

than alumina, and by all methods of reduction this large percentage of silica must be separated from the alumina before the reduction is commenced, else a large percentage of energy used in reduction will be wasted.

The ore of aluminum most used is bauxite, which occurs in great abundance in Tennessee, Virginia, North and South Carolina, Georgia, Alabama, and Arkansas. The discovery of the mineral in the latter State is a comparatively recent development, having been announced by Dr. John C. Branner, State geologist, in the early part of 1891. These deposits cover an area of 640 acres in Saline and Pulaski Counties, and vary in thickness from a few feet to over 40 ft. Good bauxite used in the manufacture of aluminum is worth about \$10 per ton at Pittsburg.

Another ore generally used in the manufacture of aluminum by the electric processes of the present time is cryolite, which is imported from Evigtok, near Arkut, Greenland, that being the only country in which this mineral is mined. The Evigtok mine is worked as a quarry and has been opened 450 ft. long, 150 ft. wide, and 100 ft. deep, while diamond drills have penetrated 150 ft. deeper and found cryolite all the way. The mine is located close to the water's edge in Arkut Fjord. The cryolite imported from Greenland sells for 7 cents per lb. in New York in barrel lots. The only place in the United States where cryolite is known to exist is at Pike's Peak, Colo., but no workable deposits have yet been found there. Early in the past year it was reported that a large vein of the mineral had been found, and a 2 ton lot was actually shipped, but the results of the exploration did not, apparently, come up to expectations.

**Method of Winning.**—Aluminum is generally produced at the present time by one of the electric smelting methods, which have almost entirely superseded the old sodium process. During the past year the Aluminum Company, Limited, which had been operating large works at Oldbury, near Birmingham, England, with the Castner process, has been obliged to abandon the manufacture of aluminum on account of the competition of the electric processes, and is now devoting itself to the manufacture of sodium only. Of the electric processes there are now four, more or less similar, in use, viz., the Cowles, Hall, Heroult, and Minet.

The general method of purification of bauxite, preliminary to the reduction to aluminum, is to calcine it with just enough sodium carbonate to form sodium aluminate, the temperature being kept below the melting point, and the mass well stirred. The incinerated mass is ground, and leached with hot water, which dissolves the sodium aluminate and leaves behind the silica and iron. The solution of sodium aluminate is then filtered off and the alumina precipitated with carbonic acid gas, filtered, washed, and dried. The alumina is next dissolved in molten cryolite (fluoride of aluminum and sodium) in suitable pots and electrolyzed, the apparatus and the details of the operation varying with the different processes.

**Production.**—Aluminum was first made in any quantity in 1855, its value at that time being \$90 per pound; with improvements in the methods of manufacture the price was gradually reduced to \$4.86 (£1) in 1887, but the recent development of the industry dates only from 1889, when the Pittsburg Reduction Company placed aluminum made by the Hall process on the market at \$2 per pound. The Pittsburg Reduction Company commenced operations in November, 1888, the Cowles Electric Smelting and Aluminum Company being engaged at that time in the manufacture of aluminum alloys, but is now producing pure aluminum; these were the only companies producing pure aluminum in the United States in 1889, in which year the production amounted to 47,468 lb., valued at \$97,335. The total production of aluminum in the world from 1860 to 1889 inclusive is estimated by Mr. R. L. Packard, Special Agent of the Eleventh Census, at 232,000 lb.

PRODUCTION AND IMPORTS OF ALUMINUM IN THE UNITED STATES SINCE 1870.

Year.	Imports.		Year.	Production.		Imports.
	Amt. lb.	Value.		Amt. lb.	Value.	Amt. lb.
1870.....	.....	\$98'00	1881.....	.....	517'10	\$607'00
1871.....	.....	341'00	1882.....	.....	565'50	6495'00
1872.....	.....	.....	1883.....	1,000	\$875	426'25
1873.....	2'00	2'00	1884.....	1,800	1,350	594'00
1874.....	683'00	2125'00	1885.....	3,400	2,500	439'00
1875.....	434'00	1355'00	1886.....	.....	27,000	452'10
1876.....	139'00	1412'00	1887.....	.....	74,905	1260'00
1877.....	131'00	1551'00	1888.....	19,000	65,000	1348'53
1878.....	251'00	2978'00	1889.....	47,468	97,335	998'53
1879.....	284'44	3423'00	1890.....	*94,881	189,762	2051'00
1880.....	340'75	4042'00	1891.....	*163,820	163,820	+1625'05

\* Partly estimated. † Fiscal years.

The principal producers of aluminum in Europe at the present time are the Cowles Syndicate Company, Limited, and the Metal Reduction Syndicate, Limited, of England, using the Cowles and Hall processes respectively, and the *Aluminium Industrie Actien Gesellschaft*, of Laufen-Neuhausen, in Switzerland, which uses the Heroult process. In the United States are the Pittsburg Reduction Company, with works at Kensington, Pa., and the Cowles Electric Smelting and Aluminum Company, with works at Lockport, N. Y. The United States Aluminum Metal Company, which controls the Heroult patents in the United States, has a plant at Boonton, N. J., which was originally erected for demonstrating this process and has produced some metal, but has not been in regular operation. The Wilson Aluminum Company is now establishing works at Leakesville, N. C., for the application of a process invented by Thos. L. Wilson, and expects to be in operation early in the present year. Works are also being erected at St. Michel, Savoy, France, at which the Minet process will be used.

The production of aluminum and aluminum in alloys in the United States in 1890 was about 95,000 lb. In 1891 there has been a noticeable increase, and the total

output for the year may be set down as 163,820 lb. The Cowles works have run steadily throughout the year, but the Pittsburg works were idle from April to November, during which time the plant was removed from Pittsburg to Kensington, Pa., this change having been made necessary by the failure of natural gas in Pittsburg. The new works were put in operation on November 12.

**Uses.**—The demand for aluminum showed a great increase in 1891 over the preceding year, and from present indications this demand is likely to still further increase as new fields for the employment of the metal are constantly being found. At the present time aluminum is being largely used to replace German silver and high grade brass and for castings for very many purposes in light moving machinery and parts of apparatus where lightness is an important element. A large amount is also used in steel castings, aluminum now being regularly employed for this purpose in almost all the important steel foundries in the United States. It is the increase in demand from the foundry-men that has, perhaps, been the most marked during the past year. Pure aluminum is also making its way into a thousand and one uses that must eventually consume enormous quantities of it; as, for instance, canteens for soldiers, cartridge shells for smokeless powder, buckles and sword scabbards, and other military accoutrements; the German government having purchased a considerable quantity of metal in the United States during the autumn for this purpose; wire for telegraph and telephone purposes, harness trimmings, surgical instruments and household utensils, for all of which uses it has demonstrated its fitness in an unequivocal manner. "Aluminized zinc" (an alloy of aluminum and zinc) is being employed in brass making, affording sounder castings, increasing the strength, and giving a finer color to the brass. This "aluminized zinc" is also of advantage to the galvanizers. Aluminum bronze is coming into greater favor for wire and sheet purposes, and is now being successfully drawn and rolled by many mills which had heretofore pronounced it utterly impossible to either make it into sheets, wire or castings. Altogether there is promise that the year 1892 will surpass 1891 in the aluminum industry as 1891 has surpassed 1890.

