may be used. Iron possesses a higher melting-point and has less tendency to scale than copper, but the latter is affected much less by the action of the furnace gases. Nickel may be used up to 1400° C., and possesses advantages in freedom from scaling and from attack by the gases.

The weight to which the cylinders are adjusted are as follows:—

Copper	137 grammes.
Wrought iron	112 ,,
Nickel	117 ,,
Platinum	402·6 ,,

In the case of copper cylinders, which lose weight by scaling, a certain correction has to be added to the figures to allow for this loss, after they have been in use some time.

For rapid determinations of high temperatures in works the pyrometer of Carnelly and Burton[1] (class 9 of Barus) may be used. It is cheap and does not readily get out of order; moreover, when once placed in position, it requires little or no manipulation except the reading off of a couple of thermometers and a reference to a table. The principle on which it is based is as follows:—If a current of water of known temperature be allowed to flow at a constant rate through a coiled metallic tube placed in the space the temperature of which is required, then the increase in the temperature of the outflowing water will be greater the higher the temperature of the space.

A new era in the measurement of heat began with the work of Sir William Siemens. He showed[2] that electrical resistance might be used practically in pyrometry. Fig. 64 gives a general

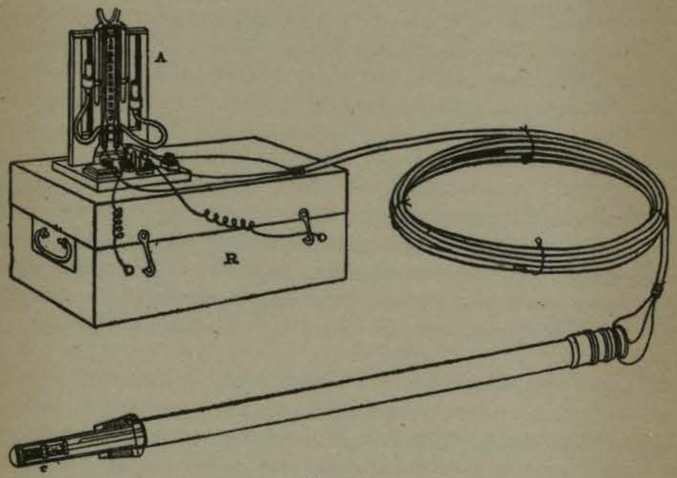


FIG. 64.

view of his apparatus, and its nature is explained by the accompanying diagram, fig. 65. A divided current passes from the battery B to a platinum wire C (coiled round a clay cylinder), and to a resistance coil R. At the ordinary temperature, the resistance of the platinum coil is balanced by the standard resistance R, and an equal current will flow through each. If, however, the platinum coil C be heated, its resistance will be increased, and this increase of resistance can be measured in various ways. Siemens adopted for use in works a small voltameter, shown at A, fig. 64; the current sent through the platinum coil *c* was of sufficient strength to decompose acidulated water, and the difference in the amount of water decomposed by that portion of the current which passed through the heated

[1] *Journ. Chem. Soc.*, vol. xlv. (1884), p. 237.
[2] Collected papers.

coil, as compared with that decomposed by the current transmitted through the standard resistance at R, fig. 65, gave, on reference to a table, the temperature to be determined. For many years this electrical-resistance pyrometer was the only appliance, believed to be trustworthy, which could be placed in the hands of artificers. Its usefulness was widely recognised, and a Committee of the British Association was appointed to report upon it. The result of the inquiry[1] rather tended to shake confidence in the instrument, as it was shown that it was liable to changes of zero. Prof. Callendar[2] has, however, done much to prove that, with certain precautions, the method may be rendered very trustworthy. He winds the platinum wire on a plate of mica, excludes reducing gases, as the Committee suggested, by enclosing the coil in a tube of doubly-glazed porcelain, and uses a zero method for measuring the resistances with the galvanometer. Fig. 66 represents, somewhat diagrammatically, the arrangement of the apparatus.[3]

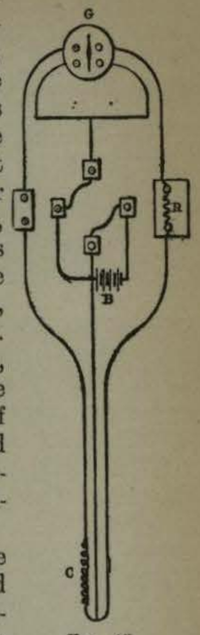


FIG. 65.

