As has been already stated, the great differences of intensity which have to be measured occasionally render it necessary to absorb some of the rays from the object or from the standard lamp, as the case may be. This is done by inserting neutral-tinted glasses in suitable holders, either at E or F. Let N′ be the linear measurement of the aperture when the luminous object, shaded by a neutral-tinted glass, is matched with the standard lamp, and let N be a similar measurement when the same object is unshaded.

Then the coefficient of absorption of the glass K will be given by the equation

$$\mathrm{K} = \left(\frac{\mathrm{N}'}{\mathrm{N}}\right)^2;$$

and when p thicknesses of the neutral glass are before the object, whilst the standard glass is left unshaded,

$$\mathrm{I} = \left(\frac{n'}{n}\right)^2 \left(\frac{f}{f'}\right)^2 \left(\frac{1}{\mathrm{K}}\right)^p.$$

On the other hand, for measuring very low temperatures, when the standard lamp is shaded by p thicknesses of glass, and there are no glasses before the diaphragm, the formula becomes

$$\mathrm{I} = \left(\frac{n'}{n}\right)^2 \left(\frac{f}{f'}\right)^2 \mathrm{K}^p,$$

the index p being required because each glass cuts off a fraction of the light received by it.

Experiments indicate that the change in intensity of the red rays from a body of temperature T is approximately given by the equation

$$\mathrm{I} = 10^{6 \cdot 7}\mathrm{T}^{-\frac{3210}{\mathrm{T}}},$$

where T is reckoned from absolute zero, so that $\mathrm{T} = (t^\circ \mathrm{C} + 273)$, t being the actual reading of the thermometer. This formula has been used to calculate the numbers given in the following table—

Temperature. Centigrade.	Intensity of Red Rays.
600°	0·00008
800	0·0046
1000	0·078
1200	0·64
1400	3·35
1600	12·9
1800	39·0
2000	93·0

—the unit intensity being that of the axial zone of the flame of a standard candle.

In one instrument, where n' (the reading obtained with a candle flame as a luminous object) was 5·2, and $\frac{1}{\mathrm{K}}$ had the value $\frac{1}{25}$, the following figures were obtained by Prof. Le Chatelier:—

Temperature.	One Glass before Standard Lamp.	No Neutral Glasses.	One Glass before Diaphragm.	Two Glasses before Diaphragm.
Centigrade.				
700°	39·5			
800	15·2			
900	7·4			
1000	3·8	19·2		
1100	...	10·8		
1200	...	6·7		
1300	...	4·2	21·2	
1400	...	2·7	13·8	
1500	...	...	10·1	
1600	...	...	7·4	
1700	...	...	5·6	
1800	...	...	4·3	21·5
1900	...	...	...	17·0
2000	...	...	...	13·8

But, inasmuch as the emissive power of different bodies for red rays is not the same under like conditions as to temperature, it will be doubtless preferable to calibrate the instrument directly by comparing it with a little mass of platinum, or of iron, which can be maintained at known temperatures as measured by a thermo-couple.

The Féry *absorption* pyrometer, which is an improved form of the optical pyrometer of Le Chatelier, has been found extremely useful for measuring the temperature of very hot but small bodies. It consists essentially of a telescope D B, fig. 82, which carries a small comparison-lamp E, attached laterally. The image of the flame of this lamp is projected on a mirror F at 45°, placed at the principal focus of the telescope; the mirror is only silvered over a narrow vertical strip $a\,b$, fig. 82A. The telescope is focussed on the object the temperature of which it is desired to measure, this object being viewed on either side of the silvered strip. A pair of absorbing-glass wedges C and C_1 are placed in front of the objective of the telescope, and these wedges are moved laterally by means of a micrometer screw until the light from the object under observation is made photometrically equal to that emitted by the standard lamp E. An auxiliary dark glass D is also fitted, to enable the instrument to work over a higher range of temperature. A table is necessary in order to convert the readings obtained by the scale into degrees Centigrade or Fahrenheit. Fig. 82A shows the telescope focussed on a small crucible, the narrow vertical silvered strip *a b* being clearly shown.