**Price.**—The price of aluminum has been subject to great fluctuations during the year, owing to the competition and litigation between the Cowles Electric Smelting and Aluminum Company and the Pittsburg Reduction Company. At the beginning of the year the Pittsburg Company was offering the metal in lots over 1,000 lb. at \$2 per lb., and in lots over 100 lb. at \$2.50 per lb. The Cowles Company asked \$1 per lb. for aluminum contained in alloys. In January the latter company offered pure aluminum at \$1.25 per lb. In March the Pittsburg Company reduced its price to \$1 per lb. for commercially pure aluminum and 90c. per lb. for metal below 97 per cent. and above 90 per cent. fine; the Cowles Company followed with a similar reduction. In the next month, however, Judge Ricks, of the Northern District of Ohio, before whom the suit between the two companies was pending, ordered that the price of the metal should be fixed at \$1.50, or the price at which the Pittsburg Company was selling, and the Cowles Company obeyed the order, but immediately offered aluminum in alloys at 75c. per lb.

In the meanwhile the price of the metal abroad had fallen, having been sold by the *Aluminium Industrie Actien Gesellschaft*, the Aluminum Company, Limited, and the Metal Reduction Syndicate, Limited, at 81c. per lb. (for commercially pure aluminum in ton lots), while the Cowles Syndicate Company, Limited, was reported to have sold its metal in New York at 90c. per lb., a price which must have been equivalent to 73c. per lb. at the works in England. Later pure aluminum was said to have been sold in Germany at 68c. per lb.

On the first of August the price was further reduced in the United States to 50c. by the action of the Pittsburg Company, the Cowles Company following suit. This great reduction was simply a *ruse de guerre*, and probably a small amount of the metal only was disposed of at this figure. In the latter part of September the price was raised to 75c. per lb. in ton lots, and 90c. per lb. in small lots, at which figures it is now held. In November the Neuhausen Company reduced its price in Germany to 50c. to 60c. per lb.—*Eng. and Min. Jour.*

## RESEARCHES AS TO THE PROPERTIES OF ALLOYS.\*

By Prof. W. C. ROBERTS-AUSTEN, C.B., F.R.S.

AT the request of the Alloys Research Committee, I began in April, 1890, to investigate the effects of small admixtures of certain elements on the mechanical and physical properties of iron, copper, and lead. The committee desired me to extend an investigation I had previously made upon the application of the "periodic law" of Newlands and Mendeleef to the mechanical properties of metals. This law, as originally expressed, states that "the properties of the elements are a periodic function of their atomic weights." It had already been shown that the effect of impurities added to gold is nearly proportional to their atomic volume, the larger the volume of the atom the greater being its effect; † and it became interesting to determine whether this holds good for other metals.

The committee considered it desirable that iron should be the metal first examined; but the problem has fortunately been attacked by M. Osmond, ‡ the results of whose recent investigations have gone far to show that there are two distinct varieties of pure iron, the  $\alpha$ , or soft, and the  $\beta$ , or hard form; and further that the action of impurities on iron does appear to be in accordance with the periodic law. The foreign elements, whose influence on the critical points of iron he has studied experimentally with more or less completeness, are ranged as follows in two columns in the order

of their atomic volumes, found by dividing their atomic weight by their specific gravity:

I.	II.
Carbon..... 3.6	Chromium.... 7.7
Boron..... 4.1	Tungsten..... 9.6
Nickel..... 6.7	Silicon..... 11.2
Manganese..... 6.9	Arsenic..... 13.2
Copper..... 7.1	Phosphorus.... 13.5
	Sulphur..... 13.7

He points out that "the elements in column I., whose atomic volumes are smaller than that of iron (7.2), delay during cooling *ceteris paribus* the change of  $\beta$  or hard iron into  $\alpha$  or soft iron, as well as that of "hardening carbon" (*carbone de trempe*) into "carbide carbon" (*carbone de recuit*). For these two reasons they tend to increase, with equal rates of cooling, the proportion of  $\beta$  or hard iron that is present in the cooled iron or steel, and consequently the hardness of the metal. Indeed, their presence is equivalent to more or less energetic hardening produced by rapid cooling. On the other hand, elements whose atomic volumes are greater than that of iron (column II.) tend to raise, or at least to maintain near its normal position during cooling, the temperature at which the change of ( $\beta$ ) hard to ( $\alpha$ ) soft iron takes place. Further, they render the inverse change during heating more or less incomplete, and usually hasten the change of dissolved or "hardening carbon" to "carbide carbon."

Thus they maintain iron in the ( $\alpha$ ) soft state at high temperatures, and must therefore have the same effect in the cooled metal. In this way they would act on iron as annealing does, rendering it soft and malleable, did not their individual properties, or those of their compounds, mask this natural consequence of their presence. The essential part played by foreign elements alloyed with iron is therefore either to hasten or to delay the passage of iron during cooling to an allotropic state; and to render the change more or less incomplete, in one direction or the other, according to whether the atomic volume of the added impurity is greater or less than that of iron. In other words, foreign elements of low atomic volume tend to make iron itself assume or retain the particular molecular form which possesses the lowest atomic volume, while elements with large atomic volume produce the inverse effect.

It will be evident that, if iron itself can exist in two widely different states, each with properties of its own, the mechanical properties of given samples of iron and steel must depend upon the relative proportions of the two modifications of iron present in the mass. And it will also be evident that the nature of the influence of impurities on iron is far more complicated than in the case of gold, their primary effect on iron being either to hasten or to delay the passage of the metal from its normal state to another, which possesses widely different molecular aggregation, and consequently different properties. In the case of gold, it is possible that the molecular constitution of the precious metal is simpler than that of iron. Each molecule may consist of but few atoms, and therefore there may not be the same scope for pronounced change of properties which could follow rearrangement of atoms in the molecules. The action of an impurity may probably be more direct in the case of gold, as its influence is not initially exerted in rearranging the atoms in a molecule, but in affecting the mutual relations of the molecules themselves. Or it may be that the lowering of the freezing point, which is effected by the presence of impurity, may enable the cooling gold to assume a crystalline structure which is detrimental to its tenacity, if not destructive of it.

