only one experiment was made at this temperature, too much reliance must not be placed upon the result, which might be due to accidental causes.

Steel containing ·5 to ·6 per cent. Carbon in small rolled sections appeared to be in its toughest and strongest condition after being heated to from 700° to 800° C., followed by either slow or rapid cooling. The larger rolled bars of this steel seemed to require the same treatment as the 1½-inch bars.

The forged bars required heating to a slightly lower temperature than the rolled bars in order to obtain the best results. The steel containing between ·6 and ·7 per cent. of Carbon in small rolled sections possessed the greatest ductility and resistance to sudden shock, as determined by bend tests, after being heated to from 600° to 700° C. The 4-inch rolled bars of this steel gave the best drop-test results at about 720° C. The rate of cooling apparently did not very much influence the results.

This steel in the forged bars of 6 inches diameter gave the best result under the falling weight test after being heated to 700° to 760° C., and followed by either rapid or slow cooling. Heating this grade of steel in large bars to temperatures of over 850° C. produced brittleness, which was very marked when the temperature exceeded 900° C.

The following table shows the heat treatment which gave the best results with each steel :—

TABLE XCIX.

Size of Bar.	Steel containing Carbon.	Temperature giving best results.	Rate of Cooling.	Remarks.
Inches.	Per cent.	°C.		
1½	0·200	650-850	fairly rapid.	Heating to 500° to 600° C. develops brittleness. Very slow cooling deleterious.
4	,,	700-800	,,	Ditto, but very much less pronounced.
6	,,	800-850	,,	Heated to 500° to 600° C. great brittleness develops very easily.
1½	0·350	650-800	,,	......
4	,,	700-800	,,	Brittle if heated to 900° C. and above.
6	,,	700-760	slow or rapid.	......
1½	0·550	700-800	,,	Rate of cooling, practically no effect.
4	,,	,,	,,	,, ,,
6	,,	600-760	,,	,, ,,
1½	0·650	600-700	,,	,, ,,
4	,,	about 720	,,	,, ,,
6	,,	700-760	,,	,, ,,

The actual temperature employed for annealing in works varies very considerably, and it is only comparatively recently that exact records of temperatures have been taken; so far as it has been possible to obtain information the best practice seems to be to anneal at about 750° to 850°, which confirms generally the results obtained by experiments on a small scale. Howe* says the best results are obtained by annealing steels with ·12 to 1 per cent. of Carbon at a bright cherry-red, which may be taken as under 900° C., probably not far from 850° C. Campbell carried out experiments on annealing at a dull yellow heat, which is probably about 900° or from that to

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* *Metallurgy of Steel*, p. 25.

1,000° C. The great difficulty in annealing on a commercial scale is the equable heating of large masses of material, and if not conducted with great care it is liable to do more harm than good. Thus, in annealing plates or bars, when a furnace is full, those on the outside are sure to be heated to a higher temperature than those in the centre of the pile, and consequently different results are obtained on heating the same class of material in the same furnace. The latest experimental work having shown that heating for a very short time and rapid cooling is all that is required, may do something to facilitate the annealing of large quantities of material, as, instead of heating very slowly and allowing to remain for a considerable time, it appears to be necessary only to pass the materials rapidly through a furnace, allowing them just time to be heated through and to acquire the full temperature of the furnace. The question of ensuring regular cooling presents also many difficulties, as to get the best results this should be fairly rapid without any local chilling, such as is produced by contact with cold plates, etc.—conditions not easy to carry out in dealing with hundreds of tons of material a day. These difficulties are so well recognised that for most structural steel it is considered safer to take material as it leaves the rolls rather than have it annealed, as, owing to the great difficulties of carrying out the operation on a large scale, there is often considerable risk of damaging rather than improving the steel.

These remarks do not apply to large forgings or castings, which are frequently annealed by themselves in a furnace to which a great deal of personal attention can be given to ensure good results.