The Wanner Optical Pyrometer[1] depends for its success on the law determining the relationship of the rays of light to the heat emitted by an incandescent body, as enunciated by Wien and Planck. Thus, for the quantity of light radiated from a hot body, it is possible to gauge the temperature. The light under observation enters through a slit and, after traversing lenses and a prism, forms a spectrum from which, by means of a diaphragm, a small region in the red is cut off for use. The intensity is measured by polarisation. A small electric, incandescent, 6-volt lamp is attached to that end of the apparatus which is directed towards the light under observation, and the light from this is also admitted to the apparatus, and utilised for the purpose of comparison with the intensity to be measured. On looking through the apparatus, the circular field of vision is seen to be divided into two halves, one of which is illuminated by the little electric light, and the other half by the light of the body under observation, the coloration being red. By inserting a rotating eyepiece containing a Nicol prism, the intensity of the two halves of the field of vision is easily equalised. The angle of rotation is measured on a circular scale, and by reading the angle, the temperature corresponding to it is found in the table which

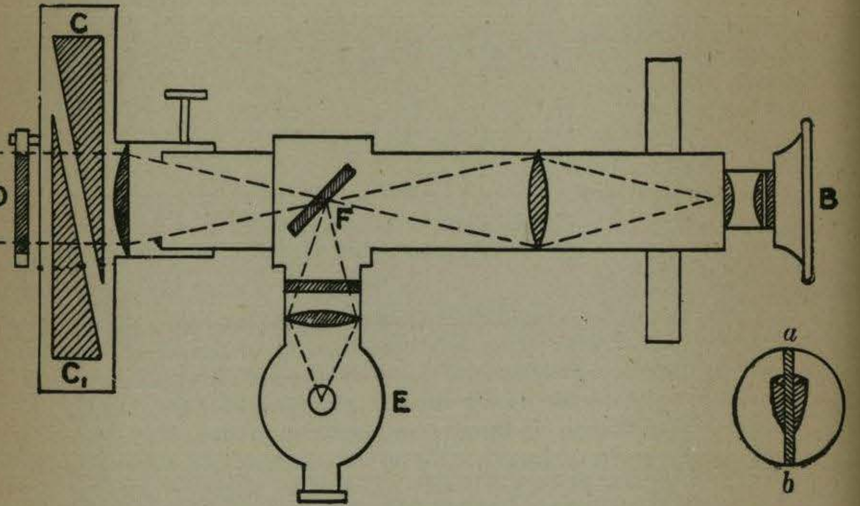

FIG. 82.—Diagrammatic Arrangement of Féry Absorption Pyrometer.

FIG. 82A.

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[1] This account is taken from the description prepared by Dr A. Weiskopf (Hanover), *Journ. Iron and Steel Inst.*, 1904, i. p. 140.

accompanies every instrument. The method merely consists in comparing the rays of a known temperature emitted by the electric lamp with the rays of an unknown temperature, and the operation is extremely simple. The apparatus is made in the form of a telescope, and the distance from the object, the temperature of which is to be measured, is of little importance, provided the field of vision is fairly filled by the light. It is essential that the standard electric light should always have the same temperature, and to avoid discrepancies it is occasionally standardised against an amyl-acetate flame.

On comparing the intensity of a certain colour apart from considering the changes of colour of a glowing body at rising temperatures, that is to say, a small section of the spectrum, it is found that with increasing temperature the strength of the rays increases very considerably. For example, if one shuts out of the spectrum all the light from a glowing body, with the exception of the narrow portion corresponding to the Frauenhofer line C, and if one assumes the intensity of this red light when at the temperature of 1000° C. to be equal to 1, by the time the temperature reaches 1200° C. the intensity is 10 times greater; at 1800° C. 804 times greater, and at 2000° C. 2134 times greater. If I represents the intensity of the rays observed, T the absolute temperature, λ the wave-length of the portion of the spectrum used, c_1 and c_2 two constants, and e the base of the natural logarithm, the following is the equation which connects the values—