A B, B C are equal resistances, forming the arms of the balance. The battery is connected at A and C, and one terminal of the galvanometer G at B. D E represents a set of resistance coils, which, together with the resistances A B and B C, may be supplied by an ordinary box of coils of the "post-office" pattern. F K represents a straight bridge-wire, with a divided scale attached. The other terminal of the galvanometer is connected to the contact-piece H, which slides along this wire. The leads A M, K N from the

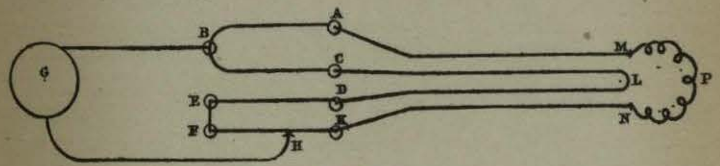


FIG. 66.

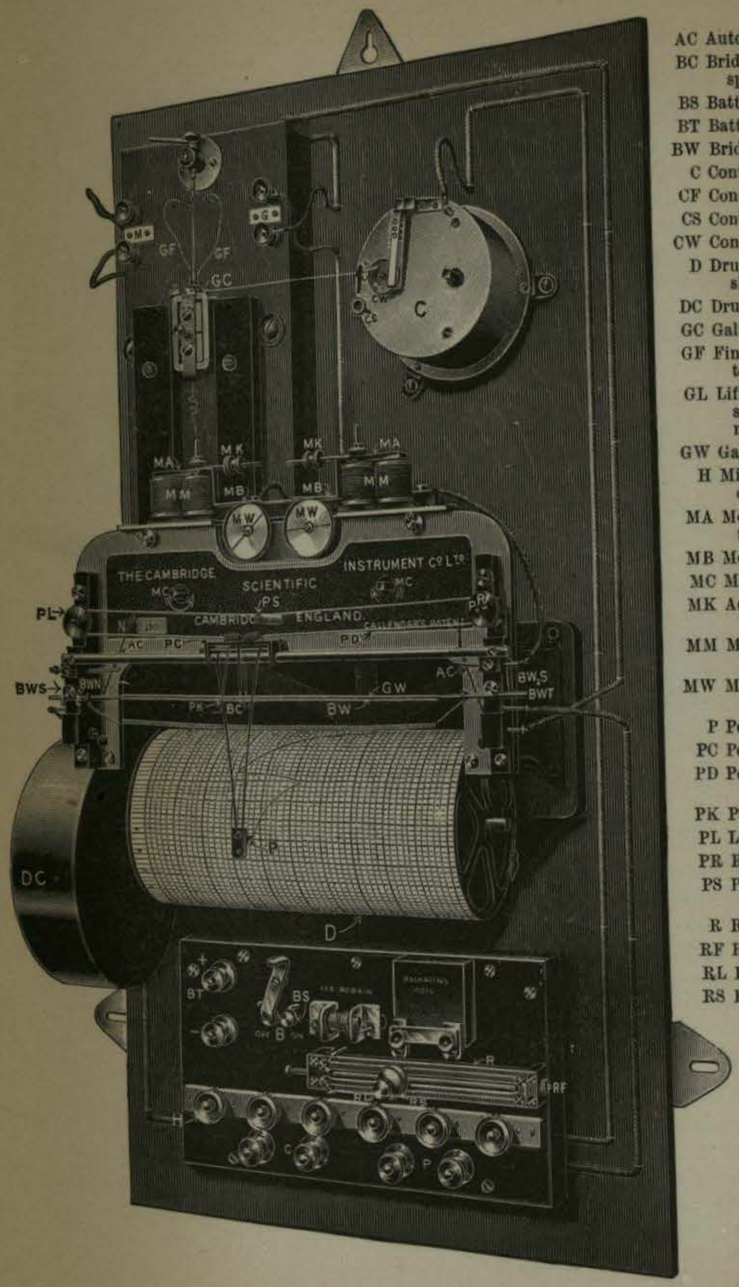
pyrometer coil P are connected to A and K; and the compensating leads C L, L D, the resistance of which is equal to A M, K N, are connected to C and D. These four leads may be of any convenient length; they are symmetrically arranged, so that corresponding parts are always at the same

[1] *British Association Report*, 1874, p. 242.
[2] *Phil. Trans. Roy. Soc.*, vol. clxxviii., 1887, p. 161.
[3] *Phil. Magazine*, vol. xxxii., 1891, p. 104, and vol. xxxiii., 1892, p. 220.