The oil quenching results of Brinell and Wahlberg seem broadly to confirm those obtained in ordinary practice, so far as results are available. The usual practice for oil quenching for guns, axles, and similar steels is to heat to a temperature varying from 750° to 850°, most usually about 800°, quench in oil at 20° C., and afterwards reheat to about 550° to 650° C. Some manufacturers never reheat above 350° C., and others go as high as 650°, but a very common temperature is 550°. The oil quenching is done in a large tank or well, generally sunk in the ground, into which the steel is lowered immediately it is withdrawn from the furnace and allowed to remain until practically cold. It is then withdrawn and reheated. The oil tank is sometimes surrounded with a water jacket to cool it down as rapidly as possible. Brinell and Wahlberg's best results, or at all events results as good as any, both in tensile and impact experiments, seem to have been obtained by quenching from 850° C. and reheating to 550°, and owing to the smallness of the bars and consequent rapid cooling this would probably be equivalent to quenching from about 800° C. in the case of large masses of steel.

The following are some results obtained by Bunt* with oil tempered mild steel forgings made in the ordinary course of manufacture. The forgings were made from acid Siemens ingots, weighing about 15 tons each, which were forged down in a hydraulic press to square bars of approximately one-fourth of the sectional area of the ingot. They were then rough-bored and turned, heated to a temperature of 700° to 800° C., plunged in oil, and, when cold, returned to the furnace and annealed at a temperature of about 500° C.

The test pieces, which were of the British Government standard size, were sawn from the full sized ends of the forgings—which were left a little long for that purpose—and, when possible, they were cut across the fibre.

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* *Engineering*, June 13, 1902, p. 794.

TABLE C.—TEN STEEL FORGINGS, POOR QUALITY.

TENSILE STRENGTH IN TONS PER SQUARE INCH AND ELONGATION PER CENT. ON 2 INCHES.

No.	Untempered.			Oil Tempered and Annealed.		
	Tons.	Elongation.	Fracture.	Tons.	Elongation.	Fracture.
1, . . .	29·56	21·09	Fair granular	39·31	26·43	Good.
2, . . .	32·57	23·44	Good.	35·75	24·21	Very good.
3, . . .	29·00	23·44	Bad.	35·39	24·21	Good.
4, . . .	31·78	21·09	Good.	38·34	23·43	,,
5, . . .	31·98	23·43	Fair.	39·91	24·21	,,
6, . . .	32·16	21·09	,,	37·89	26·56	Very good.
7, . . .	31·53	19·53	Bad.	41·04	20·31	Good.
8, . . .	28·93	23·43	,,	39·50	25·78	Very good.
9, . . .	31·50	19·53	,,	37·80	23·43	Fair.
10, . . .	31·50	20·70	,,	38·80	23·84	Very good.
Averages, .	31·05	21·67		38 37	23·93	

TABLE CI.—TEN STEEL FORGINGS, BEST QUALITY.

TENSILE STRENGTH IN TONS PER SQUARE INCH AND ELONGATION PER CENT. ON 2 INCHES.

No.	Untempered.			Oil Tempered and Annealed.		
	Tons.	Elongation.	Fracture.	Tons.	Elongation.	Fracture.
11, . . .	29·98	29·18	Good	37·80	27·34	Very good.
12, . . .	29·86	31·25	,,	39·58	23·43	Fair to good.
13, . . .	29·71	31·25	Very good.	39·51	22·65	Good.
14, . . .	28·55	30·46	Fair.	39·92	22·26	,,
15, . . .	29·61	28·90	Fair to good.	41·65	22·65	,,
16, . . .	28·55	30·46	Fair.	39·92	22·26	,,
17, . . .	29·73	32·81	Good.	37·71	25·78	,,
18, . . .	28·65	28·90	Fair.	39·32	25·78	Very good.
19, . . .	29·75	33·59	Very good.	41·74	22·65	Good.
20, . . .	28·84	31·25	,,	37·69	27·34	Very good.
Averages, .	29·32	30 80		39·48	24·16	

The average tensile strength and elongation of 200 forgings were as follows:—

Untempered: 32·01 tons per sq. in. with 27·34 per cent. elongation in 2 ins.

Tempered and annealed· 39·91 tons per sq. in. with 23·24 per cent. elongation in 2 ins.

This gives an increase in the tensile strength by oil tempering of 7·9 tons per square inch, or over 24 per cent. There is a decrease in the elongation, but it is still good. The bending tests were satisfactory, and the fractures were fine grained. The results given in Table c. were selected from the worst of the forgings, while those given in Table ci. were selected from the best.