The difficulties of obtaining for mechanical tests masses of iron with only definite amounts of a single impurity are very great, and it is therefore very difficult to extend Osmond's research; but of the practical importance of his experiments there can be no question, and their full significance may become more apparent by investigating the action of impurities on some other metal, the behavior of which suggests strong probability that it can exist in an allotropic state. In view, however, of the importance of Osmond's research, it was considered desirable to confirm his main results, adopting an independent method of observation, as will be stated subsequently.

Lead, which is one of the metals the committee selected for investigation, probably exists in more than one modification. Muschenbroeck and afterward Guyton de Morveau\* showed that the cohesive force or tenacity of lead is increased by hammering or drawing; and the latter speaks quite clearly of molecular strain produced by the mechanical treatment. Bolley † has shown that "chemically active" lead may be prepared by electrolytic action; and W. Spring ‡ has gone far to show that the polymerization (or increase in the number of atoms in a molecule) of lead-tin alloys may take place at temperatures below their melting points. The observation made by Coriolis, § that lead increases in hardness by successive meltings, even if protected from oxidation, may not be without significance. I have made a great many experiments on the mechanical properties of lead as affected by a small quantity of impurity; but as yet it has not been found possible to obtain definite or even concordant results. The tenacity and extensibility of lead seem to be greatly influenced by the temperature at which the metal is cast, and the difficulty of avoiding the presence of flaws and blowholes is very great. This portion of the inquiry has therefore been set aside for the present, as it is probable that more valuable evidence of allotropic changes will be afforded by thermal than by mechanical measurements.

## PYROMETER.

In order to carry out the investigation a really trustworthy pyrometer is required. The admirable investigations of Callendar || with the pyrometer of Siemens have restored the confidence in it, which had been shaken by a report of a committee of the British Association. ¶ The action of this instrument depends on

\* *Annales de Chimie*, Vol. lxxi., 1809, pp. 189-199.

† Liebig und Kopp, *Jahresbuch*, 1849, p. 278.

‡ *Bulletin de l'Académie Royale de Belgique* [3], Vol. xi., No. 5, 1886.

§ *Annales de Chimie et de Physique*, Vol. xlv., 1830, p. 103.

|| *Philosophical Transactions of the Royal Society*, Vol. clxxviii., 1887, p. 161.

¶ Report of the British Association, 1874, p. 242.

\* Report to the Alloys Research Committee, British Institution of Mechanical Engineers.

† *Philosophical Transactions of the Royal Society*, Vol. 179, 1888, p. 339.

‡ *Comptes Rendus*, Vol. cx., 1890, p. 346. The results of his experiments are given in detail in the *Journal of the Iron and Steel Institute*, 1890, part 1, p. 38.

the variation of resistance presented by a heated platinum wire placed in one branch of a divided circuit, and it is trustworthy for temperatures up to 500° C. or 900° F. Messrs. Callendar and Smith\* have shown that with platinum resistance thermometers a degree of accuracy of the order of 0.01° C. or 0.02° F. may be attained at temperatures between 100° and 450° C. or 212° and 840° F.

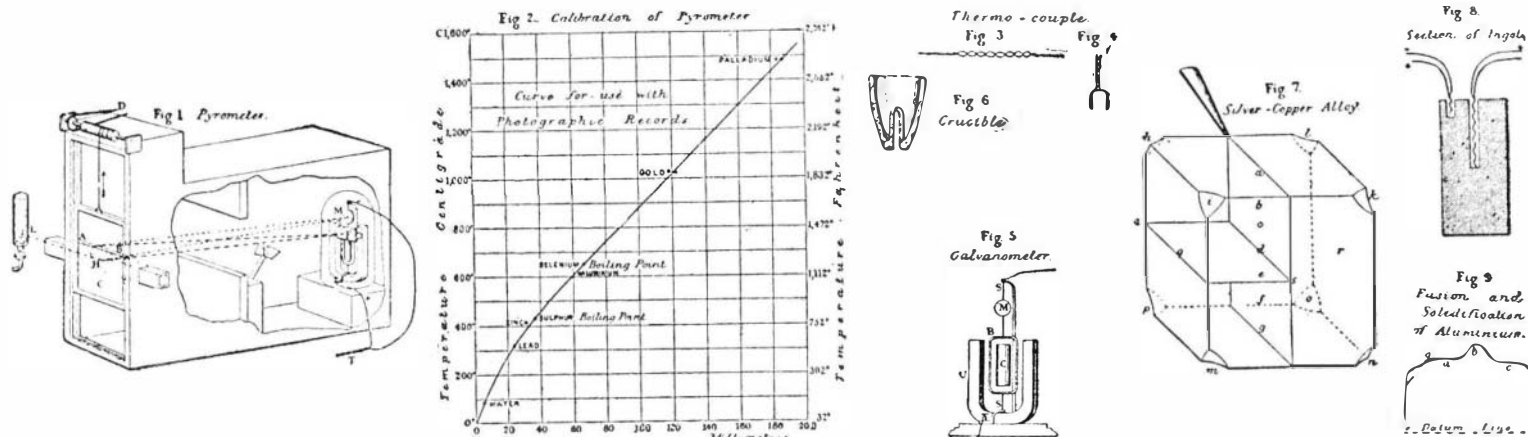
In the present investigation it is necessary to measure much higher temperatures; and fortunately an accurate method is at hand. Early in 1889 I had occasion to employ the pyrometer devised by Mr. H. Le Chatelier, and was satisfied as to its being extremely trustworthy and convenient up to temperatures over 1,000° C. or 1,800° F. The instrument, in fact, enabled me to confirm the fundamental observations of M. Osmond respecting the critical points of iron and steel, and to demonstrate the results in a lecture delivered before the members of the British Association in September, 1889.† Le Chatelier's pyrometer I believe had not previously been employed in this country, and it may be

employed in the following experiments\* has an internal resistance of 200 ohms. The arrangement of the several parts is shown in Fig. 5, in which U is a magnet, B a coil of wire suspended by a German silver wire, S S, and moving freely round an iron core, C, and M is a mirror carried by the same wire, S. The steadiness of the spot of light upon the screen when the circuit is closed is remarkable.