$$I=\frac{c_1}{\lambda^5}\cdot e^{-\frac{c_2}{\lambda T}}.$$

This is Wien's formula, but it is subject to a certain limitation, inasmuch as it only applies to so-called absolutely dark bodies. An absolutely dark body absorbs all light which falls on it, and the nearest approximation to a theoretically dark body is soot. Bright platinum reflects much light and absorbs little, and is therefore the antithesis of the dark body. Iron in the incandescent state scarcely reflects at all, consequently it closely approximates to the properties of the dark bodies. According to Kirchhoff, a theoretically dark body is a hollow space entirely surrounded by walls which are impervious to heat and perfect reflectors. The same effect would be obtained if, instead of the walls being reflecting, they were of the same constant temperature as the hollow space. By making a small aperture in the wall, the radiation is not altered in a measureable degree; it remains, in fact, absolutely dark. It will be readily seen from this that in all closed furnaces the necessary conditions are fulfilled, and in almost every case of a glowing solid or liquid body the law may be taken as correct, since, even when the body is at first not theoretically dark, it approximates more and more to the dark state as it grows hotter, so that the difference is practically negligible. The determination of the temperature of colourless flames cannot be effected by the optical pyrometer, for the reason that the radiation of the flame differs so greatly from the radiation of a dark body that the law of Wien is no longer applicable. Nevertheless it is possible to ascertain the temperature of the Bessemer converter from the light radiated by the escaping gases.

It is, of course, impossible to express the intensity of light scientifically in any given measure, for the reason that no such measure exists. Consequently it is only possible to compare two intensities with one another. If the standard of comparison be I_0 and the corresponding absolute temperature T_0, then, from equation given above,

$$I_0 = \frac{c_1}{\lambda^5} \cdot e^{-\frac{c_2}{\lambda T_0}}$$

and

$$\frac{I}{I_0} = e^{-\frac{c_2}{\lambda}\left(\frac{1}{T} - \frac{1}{T_0}\right)}.$$

If I_0 and T_0 are known in this equation, that is, the standards for measurement, and also I and c_2, then T alone remains unknown and can be calculated.

The construction of the optical portion of the pyrometer is illustrated in fig. 83.

At S_1 are two slits *a* and *b* placed vertically one above the other; O_1 is a lens fixed at a point equal to its focal distance from S_1 which makes the rays parallel. K is a direct vision prism. Every beam passing through *a* and *b* is dispersed by the spar polariser W into two polarised parts perpendicular to one another. Z is a double prism by which the rays on either side are deviated towards the axis.

The rays are collected by the lens O_2 which forms images of *a* and *b* directly in front of the slit S_2 (the ocular slit), two images of each appearing, owing to the ordinary and extraordinary rays. The dimensions of the prism Z are so contrived that an image of *a* (the ordinary rays) and one of *b* (the extraordinary rays) coincide exactly before the slit. It is evident that to form the image of *a* in front of the slit S_2 only the upper half of the prism Z can come into play, while the image of *b* can in like manner only be produced by the lower half. Both images are, however, polarised vertically to each other, and the eye behind S_2 therefore views the upper half of Z illuminated by *a* and the lower half illuminated by *b*. By means of the revolving Nicol prism N, either one or other of the images can be intensified or weakened.

The spectroscope is thus composed of the parts S_1, O_1, O_2, and K, while the photometer consists of the parts W, Z, and N.