temperature. When the balance is found by inserting suitable resistances in the arm D E, and sliding the contact-piece H, it is plain that, since the resistances A B, B C are equal, the resistance of the pyrometer and its leads, together with that of the length H K of the bridge-wire, will be equal to the remaining portion F H of the bridge-wire, together with the coils D E, and the compensation C L D. Thus the changes of the resistance of the pyrometer leads A M, K N are compensated by the equal changes in the leads C L, L D, and the resistance of the pyrometer coil itself is directly given by the sum of the coils D E and the reading of the bridge-wire. The resistance of a centimetre of the bridge-wire F K is made to correspond to such an increase of the resistance of the pyrometer coil P as is produced by a rise of 1° C. The contact-key H slides along this wire, and the galvanometer can easily be made sensitive to one-hundredth of a centimetre of this bridge-wire, so that one-tenth of a centimetre, which corresponds to one-tenth of a degree, can, of course, be measured with certainty.

For reading temperatures directly by means of a resistance thermometer, the Whipple Temperature Indicator is often used. It consists of a Wheatstone Bridge, one arm of which is a long bridge-wire in the form of a helix on an ebonite drum. A contact-maker mounted on the inside of a drum can be rotated over this wire. A scale, divided into degrees, is fixed on the outer surface of the drum. The four terminals of the resistance thermometer are connected by means of leads to the indicator, the resistance coil of the thermometer thus forming one arm of the bridge. By turning the handle, the contact-maker is moved along the bridge-wire until sufficient resistance is introduced to balance the resistance of the thermometer. The galvanometer needle shows when this electrical balance has been obtained. A pointer shows the temperature on the scale previously mentioned.

For recording temperatures by means of an electric resistance pyrometer, a Callendar Recorder is used. This instrument, shown in fig. 67, and diagrammatically in fig. 68, consists of a self-adjusting recording Wheatstone Bridge or Potentiometer, in which the movements of the slider along the bridge-wire is automatically effected by relays worked by the current passing through the galvanometer between the bridge arms. According as the moving coil of this galvanometer is deflected in one direction or the other, a relay circuit is connected through one or the other of two electro-magnets. Each of these magnets is mounted on a clock, the movement of which is prevented by a brake. When a current passes through a magnet, this brake is lifted, allowing the clock-work to revolve. These clocks are connected by differential gearing with a recording pen, which is pulled in one direction or the other when the brake is lifted from the corresponding clock. The bridge slide moves with the pen and tends to restore balance.



AC Automatic cut-outs.
BC Bridge contact springs.
BS Battery switch.
BT Battery terminals.
BW Bridge wire.
C Contact clock.
CF Contact fork.
CS Contact clock starter.
CW Contact wheel.
D Drum carrying record sheet.
DC Drum driving clock.
GC Galvanometer coil.
GF Fine wire connections to contact fork.
GL Lifter and clamping screw for galvanometer coil.
GW Galvanometer wire.
H Milled heads to zero coils.
MA Motor magnet armatures.
MB Motor clock brakes.
MC Motor clocks.
MK Adjusting weights or motor brakes.
MM Motor release magnets.
MW Motor clock brake wheels.
P Pen.
PC Pen carriage.
PD Pen carriage driving cord.
PK Pen lifter spring.
PL Left-h. cord pulley.
PR Right-h. cord pulley.
PS Pen carriage driving screw.
R Rheostat.
RF Rheo. fine adj.
RL Rheo. locking screw.
RS Rheo. contact screw.

Fig. 67.—Callendar Recorder, Laboratory Pattern, front removed.

In the pattern of recorder specially designed for laboratory use a number of resistance coils are provided, which are put in circuit by unscrewing the milled brass heads H, fig. 67. With a standard thermometer these coils have the effect of raising the zero of the record to the values 50°, 100°, 200°, 300°, 400°, and 1000°, thus giving a more or less open scale, as may be desired.