Unfortunately the elastic limit was not taken for the above samples, but from a number of experiments made on similar steels it was found to be increased about 50 per cent., or from 14·5 tons to 22·5 tons per square inch.

The results, as given in Table ci., show an average increase in the tensile strength when oil tempered of 10·16 tons per square inch, or about 35 per cent. The elongations are still good, and taken with the bending tests show that the steel is very ductile.

An important paper by Messrs. Stead and Arthur W. Richards has been read before the Iron and Steel Institute * "On the Restoration of Dangerously Crystalline Steel by Heat Treatment." They conducted a series of experiments on steels varying from ·05 to ·46 of Carbon by first rendering them crystalline and brittle by heating to a temperature of about 1,260° C., and afterwards restoring the mechanical properties by heating for about 40 minutes at a temperature between 850° and 900° C. The steel in the condition as rolled, after overheating, and after restoring, was tested for tensile stress; for impact by a falling weight, by Brinell's compression test; and by a vibration test, by subjecting the specimens to rapidly alternating stress in a machine similar to that employed by Wohler. In every case the mechanical tests applied showed that the material after restoration was quite equal to, and in most cases superior to, what it was in its normal state as it left the rolls.

The microscopic examination showed that the heating of the bars to 1,260° C. caused a great development in the size of the grain, and the reheating to 870° restored the original or a better structure. It is not claimed that steel which has been "burnt" or heated to the point of near fusion, when a separation of the crystals occur, can be restored by the above treatment, but only steels which have been rendered crystalline by continued heating at a high temperature such as is liable to occur in everyday practice, even when the greatest care is exercised.

The above experiments are of special importance, as, with one or two exceptions, they were not carried out on small samples, but either on finished rails or on 5-inch blooms, so that the mechanical tests were such as engineers rely upon in everyday practice.

That steel, containing different percentages of Carbon, which has been rendered dangerously brittle by overheating, can be restored to the *best possible condition by a simple reheating to* 870° *without forging down to a smaller size*, is a fact of the greatest importance both to engineers and metallurgists, and shows what great possibilities there are of improving the mechanical properties of steel by submitting it to suitable heat treatment.

From the above results it would appear that by subjecting large forgings to a *final* heat treatment suitable to the special class of steel, it is possible to remove any dangerous crystallisation caused by overheating, as well as the internal stresses caused by forging, and to so produce a material in the best possible condition to resist varied and suddenly applied stresses.

These experiments emphasise the great importance of carefully controlling and regulating the temperature of the reheating of large masses of steel by means of a pyrometer, and confirm the conclusions of other investigators that the best results generally are obtained by heating for a short time to a temperature between 800° and 900° C.

Pyrometers.—One of the difficulties connected with the careful regulation of the temperatures of annealing and other furnaces, was formerly the lack of a pyrometer which would record over any required time the

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* *Iron and Steel Inst. Journ.*, 1903, vol. ii., p. 119.

variations in temperature, and so enable them to be controlled. Many forms of pyrometers have been introduced from time to time, but few have been suitable for taking the actual temperature of a piece of steel during heating, or have enabled the attendant to see how the temperature was varying by reference to a dial with scale of temperatures or some equally ready method. The Uehling pyrometer, which is now being used in various works, is more suitable for taking the temperature of a hot chamber than that of any particular steel casting or forging. The Callendar electric pyrometer, which is a modification of the original Siemens pyrometer, depends upon the alteration in the electric resistance which takes place in a Platinum wire with a change of temperature; it is a very reliable instrument, and may be used either with, or without, an automatic recorder. It consists of fine Platinum wire wound on a mica frame, and it is made by the Cambridge Scientific Instrument Company. It has a very wide range, and can be relied upon from very low temperatures up to 1,200° C., although it is better adapted for temperatures between 500° and 900° C. The Platinum resistance is encased in a tube, so that it can be conveniently inserted in the source of heat it is desired to determine, and, when connected with a Whipple Temperature Indicator, the temperature can be read off direct. This pyrometer can be used with the Callendar recorder if a permanent record of the variations in temperature is required, and a continuous record obtained without the use of photography. The pyrometers are standardised, and, in the event of a breakdown, a new one can be connected to the recorder without loss of time.

The pyrometer designed by M. Le Chatelier, depending upon the following facts, is the instrument which has been found generally the most suitable, as it can be easily manipulated and is extremely accurate. It is now being largely used in many works.