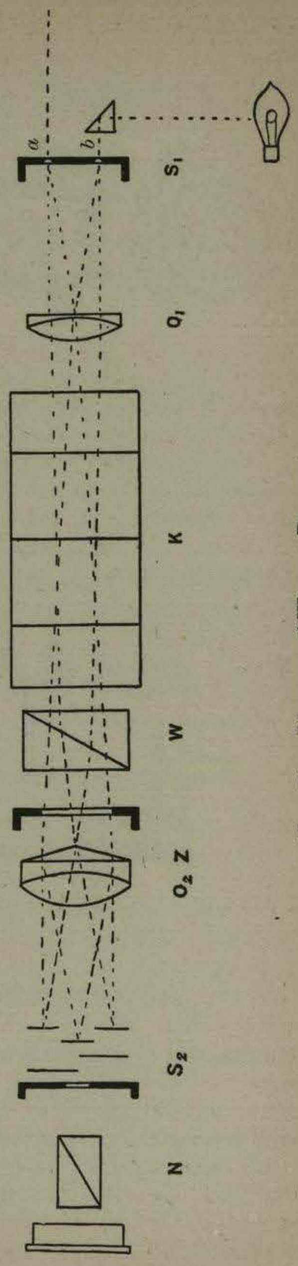

FIG. 83.—Diagram of Wanner Pyrometer.

The method of reducing the two fields of light from the hot body to be measured and the standard electric light respectively is first to polarise them in planes at right angles to each other, and then the intensity of each can be varied by viewing through a Nicol's prism which can be rotated. This angular rotation of the "Nicol" is then a measure of the intensity of the light, and therefore of the temperature.

There is another optical instrument, the pyrometer devised by Messrs Nouel and Mesuré, and used by the author for some years in the laboratory of the Royal School of Mines. It consists of a quartz plate A (fig. 84) placed between two Nicol prisms, an arrangement that renders it possible to suppress at will the radiations of any particular part of the spectrum by simply rotating one of the Nicol prisms. If a hot body be observed through the instrument, and the prism be rotated by means of the divided head B, the red colour of the body will be seen to change to yellow, then to green, and finally to blue. The angle of rotation necessary to extinguish the red colour varies with the temperature, and serves as a measure of it; but the difficulty of remembering the precise tint by which the instrument was calibrated prevents a high degree of accuracy from being attained in its use.

The Féry *radiation* pyrometer has been found very useful for measuring very high temperatures, as the whole of the instrument is placed outside the high temperature, and it is well known how difficult it is to find a material with which to construct a pyrometer to be maintained for prolonged periods at high temperatures without suffering changes in its physical properties.

A further difficulty is introduced by the chemical activities of furnace products and furnace gases, which in many cases render difficult the adequate protection of the resistance wire or thermo-couple. In use, the Féry pyrometer is placed at some distance from the furnace, and no part of it is raised above 90–100° C.

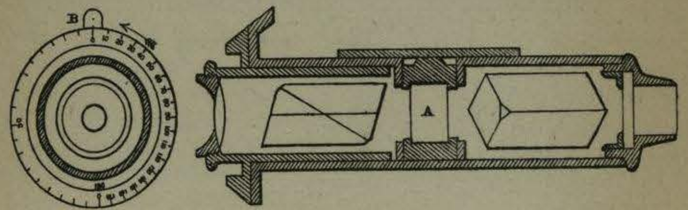

FIG. 84.

In this pyrometer, the radiation which emanates from a hot body, or which passes out through an observation hole in the wall of a furnace, falls upon a concave mirror, and is thus brought to a focus. In this focus is placed a thermo-couple whose temperature is raised by the radiation falling upon it; the hotter the furnace, the greater being the rise of temperature of the couple.

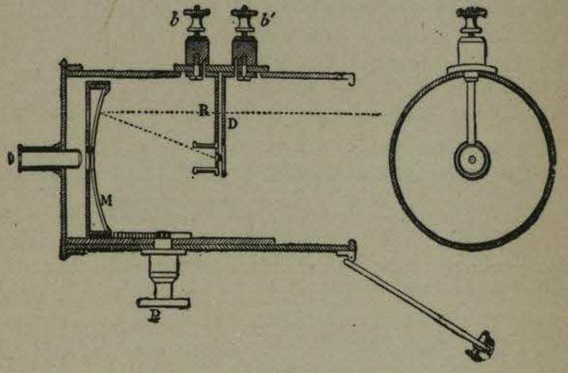

FIG. 85.—Féry Radiation Pyrometer Telescope.