#### GRADUATION OF PYROMETER.

The electromotive force produced by heating the thermo-junction to any given temperature is measured by the movement of the spot of light on the scale graduated in millimeters. A formula for converting the divisions of the scale into thermometric degrees is given by M. Le Chatelier; but it is far better to calibrate the scale by heating the thermo-junction to temperatures which have been very carefully determined by the aid of the air thermometer, and then to plot the curve from the data so obtained. Many fusion and boiling points have been established by concurrent evidence

able source of intense heat is thus obtained; and a fused globule of gold or palladium may be tilted on to the junction conveniently placed in the cavity, and then allowed to cool there. The globule may, in fact, be melted on or shaken off the junction as readily as a drop of wax; and the slight arrests of the spot of light, which mark the true points of fusion and solidification, can readily be detected by a practiced observer. It has already been shown by M. Le Chatelier that soldering the junction with gold in no way diminishes its sensitiveness; and this appears to be true of palladium. The wires, however, after brief exposure to the alloying metals at this very high temperature, rapidly become destroyed and broken. In some cases, as in that of determining the melting point of potassium sulphate, the thermo-junction may be plunged without covering into the midst of the mass, which is gradually being raised to its fusion point. In the case of a metal, the thermo-junction may either be surrounded by a portion of the metal or a strip or globule of the metal may be placed in a crucible filled with some substance difficult



well to describe it in some detail, as such an instrument has long been needed, and can hardly fail to be of much use to engineers. The pyrometer† consists of a thermo-couple of platinum and platinum containing ten per cent. of rhodium.

Thermo-couples have long been used; but as is pointed out by Barus§ in an elaborate memoir only recently published, the earlier investigators unfortunately employed unsuitable metals, iron and palladium, which, from the readiness with which they absorb gases and consequently undergo molecular change, are of all metals probably the least suited for thermo-electric pyrometry. Osmond's work alone would show that iron is specially unsuitable for high temperature thermo-couples. Le Chatelier's pyrometer is based on the measurement of the electric current produced by heating a thermo-junction inserted in a circuit with a galvanometer of considerable resistance. As already stated, this thermo-couple consists of two wires, each about 0.5 mm. or 0.02 inch diameter, one of which is of pure platinum and the other of platinum containing 10 per cent. of rhodium. The junction of the wires may simply be effected by twisting them together in either of the forms indicated by the sketches, Fig. 3 or Fig. 4. The junction may be welded, or soldered with gold, no flux being used; but neither of these methods seems to possess any advantage over a double twist. The junction may be viewed as a battery; for when it is heated a current of electricity is generated, no other source of electricity being employed. It is asserted that even long wires of the platinum-rhodium alloy are homogeneous, and therefore do not give rise to subsidiary currents, which would disturb the effect of the main current produced by heating the junction; but very careful experiments to determine whether this is the case have yet to be made. From analogy with platinum-gold alloys, it may be doubted whether the platinum-rhodium alloy is of absolutely uniform composition. The thermo-electric properties of platinum-rhodium wire are said to be hardly altered by stress, or by exposure to rapid alternations of temperature; nor

of various kinds, and are now very generally accepted. The following table contains certain of these:

Deg. F.	Deg. C.	
212	100	Boiling point of water.
618	326	Melting point of lead.
676	358	Boiling point of mercury.
779	415	Melting point of zinc.
838	448	Boiling point of sulphur.
1,157	625	Melting point of aluminum.
1,229	665	Boiling point of selenium.
1,733	945	Melting point of silver.
1,859	1,015	" " potassium sulphate.
1,913	1,045	" " gold.
1,929	1,054	" " copper.
2,732	1,500	" " palladium.
3,227	1,775	" " platinum.

The known temperatures employed for calibrating the thermo-junction referred to in this report are the boiling point of water 100° C., the melting points of lead 326°, zinc 415°, and aluminum 625°, the boiling points of sulphur 448°, and selenium 665°, and the melting point of potassium sulphate 1,015°. The melting point of silver, 945°, is one of the points which rests on more evidence than any other. I find, however, that when it is carefully determined and interpolated in the curve, the number is only 920° C.; this is doubtless owing to retention of gas by the metal. The melting point of gold, 1,045° C., and Violle's‡ determination of that of palladium, 1,500°, are generally accepted. These several fixed temperatures have been used as the basis of the calibration.

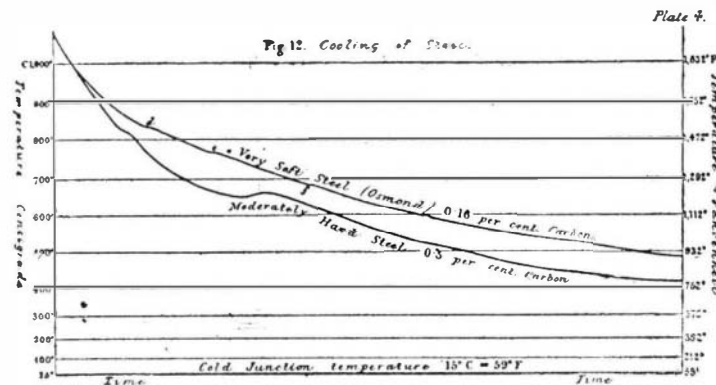
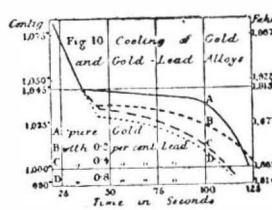
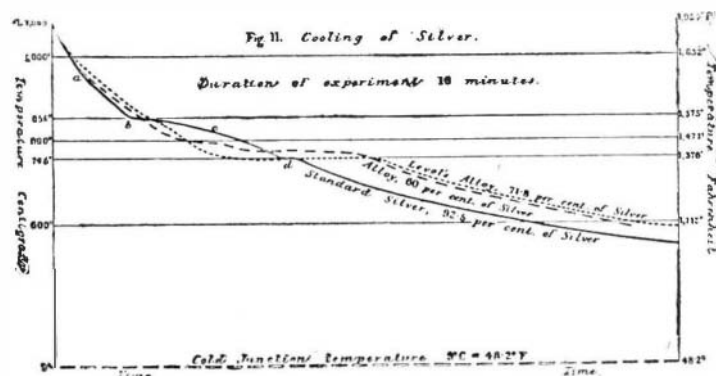
In Fig. 2 these temperatures are taken as ordinates, while the abscissae are the deviations of the spot of light which marks the temperature at the thermo-junction.