If, when two wires or strips of dissimilar metals are joined together at both ends, so as to make a complete circuit, one of these junctions be at a different temperature to the other, a difference of electric potential is set up at the junctions, and an electric current traverses the wires. Such a pair of wires is called a thermo-electric couple. If the wires are of uniform composition, the potential difference depends on the difference of temperature alone, and the strength of the current will vary directly as the difference of temperature. If a galvanometer be inserted in the circuit this current can be measured, and if the current corresponding to various differences of temperature be once ascertained, the apparatus can be used as a means of measuring temperature. The current obtained from a couple of iron and German silver is fairly strong, but it cannot be used for high temperatures. For temperatures approaching a red heat and upwards, the usual couple consists of a wire of pure Platinum, joined at one end to a wire of Platinum alloyed with 10 per cent. of Rhodium or Iridium. In works practice the galvanometer is usually situated at some distance from the source of heat the temperature of which is to be measured, necessitating the use of long wires. On account of the cost, the Platinum and Platinum-Rhodium or Platinum-Iridium wires cannot be used over the whole length, and copper leading wires are generally used to connect the couple with the galvanometer. This means the presence in the circuit of two extra thermo-couples—one Copper-Platinum, and the other Copper-Platinum-Rhodium, and unless care be taken to keep both of these at the same temperature, they will give rise to currents which will interfere with the current from the Platinum couple.

This difficulty can be overcome by placing the two copper junctions in a water jacket, which can be kept at a fairly constant temperature, which is registered by a thermometer, so that a correction can be made for this when noting the temperature to be measured. For ordinary work a wooden box, to protect the junction from radiated heat, and in which is enclosed a thermometer to register the temperature of the surrounding air is found sufficient.

To form the hot junction the ends of the Platinum and of the Rhodium-Platinum wires are fused together in the Oxyhydrogen blowpipe, and the two wires are then kept separate for the remainder of their length, by threading upon them small fireclay or porcelain tubes. Instead of using separate fireclay tubes for each wire, single tubes with two holes for the wires to pass through may be used, and are supplied for the purpose. By this means the wires are completely insulated from each other except at the junction, and all fear of their short circuiting by coming into contact is avoided.

If the porcelain tubes are in lengths of 2 or 3 inches it enables the couple to be bent so that it can be placed in any position. For most furnace purposes the entire couple may be enclosed in an iron or porcelain tube to protect it from the direct action of the flames. When it is required to take the temperature of molten metals, the ends of the hot junction must be protected by a porcelain tube or other suitable device.

Before the instrument can be used it has to be calibrated, and this is done by determining the deflections of the galvanometer needle or mirror for the known melting points of a number of bodies, by plotting the temperatures and deflections obtained as ordinates and abscissæ, and drawing a curve through the points of intersection. The deflection of the mirror is read in the usual way by the movement of a spot of light reflected from the galvanometer on to a millimetre scale. By this means, provided a reasonable number of observations are taken through the range of temperature required, the difference in temperature between the hot and the cold junctions may be read off from any given deflection. The calibrating operation may be conducted as follows:—The substance to be melted is placed in a small crucible, which in turn is placed in a larger pot, and the annular space between the crucibles packed with dry fireclay. The crucible is then placed in the furnace, and the metal or other substance melted. The couple, protected by a fireclay tube, is immersed in the liquid metal, and the whole allowed to cool slowly. When the solidifying point is reached, the spot of light instead of continuing to slowly move across the scale will remain stationary for some time, this arrest being due to the latent heat of fusion evolved on solidification. This is taken as the point corresponding to the melting point of the substance.* In this way a series of points is obtained, those most usually employed being:—

Boiling point of water, .	100° C.	Melting point of aluminium,	657° C.
Melting „ tin, . .	232° C.	„ „ silver, .	962° C.
„ „ lead, .	327° C.	„ „ gold, .	1,064° C.
Boiling „ sulphur, .	445° C.	„ „ copper,	1,084° C.