The complete instrument consists of a telescope and a galvanometer, arranged for direct reading or for photographic or autographic recording. The telescope (fig. 85) has fixed within it, at a point upon its optic axis, a copper-constantan thermo-couple, arranged in the form of a cross. The two wires are attached to two brass strips D and R, which are attached to the terminals *b b′*.

These terminals are connected by leads to the galvanometer.

When used for measuring the temperature of a furnace, an observation hole in the wall of the furnace is sighted through the eyepiece O, the image of this hole being brought into coincidence with the thermo-junction.

It is necessary that the image of the observation hole should slightly overlap the junction which appears to the eye as a black disc in the centre of the field of view. The readings of the instrument are then independent of the size of the observation hole. The image of the hole is reflected to the eyepiece O by two mirrors placed close to the couple. These mirrors serve for the adjustment of focus; they are so arranged that the image of the hole appears to be split into two parts, which only coincide when the focussing is correct. The image thus formed upon the junction produces a rise of temperature which has been shown experimentally to be proportional to the amount of radiant energy which enters the telescope. The junction acquires exactly and with great rapidity the temperature of the image. The electromotive force which is thus generated is measured by the ordinary methods, and the Thread Recorder (p. 178) is very largely used in connection with this pyrometer for recording the temperature of furnaces, etc. Temperatures as low as 600° can be read, but the instrument is most useful for high temperature work.

The graduation of the galvanometer scales, either direct-reading or recording, is based upon the *Stefan-Boltzmann radiation law* which expresses the relation between the temperature of a body and the amount of radiant energy which it emits. The law is as follows: "The radiant energy emitted by a black body is proportional to the fourth power of the absolute temperature of the body," or

$$E = K(T^4 - T_0^4),$$

where E is the total energy radiated by the body at absolute temperature T to surroundings at absolute temperature T_0, and K is a constant depending on the units used.

This law has received abundant experimental support throughout the widest range within which temperature measurements can be made.

As indicating the precision to be attained with the Féry Pyrometer over the range of temperatures independently controllable with a thermo-couple pyrometer, some data obtained by M. Féry, and reproduced by Messrs Waidner and Burgess in Bulletin No. 2 of the Bureau of Standards, Washington, U.S.A., may be given. In the investigation referred to, the Stefan-Boltzmann Law was assumed to hold in the form

$$CE = d = 7{\cdot}66T^4 \times 10^{-12},$$

where E is the total energy of radiation, d the galvanometer deflection, T the absolute temperature, and C a constant.

d.	Temperature from Thermo-couple.	Temperature from Stefan's Law.	Δ in Degrees.	Error in Percentage.
11·0	844°	860°	+16°	1·85
14·0	914	925	+11	·84
17·7	990	990	0	·0
21·5	1054	1060	+ 6	·60
26·0	1120	1120	0	·0
32·2	1192	1190	− 2	·17
38·7	1260	1250	−10	·80
45·7	1328	1320	− 8	·60
52·5	1385	1380	− 5	·36
62·2	1458	1450	− 8	·50

If the galvanometer used with the pyrometer has a uniformly graduated scale and the temperature T_1, corresponding to any one scale reading R_1, is known, that for any other reading R_2 may be found from the relation

$$T_2 = T_1 \sqrt[4]{\frac{R_2}{R_1}}.$$

It is here assumed that T_0^4 is negligible in comparison with T_1^4 or T_2^4, T_0 being here the absolute temperature of the thermo-junction at the focus of the telescope.

For very high temperatures a diaphragm is placed in front of the receiving mirror (see fig. 86) to reduce the radiation falling upon it. The radiation in the two cases is proportional to the areas of the respective apertures.

By altering the aperture of the diaphragm and converting the galvanometer readings by means of the formula given above, temperatures far beyond the scale on the galvanometer can be deduced.