It will be evident, since these points fall so close to an even curve, that much confidence may be placed in the trustworthy nature of the pyrometer. It may be noted

of fusion—silica or calcined magnesia—in close proximity to the thermo-junction. The temperature is very gradually and steadily raised, until the metal begins to fuse. A Fletcher oxygen furnace answers well. The moment at which fusion begins is indicated by an arrest in the movement of the spot of light, followed, if the mass of metal be small, by a rapid forward movement when the fusion is complete. The point that the spot of light has attained on the graduated scale at the moment of its arrest is the point to note as the melting point of the metal. A little practice will enable this point to be readily determined; but all uncertainty in the matter is removed by reducing the spot of light to a fine vertical line and securing a photographic record of its movement.

The following plan may therefore be recommended when a high degree of accuracy is required. The vertical line of light, from an Argand gas burner, L, and mirror, H, Fig. 1, is reflected from the mirror, M, of the galvanometer, and is allowed to fall upon a sensitized plate through a carefully adjusted horizontal slit, A B. Eastman's gelatine films have been found to answer well. The slit entirely crosses the plate, which is made to travel upward at a uniform rate by gearing, D, driven by clockwork; the regularity of the rate of travel may be tested by a time signal in seconds, produced by periodically obscuring, by the interrupter, E, worked by a clock, the light from a second fixed mirror, F, placed immediately below the suspended mirror, M, of the galvanometer, so as to send a fixed beam of light to the zero of the galvanometer mirror scale, that is, to the further end of the horizontal slit, A B.

The amplitude of the deflection of the galvanometer mirror, M, will of course depend on the temperature to which the thermo-junction, T, is heated. The same source of light illuminates both mirrors; and the result is, first, a beaded datum line from the intermittent light of the fixed mirror, F, which gives the rate of travel of the plate; and second, a continuous curve which is photographically traced by the line of light



does the nature of the gaseous atmosphere in which the couple is placed appear to render its action untrustworthy. The present experiments have shown that the wires must certainly be protected from the vapor of silver, or from contact with carbon or silicon. The free ends of the platinum and platinum-rhodium wires are soldered to copper terminals, which are kept at a constant temperature by being plunged into test tubes filled with alcohol and immersed in water, the temperature of which can be observed with a thermometer. The thermo-couple measures the difference of temperature between its heated junction and the copper terminals.

The galvanometer which appears to be best suited for use in connection with the couple is a reflecting dead-beat one, which bears the names of Deprez and d'Arsonval; it is now well known in this country. That

that the position here marked for the boiling point of water, namely, at about 90° C., is, of course, not the true boiling point of water, but is the difference between the true boiling point, 100° C., and the observed temperature, 10° C., of the cold junction of the pyrometer. In the various determinations the latter temperature varied from 10° to 15° C., or 50° to 60° F.

It was hardly to be expected that the determination of the melting point of palladium would yield a figure which falls so fairly into line with lower melting points; and it may be well to add a few details as to the manipulation. A globule of palladium weighing about 2 grammes or 30 grains may readily be melted by placing the metal in a cavity in a sound piece of charcoal. The charcoal near the button is ignited, and a stream of oxygen from a fine clay tube about 1 mm. or 0.04 in. diameter is directed into the cavity. A very manage-

from the galvanometer mirror, M, this photographic curve being the resultant of the movements of the tiny spot of light and of the sensitive plate.

The nature of the photographic curve in the case of a melting point may be illustrated by that which represents the fusion and solidification of a mass of aluminum weighing 10 grammes or 150 grains. The thermo-junction was in this case protected by a thin covering of pipe clay 1 mm. or 0.04 in. thick. While the plate is at rest the spot of light traces the straight line, e f, Fig. 9; then as the plate advances it traces the somewhat sinuous curve, f g, owing to the necessarily irregular heating of the mass of metal; but it is arrested at g when fusion begins, and a line parallel to the datum line is traced until the mass is fluid, when the temperature is raised above the melting point, as is shown by the portion of the curve marked b. The gas being then turned off, the metal cools and freezes, as is indicated by the second arrest, c, at a point slightly below its melting point.

It will be evident that a chronographic record might

\* Proceedings of the Royal Society, Vol. xlviii., 1890, p. 220.

† Nature, Vol. xli., Nov., 1889, pp. 11, 32.

‡ Journal de Physique, Vol. vi., Jan., 1889, p. 23.

§ Bulletin of the United States Geological Survey, No. 54, 1889.

\* Constructed by M. Carpentier, 20 Rue Delambre, Paris.

† Philosophical Magazine, Vol. viii. (Series V.), 1879, p. 501, and Vol. xiii., 1882, p. 147; Comptes Rendus, Vol. lxxxix., No. 17, pp. 702, 703.

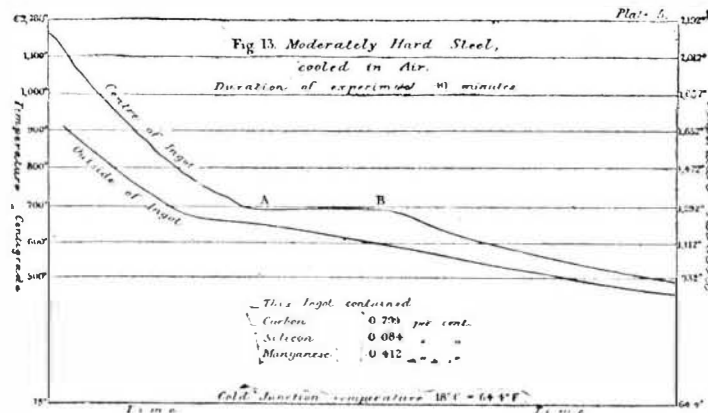


replace the photographic one. In fact, in beginning the investigation the chronographic method was employed. The time taken by the spot of light from the galvanometer to pass each division of a transparent graduated scale was noted on the paper ribbon of a delicate Bain instrument by an electric signal, side by side with a series of electric time signals from a clock beating half seconds. This method, though very delicate, involves much labor in the translation of the ribbon and in plotting the curves, and is, therefore, much less convenient than the photographic one, which gives a curve automatically.

The calculations by which the final results are obtained are as follows: From the curve representing a particular experiment the temperature of any point of interest may be obtained by reference to the calibration curve. This temperature has to be corrected, first, for error,  $e$ , in indications of the galvanometer, due to change of its temperature; and, second, for alteration,  $j$ , in the temperature of the cold junctions. The measurement of temperature by the thermo-

junction produced by the source of heat, the temperature of which was to be determined. This deflection is then compared with the deflection (also corrected) that is obtained by the introduction of known high temperatures, usually afforded by a crucible filled with pure molten gold; and the difference multiplied by the constant obtained from the part of the calibration curve (of the particular wire) which corresponds to the range of temperature, gives the difference in degrees Centigrade from the known high temperature.