Before starting the determination of the melting points it is necessary to determine the zero of the instrument by bringing the hot and cold junctions close together, so that they acquire the same temperature, and noting the reading on the scale when the spot remains at rest. Metals, etc., of the greatest

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* Copper during fusion should be covered with a layer of charcoal, as otherwise the solidifying point will be 8° to 10° C. too low.

purity must be selected for calibrating purposes. The melting or boiling points of the above materials on the curve will correspond to the known temperature *minus* the temperature of the cold junction. Thus assuming the deflections for boiling water after deducting the deflections for zero of the instrument were 15 mm., and that the cold junction temperature was 20° C., 15 mm. would register a temperature of 100° – 20° C. = 80° C.; that is to say, the difference in temperature between the hot and the cold junctions would be 80° C., and correspond to 15 mm. deflections. In the same manner the other points would be determined, and by plotting these points as suggested and joining them up, a curve is obtained from which the temperature for any given deflection can be arrived at.

Sir William Roberts-Austen's well-known recording pyrometer is the Le Chatelier pyrometer to which is attached a revolving drum carrying a sensitive Bromide paper, or a rising and falling dark slide. carrying a photographic plate moving at right angles to the beam of light, so that the light leaves a permanent record in form of a curve, showing the variations in temperature over any given period up to twenty-four hours. The pyrometer in this form is extremely valuable for practical purposes, as the registering galvanometer and recorder can be placed out of danger in the office of the manager or other convenient position, and any sudden variations in temperature due to carelessness or neglect on the part of the workmen, or from other causes, are at once shown on examining the curve.

Fig. 260.

A much cheaper and very convenient form of portable recording pyrometer of the Le Chatelier type is made by Messrs. Baird & Tatlock, and, although not so extremely accurate as the instrument designed by Sir William Roberts-Austen, it is sufficiently sensitive for ordinary work. The galvanometer and recorder are contained in a small case about 20 inches long by 12 inches wide (fig. 260), and the whole can be carried about without affecting the calibration. The instrument is calibrated before being sent out, and the temperature can be read off direct from a scale attached, or, if desired, a permanent record for twenty-four hours can be obtained on sensitive paper. Fig. 261 shows a curve obtained in practice.

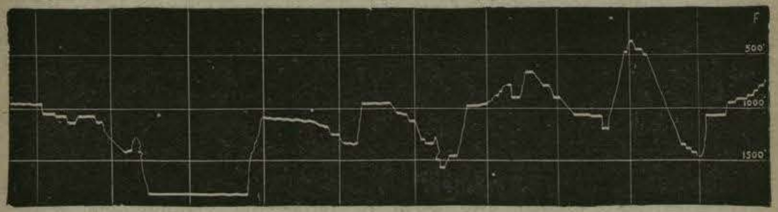

Fig. 261.—Photographic Curve from Baird & Tatlock Pyrometer.

Fig. 262 shows the iron tube containing the thermo-couple ready for inserting in the furnace, the cold junctions being protected from radiant heat by enclosure in a small wooden box as shown, with a thermometer attached for registering the temperature. In this sketch the tube is shown connected to a smaller form of registering instrument which is not provided with a photographic recorder. The wires forming the couple in the iron tube are insulated from each other by being drawn through small porcelain tubes.

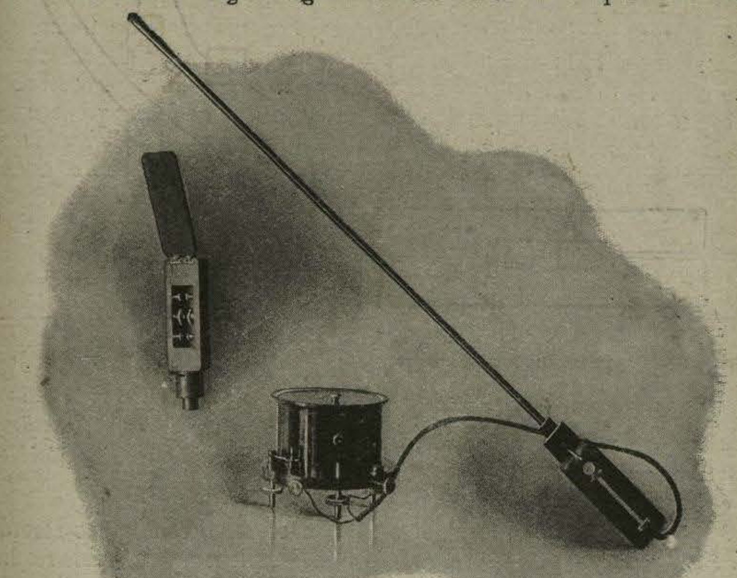

Fig. 262.—Iron Tube containing Platinum-Rhodium thermo-couple. Junction ready for use. Wooden box attached contains the cold thermo-couple. On the left of sketch the box is open, showing method of making connections.