Measuring the increased resistance of a heated conductor is not the only way in which electricity has been made serviceable in the measurement of high temperatures. It has long been known that if a junction of two metals be heated, the electrical equilibrium of the system is disturbed, and the measurement of the difference of potential produced affords a means of estimating the temperature of the junction. The use of such thermo-junctions appears to have been suggested by A. C. Becquerel in 1826, and adopted by Pouillet[1] ten years later. Unfortunately, the metals composing the thermo-junctions were badly chosen, and their use was consequently greatly retarded until, in 1887, Professor H. Le Chatelier[2] advocated the use of platinum, in conjunction with platinum alloyed with 10 per cent. of rhodium. The author first adopted this couple in 1889, and afterwards constantly used it, in conjunction with a photographic recorder, devised for the purposes of an investigation which was entrusted to him by the Institution of Mechanical Engineers. C. Barus has shown that the indications afforded by thermo-junctions are trustworthy at very high temperatures, and he has enabled great confidence to be placed in the platinum platinum-iridium thermo-junction originally suggested by Tait. In its latest form the instrument consists of two wires, one of the metal and the other of the alloy mentioned above, simply twisted at their ends or "autogène," soldered by means of the oxyhydrogen flame, which method is much to be preferred, and connected with a dead-beat galvanometer of about 200 ohms resistance. The suspended coil galvanometer, particularly the later types of this instrument, is admirably adapted for use with this thermo-couple.

The deflections of the galvanometer may be converted into thermometric degrees by Tait's empirical formula,

$$E = A(T_1 - T_0) + B(T_1^2 - T_0^2),$$

in which E is the electro-motive force in terms of the absolute temperature T_1 and T_0 of the two elements of the couple. It is only necessary to introduce into this formula the values of E corresponding to two fixed points, in order to determine the coefficients A and B, and to construct a table of ordinary temperatures corresponding to each millimetre of the scale. Le Chatelier, however, showed that the second term of the equation

[1] *Comptes Rendus*, vol. iii. (1836), p. 782.
[2] *Bull. Soc. Chim. Paris*, vol. xlvii. (1887), p. 2; *Journ. de Physique*, vol. vi. (1887), p. 23.

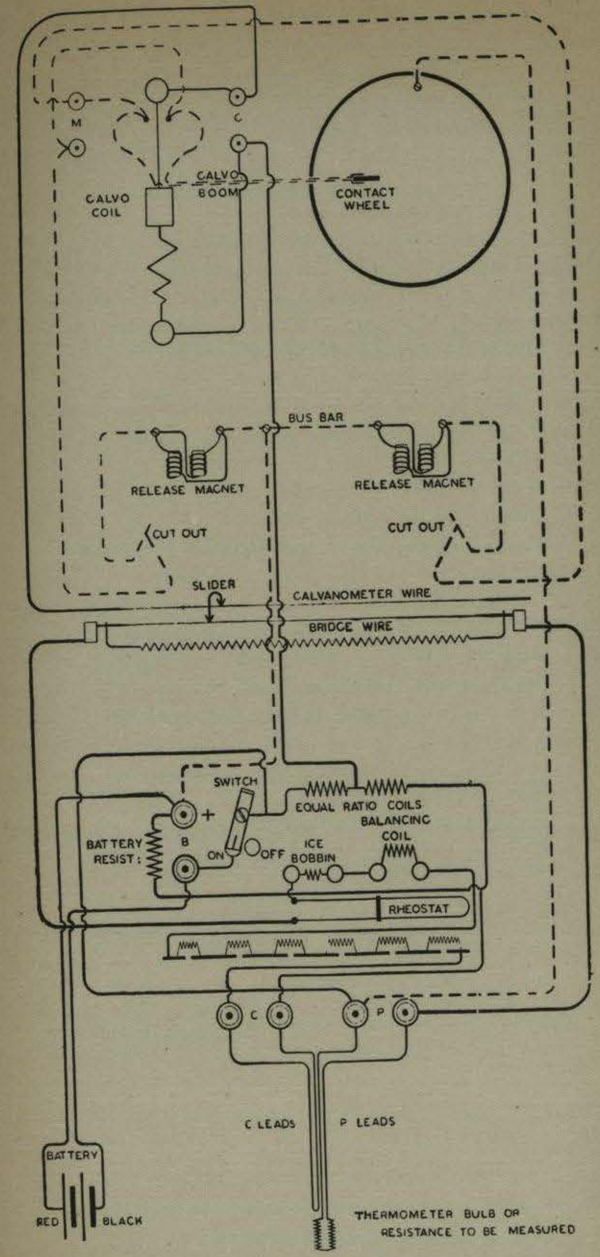


FIG. 68.

C Terminals for "C" leads. P Terminals for "P" leads.