If the thermo-junction be ruptured, the ends of the wires may be joined again after the removal of the defective part. Nevertheless, in conducting a series of experiments it is very desirable to employ for as long as possible the same thermo-junction; and it is therefore necessary to adopt precautions with a view to its preservation. This gives rise to considerable difficulty, in view of the absolute necessity for bringing the couple into close proximity to the molten metal; and several methods of protecting the couple were adopted. Clay coverings were open to the objection of their



junction depends, as is well known, on the measurement of an electromotive force by means of the current set up in a circuit of known resistance. Theoretically there are a number of corrections to make, such as those which arise from the varying resistance of the junction itself and of the leads; but the comparatively high resistance of the galvanometer renders these insignificant. Thus the resistance of the wires forming the couple was in one experiment 2.42 ohms, of the leads 0.175 ohm, and of the galvanometer 201 ohms. The part of the wires heated to a high temperature was too short to form an appreciable part of the resistance, even if its own resistance were doubled. Consequently the first correction,  $e$ , reduces itself to a simple temperature correction, applied to the galvanometer. This at first sight might appear to involve several corrections: first, a correction for change  $c$  in resistance of the coil; second, a correction for variation  $v$  in the torsion of the suspending wire; third, a correction for any modification  $m$  of the magnetic field of the galvanometer.

The correction for change  $c$  in resistance of the coil is easily made. The coil is of German silver, which has a temperature coefficient of 0.00038 per degree Centigrade. The deflection at the melting point of gold is 16 centimeters upon the scale; hence a rise in temperature of 1° C. decreases the deflection from 16 to 15.994.

The variation  $v$  in the torsional resistance of the suspending wire was found to be quite negligible. Time readings were taken of the oscillations of the mirror, 500 consecutive oscillations being taken several times each day on different days and at different temperatures. No difference in time of oscillations greater than 0.2 second could be detected with a stop watch. One indirect effect, however, was observed. The pillar of the instrument supporting the wire and coil does not appear to be made of the same material as the suspending wire itself; and as this suspending wire has some initial torsional strain, the zero of the instrument changes slightly with changes of tempera-

ture. After this was discovered special care was taken to watch the zero. The modification  $m$  of the field in which the coil hangs is probably very small; any alteration would be at once checked and provided for by the system of introducing known high temperatures. The temperature as indicated by the deflection of the mirror has also to be corrected for variation  $j$  in the temperature of the cold junctions. Obviously the pyrometer measures only the differences of temperature between the copper junctions and the junction of the special wires; but by keeping the former at one temperature the indications of the pyrometer are measures of the difference between this temperature and that of the heated couple. The curve connecting the deflections with their corresponding temperatures is very nearly a straight line throughout the range of the experiments; and consequently it is legitimate to add to or subtract from the deflection an amount corresponding with the small variation of the cold junction from some normal temperature taken at 18° C. This correction and that for change in resistance of the coil of the galvanometer are applied to the observed deflec-

#### LIQUATION OF SILVER-COPPER ALLOYS.

In order to gain some evidence as to the capabilities of the appliance, it was subjected to the following tests in connection with the liquation of silver-copper alloys, that is, the separation of their more fusible constituents. This series of alloys has previously been the subject of careful experiment, and much is now

ALLOY CONTAINING 92.5 PER CENT. SILVER AND 7.5 PER CENT. COPPER, COOLED RAPIDLY. (SEE FIG. 7.)

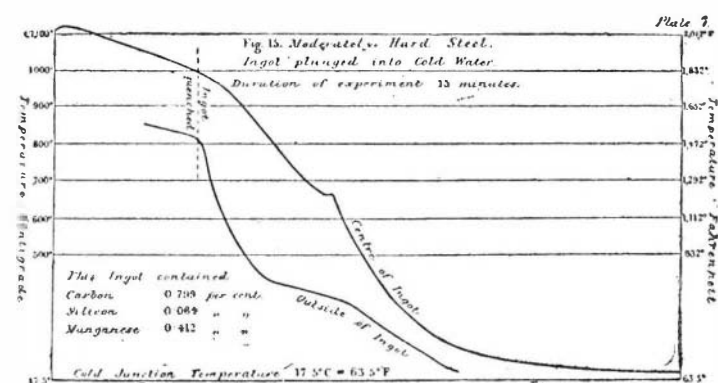
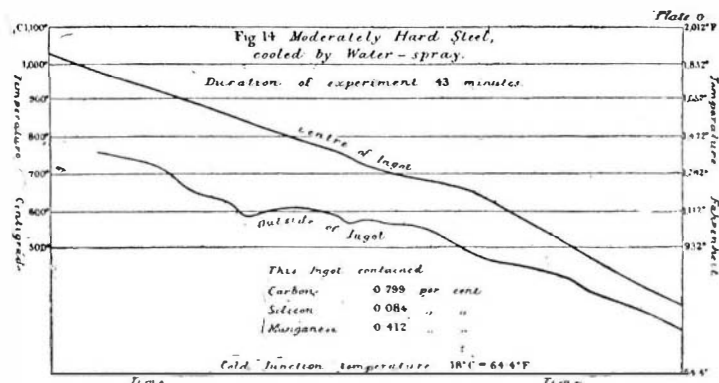
Central vertical plane.	Percentage of silver.	Corners.	Percentage of silver.	Sides.	Percentage of silver.
a	92.46	h	92.32	q	92.36
b	92.40	i	92.37	r	92.38
c	92.91	k	92.33	s	92.31
d	93.55	l	92.33		
e	93.10	m	92.39		
f	92.50	n	92.38		
g	92.42	o	92.27	Dip assay	92.51
		p	92.32		

Maximum difference, between center  $d$  and corner  $o$ , 1.28%.

The results of a memorable research led Guthrie\* to the conclusion that certain alloys in cooling "throw off atomically definite bodies, leaving behind a fluid mass which is not definite in composition;" so that ultimately the most fusible alloy of the series is left, which he calls the *eutectic* or most fusible alloy, and in it the "proportions between the constituent metals are not atomic proportions." Guthrie's experiments dealt only with alloys of low melting points, such as the fusible metals; but photographic records of the rate of cooling, as measured by the platinum and platinum-rhodium thermo-couple, might be expected to show at what temperatures groups of silver-copper alloys solidify and fall out of solution. And at the same time evidence as to the probable composition of the eutectic alloy of the series should be as readily obtained by these means as it was, in the earlier experiments, by placing an ordinary mercurial thermometer in a bath of fusible metal.