The insulated wires running from the cold junction are copper, and may be connected to the recording instrument any reasonable distance away, as in the office or elsewhere. If a number of furnaces at different distances are connected up to one instrument, a compensating switch is introduced into the circuit to allow for variations caused by the different lengths of wire connecting the furnaces.

Various modifications of this form of instrument are now made by different makers, and a very ingenious recorder, known as the Thread recorder, which gives a permanent ink record on a revolving drum, is made by the Cambridge Scientific Instrument Company for use with this class of pyrometer.

In steel works, pyrometers are used for controlling the temperatures of furnaces, ovens, baths, flues, &c., and also for the thermal examination of the metal as a guide for practical heat treatment. For controlling furnace temperatures, &c., almost any form of indicating arrangement may be used either direct reading, scale reading, or some form of continuous recording instrument being employed, according to circumstances and exact nature of the work. For the thermal examination of steel, continuous recorders may be used or results may be obtained from simple lamp and scale readings using a mirror galvanometer, or the "differential" or "difference" method should be adopted.

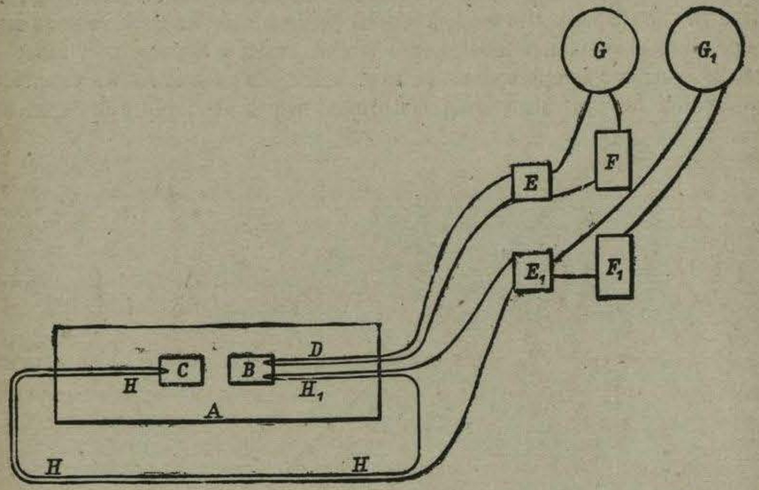

Fig. 263.—A, Electric furnace; B, Steel under examination; C, Neutral metal, Ni-steel, or Platinum; D, Thermo-couple for temperature; E E_1, Cold-junctions; F F_1, Resistance boxes; G, Galvanometer for temperature; H H_1, Compound thermo-couple; G_1, Differential galvanometer.

This 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 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 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 or absorbed during the critical changes.

Fig. 263 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 differences in temperature of the metal B under examination and the neutral metal C.

Many workers prefer some form of potentiometric method to the simple galvanometric method of taking readings as being more accurate. Stansfield's[*] method consists of compensating the greater part of the E.M.F., leaving a small part to be read on the scale in the usual manner. A large cell is used to produce the balancing E.M.F., and a sensitive galvanometer used for reading. The sensitiveness may be so arranged that the scale, some 60 cm. long, represents only 10° to 15°. When the spot of light reaches the end of the scale, the resistance of the potentiometer is altered, so reducing the balancing E.M.F., and bringing the spot back to the beginning of the scale.

In both the Resistance and the Thermo-electric pyrometers the resistance coil or the thermo-couple has to be placed in the source of heat it is desired to measure, until it acquires the same temperature, and in many cases, especially in the case of molten metals of very high melting points, this is impossible. A great advance in pyrometry has been made by Professor M. Féry, of the École de Physique et Chimie, by his invention of a Radiation pyrometer, by which the temperature of any hot bodies may be determined by an instrument placed entirely outside the source of heat. The radiations which emanate from a hot body are made to fall upon a concave mirror, and are thus brought to a focus. In this focus is a thermo-electric couple whose temperature is raised by the radiations falling upon it; the greater the tem-

[*] *Phil. Mag.*, 1898, vol. xlvi., p. 59.

perature of the body, the greater the amount of heat radiated, and the greater the rise in temperature of the couple.