(a parabola) ceased to be of importance with the platinum platinum-rhodium couple for high temperatures, and that between 300° and 1200° the equation becomes approximately that of a straight line,

$$E = a + bt,$$

in which E is the electro-motive force, t the observed temperature, and a and b numerical coefficients.[1]

One important feature is the small space occupied by the thermo-junction, which may be suitably protected, and inserted into the midst of a very small mass of metal. The pyrometer is calibrated by exposing the thermo-junction to certain known temperatures, such as the solidifying points of salts or metals. There is no difficulty in recognising the melting or the solidifying point; for, as the mass passes from the solid to the fluid state, the temperature remains constant for a brief period, the duration of which depends on the amount of material operated upon, and its latent heat of fusion; the result being that the spot of light from the galvanometer will be arrested, and the position on the scale, at which it stops, marks the temperature to be determined. Increased sensitiveness in this method of detecting and recording molecular changes has been obtained[2] by arranging that a portion of the current of the thermo-couple is balanced by an opposing electro-motive force from a Clark's cell.

The electro-motive force produced by heating the thermo-junction to any given temperature is measured by the movement of the spot of light on the scale, and, as has been above indicated, the scale is calibrated by heating the thermo-junction in contact with substances of known melting-points.

The following list gives a sufficient number of such fixed points, which have been established by concurrent evidence of various kinds:—

100° Centigrade . . .	Boiling-point of water.
232 ,, . . .	Melting-point of tin.
327 ,, . . .	,, ,, lead.
419 ,, . . .	,, ,, zinc.
445 ,, . . .	Boiling-point of sulphur.
657 ,, . . .	Melting-point of aluminium.
860 ,, . . .	,, ,, sodium sulphate.
1084 ,, . . .	,, ,, copper.

They rest mainly, however, on determinations made with the air thermometer.

Some years ago Carnelly[3] determined the melting-points of certain substances by the method of mixtures, and used them,

[1] For a further development of this formula, see Osmond, *Transformations du Fer et du Carbone* (Paris, 1888), p. 16.

[2] Alloys Research Committee, *Inst. Mech. Eng.*, 4th Report.

[3] *Journ. Chem. Soc.*, vol. xxxiii. (1878), pp. 273, 281; vol. xlv. (1884), p. 237.

when enclosed in capillary tubes of glass, to ascertain at what temperatures substances of unknown melting-points actually fuse. Le Chatelier[1] has since tested, with the aid of his thermo-couple, the accuracy of Carnelly's experiments, and has obtained in many cases very concordant results, as is shown in the following table:—

TABLE OF MELTING-POINTS.

	Le Chatelier.	Carnelly.
Potassium chloride . .	740°	734°
Sodium ,, . .	775	772
Calcium ,, . .	755	719
Barium ,, . .	847	772
Tin ($SnCl_2$) ,, . .	840	812
Sodium carbonate . . .	810	814
Barium ,, . . .	795	
Potassium ,, . . .	885	834
Sodium sulphate . . .	867	861
Barium nitrate . . .	592	
Potassium sulphate . .	1015	
,, bichromate . .	975	
Sodium phosphate. . .	957	
Potassium chlorate . .	370	359
Cuprous sulphide . .	1100	
Pure white pig-iron . .	1135	
Grey pig-iron . . .	1240	
Grey forge pig-iron . .	1220	

The details of the method to be adopted in using a *thermo-electric pyrometer* will vary according to the nature of the investigation to be undertaken.

In the first place, the choice of couple will depend on the range of temperature required to be covered during the observation, and as a general rule it may be taken that copper-constantan couples may be used for temperatures up to 500° C., giving a very open scale; platinum platinum-iridium couples may be used for temperatures up to 1400° C., as these give a more open scale than platinum-rhodium couples, and finally platinum platinum-rhodium couples should be used if it is required to go up to 1600° C.

When accurate measurements are required, it is necessary to introduce a cold-junction, that is to say, arrangements are made to keep the junction of the pyrometer wires and the galvanometer leads at a constant or known temperature; for this purpose they are enclosed in a bottle containing cold water, and the temperature noted by means of a thermometer; or kept in an ice box, temperature 0°, or in a steam box, temperature 100°.

[1] *Bull. Soc. Chim. Paris*, vol. xlvii. (1887), p. 300.

For this book three types of investigation may be considered, viz. (1) The simple melting-points of alloys; (2) A continuous record of furnace temperatures; and (3) The thermal changes which take place during the cooling of a piece of steel.