Fig. 11 represents such a photographic record of the rate of cooling of a mass of standard silver weighing 11 oz. It will be seen that the initial temperature indicated is 1,068° C., and that there is an abrupt fall to 856° C. at  $b$ , when the freezing of the mass as a whole begins. Just before this abrupt turn in the curve takes place there is a slight change in its direction at  $a$ , probably caused by a falling out of alloys rich in copper. After the abrupt break at  $b$  a slight upward tendency,  $c$ , shows that heat is evolved; but the curve continues to fall until another abrupt change occurs at 748° C. at  $d$ , which indicates that a second critical point has been reached. That this is attended by the evolution of heat is seen, for the spot of light remains stationary for 40 seconds; and it is doubtless caused by the solidification of the eutectic alloy, that is, the most fusible alloy of the series.

Similar photographic records of the cooling of Levot's alloy,  $Ag_3Cu_2$ , containing 71.89 per cent. of silver, show that there is only a single break, Fig. 11, which occurs at this same temperature, 748° C.; solidification throughout the mass then takes place. A record of the cooling of a mass of silver-copper,  $AgCu$ , containing 63.029 per cent. of silver, also gives only a single break at 748° C.; but, although the freezing point of the eutectic alloy is evidently close to this temperature of 748° C., it would not be safe to conclude that either  $Ag_3Cu_2$  or  $AgCu$  is itself the eutectic alloy; they are probably only the last alloys (in which the constituents are in simple atomic proportions) to fall out of a bath of indefinite composition. Other alloys of this series have been examined, and the curve of the one containing 60 per cent. of silver is also shown in Fig. 11. It seems to show that in a series of alloys the second point of solidification is not quite constant. The behavior of a solidifying mass of gun metal appears to present exactly the same characteristics; but the experiments have not as yet been concluded. It is easy in the case of alloys like fusible metal to keep the alloy melted, and to ascertain what the composition of the most fusible alloy really is, by repeatedly straining the fluid mass from the suspended crystals through a



ture. After this was discovered special care was taken to watch the zero.

The modification  $m$  of the field in which the coil hangs is probably very small; any alteration would be at once checked and provided for by the system of introducing known high temperatures.

The temperature as indicated by the deflection of the mirror has also to be corrected for variation  $j$  in the temperature of the cold junctions. Obviously the pyrometer measures only the differences of temperature between the copper junctions and the junction of the special wires; but by keeping the former at one temperature the indications of the pyrometer are measures of the difference between this temperature and that of the heated couple. The curve connecting the deflections with their corresponding temperatures is very nearly a straight line throughout the range of the experiments; and consequently it is legitimate to add to or subtract from the deflection an amount corresponding with the small variation of the cold junction from some normal temperature taken at 18° C. This correction and that for change in resistance of the coil of the galvanometer are applied to the observed deflec-

known respecting them. Not the least interesting fact connected with them is the remarkable molecular rearrangement they undergo during solidification. Levot,† who is the chief authority on the subject, concluded that the only homogeneous alloy contains 71.89 per cent. of silver and 28.107 per cent. of copper; and he considers it to be a definite combination of the two metals having the formula  $Ag_3Cu_2$ . Many years ago I also examined the behavior of the silver-copper alloys during cooling; and the following figures and diagram, Fig. 7, taken from my paper,§ may be given, as showing the way in which a cubical mass, 45 mm. or 1½ in. side, will arrange itself in cooling rapidly. It will be evident that the silver becomes concentrated toward the center of the mass, which is richer in silver by 1.28 per cent. than the external portions.

\* Bulletin of the United States Geological Survey, No. 54, 1889, p. 92.

† Philosophical Transactions of the Royal Society, Vol. clxxviii., 1887, p. 161.

‡ Annales de Chimie et de Physique, Vol. xxxvi., 1852, p. 193; Vol. xxxix., 1853, p. 163.

§ Proceedings of the Royal Society, Vol. xxiii., 1874-5, p. 481.

\* Philosophical Magazine, Vol. xvii., 1884, p. 462.

probably also another slight evolution of heat, *c.*, at 767° C. or 1473° F. It is interesting to compare this curve with the one below it, obtained during the cooling of a mass of steel containing nearly 0.5 per cent. of carbon, in which there is a distinct evolution of heat at 820° C. or 1,508° F., and a prolonged one at 650° C. or 1,202° F. With reference to these curves, M. Osmond himself wrote to me on December 18th, 1890: "The photographs are very beautiful, but, as you say, this mode of representation [by time-temperature] is not well adapted for showing slight evolutions of heat which occur while the cooling of the mass is slow [and is represented by the flat part of the curve]. It is certain, however, that the slightest prominence shown in the curve is a real one, and is not due to errors of plotting. The curve representing my steel is perfectly clear, but your specimen appears to have been well chosen for showing the two critical points."

#### EFFECT OF SMALL QUANTITIES OF IMPURITY ON THE FREEZING POINT OF GOLD.

The fundamental effect of an impurity in modifying the mechanical properties of metals has been abundantly established; but the part played by the impurity may be twofold. It may act directly on its own account upon the mass; and, by changing its structure, may alter its mechanical properties when solid. Or, as Osmond's\* work has shown, it may cause, retard, or hasten the passage of a metal in which it is hidden from its normal to an allotropic state, and may affect its properties indirectly. For the purpose of investigating these two distinct sets of phenomena, gold offers many advantages. It may be prepared in a very high degree of purity; it is not liable to contamination by oxidation; and much is already known respecting certain of its mechanical and thermal properties as influenced by small quantities of impurity, which exert a truly astonishing influence on its strength and extensibility. Platinum would no doubt be even better; but its manipulation is attended with many difficulties. In the case of gold such difficulties can be met; and when they have been surmounted the work may be carried on with confidence, so as to prepare for the extension of the experiments to metals in ordinary use. It would appear, therefore, most desirable to obtain thermal evidence as to the influence of impurities on a cooling mass of gold. In what degree, for instance, is the freezing point of gold influenced by the presence of definite impurities? And is the final solidification of the mass preceded in the respective stages by a pasty stage? Or does the passage from the fluid to the solid state take place rapidly? Many years ago I called attention to the remarkable lowering in the melting point of gold produced by the presence of silicon; but the want of a suitable pyrometer has hitherto prevented my making direct experiments upon the subject.

The method of preparing gold of a high degree of purity has already been described.† In each experiment now to be more fully described, 132 grammes, or 2,037 grains, of gold were melted in one of the crucibles provided with a central tube or socket, as already described, and weighing, with its cover, 130 grammes, or 2,006 grains.