The Stefan-Boltzmann Law is strictly true only of "perfectly black" bodies; bodies, that is, which absorb all the radiation falling upon them, and are destitute of reflecting power. Some bodies conform so nearly to this definition that no appreciable error is introduced by treating them as perfectly black, and by taking their true temperatures to be given by the readings of a Féry pyrometer, sighted and focussed upon them. Such substances are coal, carbon, and those metals which, on being heated, become coated with a black oxide; for example, iron and copper.

But a far larger class of *effectively black* bodies is furnished by enclosed furnaces, muffles, combustion chambers, and the like. When the interior of such a furnace or chamber is at nearly the same temperature throughout, and when the observation hole is only of moderate dimensions compared with the distance behind it of the nearest furnace wall or solid body, the radiation issuing through the hole is independent of the quality of the radiating surfaces, and is the same as if those surfaces were perfectly black.

Flames interposed between the observation hole and the solids behind, provided they are at the same temperature as the furnace, will not alter the case in the least. But even when their temperature differs from that of the furnace, such flames are too transparent to absorb or emit any perceptible radiation, so that in practice no error arises from this cause. When the pyrometer is sighted upon a body which is neither black nor the effectively black interior of a furnace, the temperature directly read off from the scale of the galvanometer will be *lower* than the true temperature of the body This uncorrected reading is called the *black-body temperature* of the body observed, and the greater the reflecting power of the body, the more widely does the black-body temperature differ from the true temperature. As an example it may be mentioned that if the "black-body temperatures" of carbon and platinum are equal, their actual temperatures may differ considerably (180° C. or so, at 1500° C.).

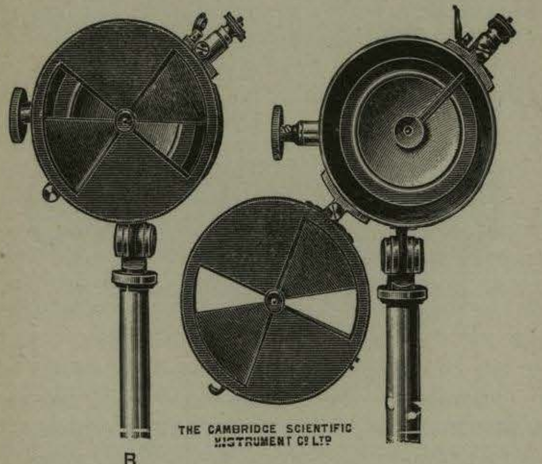

FIG. 86.—Féry Radiation Pyrometer, showing Diaphragm for reducing Aperture of Telescope.

Transparency of the observed body would further tend to increase the discrepancy, but in any practical case the thickness of the body in the line of sight would be sufficient to ensure opacity, so that the error thus arising would not be perceptible.

In practice, if the true temperature be required instead of the black-body temperature, it will be necessary to apply corrections, based on independent investigation, the data being in some cases already available. On the other hand, *for any given substance with its surface in a specified condition, the black-body temperature serves just as certainly and definitely as the true temperature to define the thermal state.* It is precisely this certainty and definiteness which is of paramount importance in industrial operations, and in a very large number of cases black-body temperatures will be found the most convenient for specifying the thermal conditions under which a process is to be carried out.

The temperature readings, within limits, are independent of distance, and this is a point which may need further explanation. If it is supposed that the pyrometer is sighted upon a hot body of limited dimensions, the total amount of radiation reaching the aperture of the mirror will vary with the distance from the hot body, and will be inversely proportional to the square of the distance. If, then, the receptive surface of the thermo-junction were sufficiently extended to receive the whole of the radiation which is converged to a focus by the mirror, it might be expected that the indications of the galvanometer would fall off as the distance was increased. The thermo-junction, however, is not large enough to receive the whole of the radiation which converges towards it. The real image of the source, formed by the mirror, overlaps the thermo-junction on all sides (fig. 87, a), so that when the source is approached more nearly, thus increasing the size of the image produced, the only effect is to increase the amount of overlapping, while the thermo-junction receives no more radiation than before (fig. 87, b). On the other hand, if the pyrometer is withdrawn to so great a distance that the image formed is too small to cover the thermo-junction completely (fig. 87, c), the readings obtained will be too low, and will become lower and lower as the pyrometer is withdrawn further and further from the source of heat.