The complete instrument consists of a telescope connected with a sensitive galvanometer; within the telescope, at a point upon its optical axis, is fixed the junction of a Copper-constantan thermo-couple, arranged in the form of a cross and connected by wires with terminals on the outside of the telescope (fig. 264). These terminals are connected by leads with a galvanometer, which may be provided with a temperature scale; or, if a permanent record is required, the Thread recorder may be used.

To measure the temperature of a furnace, an observation hole must be provided and sighted through the eye-piece of the telescope, the image of this hole being brought into coincidence with the thermo-junction; the image of the hole is reflected to the eye-piece by two mirrors placed close to the thermo-couple. These mirrors serve for the adjustment of the focus, and are so arranged that the image of the hole appears to be split into two parts, which only coincide when the focussing is correct. It is essential 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 image formed upon the thermo-junction produces a rise in temperature, which has been shown experimentally to be proportional to the amount of radiant energy which enters the telescope; the junction rapidly acquires the exact temperature of the image, and the electro-motive force thus generated is measured by a very sensitive galvanometer.

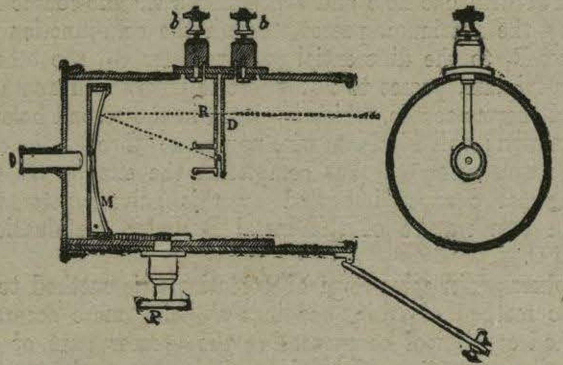

Fig. 264.—Féry Radiation Pyrometer Telescope—O, Eye-piece; D R, two brass strips attached to terminals, *b b′*; *b b′*, terminals for leads to galvanometer.

In order that the amount of radiation falling upon the thermo-couple may be varied, an adjustable diaphragm is fitted in front of the telescope, and, when measuring very high temperatures, the diaphragm partially covers the aperture of the telescope (fig. 265, B). Within very wide limits, the readings obtained with the instrument are uninfluenced either by the size of the hot body or the distance of the hot body from the instrument; the amount of radiant heat absorbed in passing through the atmosphere is so small, and, in measuring temperatures of from 1,000° to 1,200° C., it has been found experimentally that, whether the hot body was 3 feet or 60 feet from the instrument, there was no appreciable difference in the readings. To avoid any possible error, however, it is recommended that the diameter of the furnace opening, or the hot body, should measure as many inches as the distance between the source of heat and the instrument measures yards. The pyrometer is more sensitive at high temperatures than low, owing to the fact that the energy radiated from a hot body increases very rapidly with the rise in temperature, but temperatures as low as 600° C. can be measured.

The Uehling pyrometer before referred to is based upon a principle entirely different from those already described, and depends upon the flow of air through small apertures under a constant suction. A tube has an aperture of the same size at each end—one end is placed in the source of heat, and the other end cooled to a constant temperature and connected with a chamber, in which a constant suction pressure is maintained by a steam jet. As air expands with heat, the higher the temperature to which the air entering the hot end of the tube is raised, the smaller will be the quantity of air drawn through the aperture by a given suction, and, as the air is considerably cooled to a constant temperature before it reaches the aperture at the other end of the tube, a greater quantity of air will be drawn out of this aperture than is drawn in through the opening at the hot end, so that the suction will increase in the tube and decrease in the exhaust chamber. The suction being kept constant by a specially-designed regulator, the velocity of the air passing in through the hot end of the tube will increase, and the velocity of the air passing out through the cold end will decrease, until the same quantity of air flows through both. Therefore, every change of temperature in the air entering at the hot end of the tube will cause a corresponding change in the pressure in the tube, and by connecting monometers with the tube and with the exhaust chamber, the constant pressure in the exhaust chamber, and the variable pressure in the tube, can be registered, and this latter is a true measure of the temperature of the hot air entering, and can be read off