1. For determining the freezing-points of alloys, a couple consisting of platinum and platinum-iridium, containing 10 per cent. iridium, may be used. The wires composing the couple are insulated their whole length by threading them through double-drilled fireclay tubes, and the couple end is placed in a clay, silica, or hard glass tube closed at one end. Care must be taken that the wires do not touch except at the junction. The free ends of the pyrometer wires are connected with copper leads which pass to the galvanometer, including in the circuit a suitable resistance to get the correct range of movement on the scale for the temperatures required. As already mentioned,

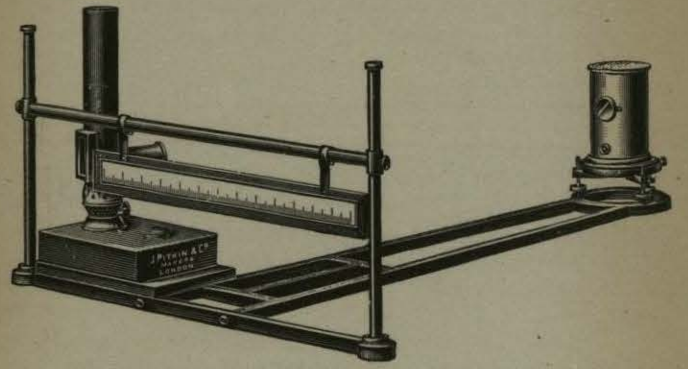


FIG. 69.

the connection between the platinum wires and the copper leads should be kept at a constant temperature.

Fig. 69 shows a suitable stand, including galvanometer, lamp, and scale, for taking the readings, made by Messrs Pitkin.

The couple is first calibrated by taking several readings from metals of known freezing-points, and these are plotted into a curve, having as co-ordinates scale readings and temperatures. Then this curve is used for interpreting the result of scale readings obtained from materials of unknown freezing-points.

There are several kinds of curves obtained by this method, the most important being *time-temperature* and *inverse-rate* curves. For the former, the position of the ray of light is taken at regular intervals of time and plotted with the time, and for the latter the time required for the ray of light to pass regular intervals or divisions on the scale is taken and plotted with the temperature.

2. For taking a continuous record of furnace temperatures,

etc., either a photographic or autographic method is most suitable.

The photographic recorder which was devised by the author[1] may be described as consisting of two mahogany cases, fig. 70, impervious to light, the larger of which (A) contains a Holden-d'Arsonval dead-beat galvanometer, with a suitable arrangement of lenses and mirrors. The other case (B) contains a drum which is made to revolve by clockwork once in 24, 12, or 6 hours. A ray of light, either from a gas jet or from an electric lamp, is thrown, by means of a mirror placed at an angle of 45°, on to the mirror of the galvanometer, and is projected thence to the surface of the drum, acting photographically on the sensitised paper. The galvanometer is connected by copper leads to a

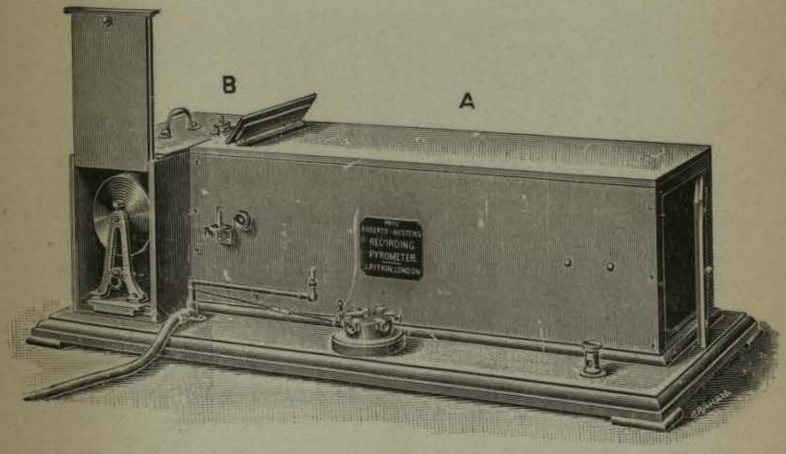


FIG. 70.

thermo-junction inserted in the space or object, the temperature of which it is desired to record. Another form of this apparatus (also made by Messrs Pitkin) is often used in which the revolving drum is replaced by a dark slide containing a photographic plate, and which is made to move vertically by clockwork. It must be understood that this form of instrument can equally well be used for recording freezing-points of alloys and thermal changes of metals: the movement of the ray of light varying with the temperature, and the position of the drum varying with time, gives a record which can readily be interpreted.

As an example of the autographic method of recording temperatures, mention may be made of the Patent Thread Recorder of the Cambridge Scientific Instrument Co., of which a

[1] *Journ. Iron and Steel Inst.*, ii., 1892, 33.