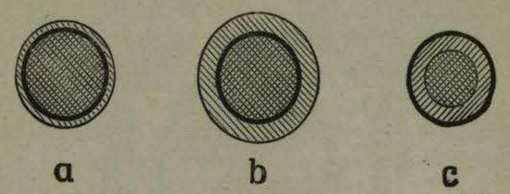

Fig. 87.

From the above it will also be readily understood that when working at any given distance from a hot body, it is necessary for the body in question to be of sufficient size, otherwise the image of the body would be too small to overlap the thermo-junction on all sides. But provided the hot body is large enough to secure the necessary overlapping, no further increase in its dimensions will add to the amount of radiation actually received by the thermo-junction. The diameter of the hot body (or furnace aperture) should measure as many inches as the distance from hot body to pyrometer measures yards, or, in other words, the aperture should measure in diameter about one-fortieth of the distance the pyrometer is away from the hot body.

General Considerations.

The accurate measurement of high temperatures is increasing in interest, in view of the rapid development of the study of chemical dynamics. It is now recognised that the industrial chemist, as well as the engineer, has to deal with the influence of mass. Many chemical processes are reciprocating, so that the original product may be obtained from the product of the reaction. The result of such opposed processes is a state of chemical equilibrium, in which the original and the newly formed substances are present in definite quantities, and remain the same so long as the conditions, more especially those of temperature and pressure, do not undergo further change. In conducting many operations, temperature and pressure are reciprocal factors; hence the importance of being able to measure with accuracy a bright red heat. Now, as Prof. Le Chatelier has already pointed out, in the production of chlorine by the Deacon process, or in the baking of porcelain, a variation of temperature of only 20° may be attended with complete failure of the operation. There is, however, one other case of more direct interest to the engineer in relation to steel. It involves the consideration of the possibility of the occurrence, at high temperatures, of molecular changes in steel, which profoundly modify its mechanical properties, in a way that was indicated on p. 144. It is difficult to describe briefly the nature of this change, but the following statement may be sufficient.

When a mass of steel is cooled from a very bright red heat, say from 1200° Centigrade, to the ordinary temperature of the atmosphere, at least three critical points, each attended by an evolution of heat, may be detected by the pyrometric methods already indicated; and their position may be determined very precisely by the aid of the differential method already described and illustrated. The development of the theory of the importance of these critical points is mainly due to Osmond,[1] who has fixed the normal temperatures at which they occur during the slow cooling of a mass of steel in which the notation of Chernoff and of Osmond has been retained.

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[1] See Report by the Author to the Alloys Research Committee of the Institution of Mechanical Engineers, *Proceedings*, No. 5, 1891, p. 543, and *Nature*, vol. xli., 1889, pp. 11, 32, where references are given to Osmond's papers.

The author has already stated his belief that these changes are of great importance in modifying the structure, and consequently the mechanical properties, of steel; he shared this opinion with the late Sir W. Anderson, formerly Director-General of Ordnance Factories, who instituted, at Woolwich Arsenal, some interesting experiments bearing on the question. The initial temperature of the mass, and its rate of cooling, are not without influence on the temperatures at which these critical points occur. For instance, in hardening large pieces of steel, such as the "A" tubes of guns, it may happen that, when the mass is plunged into the oil bath, a portion of the metal may be at a temperature below that at which the molecular transformations occur. It is, moreover, only necessary for the temperature of different parts of the mass to vary within a narrow range, in order that the bath may exert different influences on adjacent parts of the steel. This is a matter of great importance; and M. Barba of the Creusot Works began its study in 1880, but abandoned the attempt for want of sufficiently exact and practical methods of measuring high temperatures. The author attacked the problem in 1891, and published the results of the only experiment which had then been made. For the purpose of conducting it, Sir W. Anderson caused an ingot of steel to be prepared, 8 inches high and 4 inches in diameter. It contained carbon 0·799, silicon 0·084, manganese 0·412. A Le Chatelier thermo-junction was placed in a hole drilled to the centre of the mass, and another thermo-junction was fixed in a hole drilled near the surface. The mass was heated to bright redness, the external junction indicating 1100° Centigrade, each thermo-junction being in turn switched into connection with a recording apparatus, and dotted curves representing the cooling of the exterior and at the interior of the mass were thus obtained. The cooling was effected by plunging the mass into water. The effect of rapid cooling on the surface was, of course, to contract it and to compress the mass, the pressure being very marked in the zone of the ingot in which the external thermo-junction was inserted. The result appeared to be a lowering of the critical point (which should have occurred at about 690° Centigrade) to a little over 400° Centigrade.