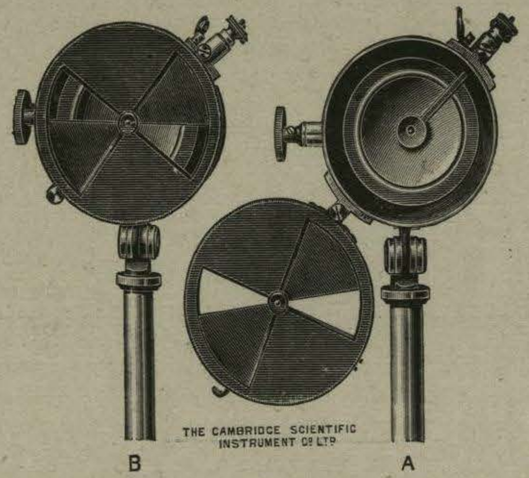

Fig. 265.—Féry Radiation Pyrometer, showing Diaphragm for Reducing Aperture of the Telescope.

direct from a scale attached. The details of the instrument as supplied commercially have been worked out with the greatest care and ingenuity, but space does not permit of a description of these, as this could be given only with a series of diagrams. Full particulars can, however, be obtained from Messrs. J. Wild & Co., Middlesbrough. One great advantage of the pyrometer is that it has an automatic recorder, seven hours of which are always in view, so that all variations for this period can be seen at a glance. It is especially adapted for recording the temperature of hot gases, or of large heated chambers, such as annealing furnaces, and a large number are in use both in Europe and in America.

CHAPTER XIX.

MICROSCOPICAL EXAMINATION OF STEEL.

THE study of the microstructure of steel originated with Dr. Sorby of Sheffield many years ago, but for a considerable time after the publication of his first paper little attention was given to this method of research in this country, although substantial progress was made in Germany by Professor Martens. It is only during the last twenty years or so that British metallurgists have given the subject serious consideration, but during that time it has been extensively studied and progress has been very rapid, so that now the microscopic examination of iron and steel alloys is not only largely carried out in all laboratories devoted to scientific research, but has become an essential part of the work of many of the chemical laboratories connected with our leading steel works.

Microscopic examination not only aids in the determination of the soundness of a steel and the detection of mechanical defects, but also throws much light on its internal constitution and the heat treatment to which it has been subjected, and it is in the latter relation that the greatest assistance may be anticipated from the use of the microscope.

The term "microscopic metallography" has been assigned to the method of microscopical examination of metals in general.

Preparation of Samples.—In order to examine the structure of metals microscopically it is necessary first of all to polish a small section until it is as free as possible from even the most minute scratches.

The details of the methods employed vary with different investigators, but in general principles they are alike, and consist of first filing the sample as dead true as possible, then grinding on an emery wheel, and polishing, either by hand or on revolving wheels covered with emery paper of different degrees of fineness, and finally buffing up on a cloth, kidskin, or similar disc with some fine polishing powder. The details of the methods used by Sorby, Osmond, Roberts-Austen, Arnold, Martens, Stead, Ewing and Rosenhain, Le Chatelier, and Sauveur respectively are given below, and it is most desirable that the student should try the different methods, and adopt the one which he finds gives the best results for the particular material with which he has to deal.

Sorby's Method.—Dr. Sorby used small slices, about $\frac{1}{10}$ of an inch (2·5 mm.) in thickness, and by filing, and grinding on an emery wheel obtained as true a surface as possible. The section was then fixed on a glass plate with a little Canada balsam and the surface further ground by rubbing backwards and forwards on, first coarse, and afterwards finer grades of emery paper fixed on a glass support. Before polishing, the surface of the sample was ground on fine-grained Water-of-Ayr stone, which removes all the scratches left by the emery. The final polishing was then effected by rubbing the sample with some crocus powder and afterwards with the finest levigated rouge on a wet cloth stretched over a flat piece of wood, which was kept moist by adding a few drops of water occasionally during the time of rubbing.

It sometimes happens that the sample contains some portions softer than others, and this method causes the surface to be worn away unequally. In