It would therefore appear that the great problems of chemical equilibrium are applicable to the relations between the constituents of the complex material, steel; and that the pressure exerted on the molecules of a metallic mass must be measured, as well as its temperature, in investigating the molecular grouping of metals, upon which their mechanical properties depend.

It may now be well to indicate very briefly some other directions in which the measurement of high temperatures may be useful. The spent gases from boiler furnaces are often hotter than 400°, and their temperature should, in many cases, be accurately known. In researches on heat engines, complex problems arise demanding a knowledge of temperatures of about 500°. Foundry practice presents numerous cases, as, for instance, casting guns by the Rodman system; in conducting which it is most important, as Prof. H. M. Howe has pointed out, to be able to measure and control the rate of cooling of the core of the gun, as compared with its outside. By this means it is possible to avoid setting up prejudicial stresses, and to promote the development of useful ones in castings of all kinds. Addy has appealed to the importance of pyrometry in connection with experiments on armour-piercing projectiles; and it will be evident that the use of projectiles and explosives is a branch of engineering fertile in problems, the solution of which must, in a great measure, be based on pyrometry.

The gradual introduction of new alloys is changing the methods of investigation which must precede and govern the use of materials in construction. It may be thought that work of the kind indicated here is not sufficiently practical to deserve the attention of either the metallurgist or the engineer. If fears of this kind should arise, the author would recall the eloquent words addressed by the Director-General of Ordnance Factories to such doubters, who, he says, "can never have been placed in positions of responsibility, where the safety of ships, the lives of their passengers and crews, the efficiency of armaments, and their own financial position were in question; they can never have looked at masses of steel with the view of deciding whether they were fitted for the purpose for which they had been produced; nor can they ever have felt the helplessness, and the want of reasonably secure guidance, which it is still the lot of the responsible judge to experience." The guidance for which Sir W. Anderson appealed can only be afforded by employing to the fullest extent the methods, as well as the results, of physical and metallurgical research.

Since the above was written, the industrial application of pyrometry has extended in almost all branches of our technical industry, and the accurate and systematic determination of temperatures to enable the scientific control of the various operations is in many works a part of the daily routine. In the Royal Gun Factory, Woolwich,[1] a very elaborate pyrometric installation has been fitted, in which the following branches are wired up to, and are under pyrometric control from, the metallurgical laboratory — the heavy forges, including heating and reheating furnaces; the oil-hardening and tempering branches, including various furnaces and baths; the case-hardening shop, the drop forging shop, the lead bath (specimen treatment plant), and the gas muffles throughout the department, used by toolsmiths and other craftsmen. The various sections of the gun department are also in direct telephonic communication with the

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[1] Lambert, *Journ. Iron and Steel Inst.*, 1908, No. 1, pp. 109–136.

metallurgical laboratory, and this is found to be a great aid to the use of the pyrometric plant.

In bicycle and motor-car works, where large quantities of special steels are used which require most careful thermal treatment, the value, and even necessity, of pyrometric control is not overlooked, and most of these works are fitted with a more or less efficient plant, wired up to the various departments.

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