The initial temperature of the molten mass was high, somewhere about 1,200° C. or 2,200° F.; and the durability of the thermo-junction and the constancy of its readings had therefore to be carefully tested. It was found by repeated trials that different crucibles of the same size, filled with identical weights of gold, gave closely concordant results; but it occasionally happened that the platinum wire of the couple became brittle and broke. In such cases the fractured portion was removed, and the ends were twisted together again. Throughout the course of the experiments, a crucible filled with pure gold was kept at hand, and the freezing point of the molten metal was determined from time to time as a check.

The object of the experiments was primarily to ascertain whether the influence of impurities on the metal was really tangible, that is, whether the insertion of the point of a fine stirrer of clay would indicate the existence of a pasty or gritty stage; but advantage was taken of the installation of the appliances to determine what retardation of the freezing point of gold is produced by the known elements which are added to it.

The result of Raoult's investigations on the lowering of the freezing points of solutions led him to the conclusion that one molecular proportion of any substance, dissolved in a hundred molecular proportions of any solvent whatever, lowers the freezing point of that solvent 0.62° C. or 1.12° F. This had not been tested in the case of solutions of metals in metals until Heycock and Neville‡ began an elaborate investigation of the subject. Their research, as far as it has at present been carried, deals with lowering the freezing points of sodium and tin, produced by the addition to them of certain metals; and, second, with the molecular weights of metals when in solution. The results of their experiments when compared with the empirical laws of Coppey and Raoult may be briefly stated as follows: They are in accordance with the law that "for moderate concentration the fall in the freezing point is proportional to the weight of the dissolved substance present in a constant weight of solvent." By making the assumption that the molecule of zinc or of mercury is monatomic when in solution in tin, they confirm the second law that "when the falls produced in the same solvent by different dissolved substances are compared, it is found that a molecular weight of a dissolved substance produces the same fall, whatever the substance is." But the third law, which states that "if a constant number of molecular weights of the solvent be taken, the fall is independent of the nature of the solvent," they found to be probably incorrect, and theoretical considerations, indeed, would lead us to expect this. In the case of silicon in standard gold, which has already been mentioned, a long semi-fluid stage appears to be set up. The metal may contain solidified particles, and yet be sufficiently fluid to flow readily. This phenomenon has not yet been fully investigated.

In a research of much interest, Ramsay\* has determined the molecular weight of a number of metals by Raoult's vapor pressure method; that is, he ascertained the depression of the vapor pressure of the solvent, produced by a known weight of dissolved substance, and he finds that although sodium behaves irregularly, yet "it would appear legitimate to infer that in solution, as a rule, the atom of a metal is identical with its molecule, as the physical properties of those metals which have been vaporized would lead us to suppose."

The experiments were conducted as follows: The gold was melted in the crucible and its freezing point noted in two ways: first, by recording with the aid of a chronograph the rate at which the mass cooled, the results being plotted in a curve with time and temperature as co-ordinates. The exact freezing point was then indicated by the abrupt change in the direction of the curve. Second, freezing point was also actually observed in the following way: The cover of the crucible had an orifice, which could be covered with a plug of charcoal, and through this orifice was inserted a fine pipe clay rod held in the hand. A little experience with this, in touching the surface of the molten mass, enabled the existence of either a pasty or a gritty stage to be detected, and the point of actual solidification to be noted; and this point was telegraphed on to the chronograph tape by a distinctive sign. The gold was then remelted, and the impurity to be added was carefully weighed, wrapped in pure gold foil, and added to the molten mass, which was well stirred with a fine clay stirrer, and replaced in the furnace to make sure that the mass was thoroughly fluid. The crucible was placed in position over the thermo-junction, and the freezing point observed as before. Lead and bismuth exert great influence in diminishing the tenacity and extensibility of gold. They were therefore first selected with a view to study their action upon its freezing point. In the gold lead series, Fig. 10, the full curve A is the normal line, representing the freezing of pure gold, and the dotted curves B C D were obtained as the results of successive additions of lead, B corresponding with 0.2 per cent., C with 0.4 per cent., and D with 0.8 per cent. of lead. The lowering of the freezing point was found to be proportional to the amount of lead added. No marked pasty stage was detected, and the lowering of the freezing point appears to be about 19° C. or 34° F. for every atom of lead added to 100 atoms of gold.

The calculations are as follows: The atomic theory assumes that there are as many atoms in 196 parts by weight of gold as there are in 208 parts by weight of lead. Consequently, if 0.2 per cent. of lead be added to a mass of gold, there will be  $0.2 \times 196 \div 208 = 0.19$  atom of lead per hundred atoms of gold. Dividing the observed fall of the freezing point in degrees Centigrade by the number of atoms of impurity which causes it in a hundred atoms of gold, the figure known as the "atomic fall" is obtained; and this is nearly constant for any given mass of an individual metal. As soon as 0.3 per cent. of lead is present, oxidation causes a little trouble; and apparently a simple molecular action gives place to one of more complex character, the result being that the further alteration of the freezing point is not so great as it was initially.

The series with bismuth showed a very regular lowering of the temperature of the freezing point, giving an atomic fall of 17° C. or 31° F. up to 2 per cent. or 3 per cent. of bismuth. Even with 19 per cent. of bismuth there is a point well marked in the curve showing where solidification commences. A study of these curves gives rise to a suspicion that a "trace" of impurity has an important effect upon the latent and specific heats; but until the experiments are repeated under very accurate calorimetric conditions, this point is uncertain. Bismuth probably gives a eutectic alloy of very low melting point, the pasty stage being maintained down to temperatures differing but little from that of melting lead; but the experiments have not been carried further at present. It is remarkable that a small quantity of bismuth in gold produces a lead gray or almost purple color of the fractured surface, which, upon burnishing, becomes at once golden yellow. This is doubtless due to the very distinct liquation that can be observed, the granules of nearly pure gold being surrounded by a brittle and impure mass.

Platinum gave an interesting series of results, which indicated an atomic fall of 17° C. or 31° F. But gold is very soon saturated with platinum; apparently 0.6 per cent. is sufficient for that purpose. The first addition of platinum at once stopped the "piping" of the solidifying mass, which is so marked a feature in very pure gold, and gave the characteristic crystalline surface which indicates the presence of platinum. An accident prevented the series from being carried beyond 1 per cent. of platinum, which amount, however, is sufficient to raise the freezing point again to that of pure gold.

Silicon, which has a small atomic weight, exerts a great influence on the freezing point of gold; but much difficulty was experienced in getting it to alloy with the gold. The fall produced was at the rate of 16° C. or 29° F. for each atom in a hundred atoms of gold.

Manganese was also somewhat difficult to alloy; but after the union of the gold and manganese had been effected the mass behaved in a peculiar way, indicating considerable internal changes in their mode of association near the freezing point. The bath remained quite mirror-like and limpid until the freezing point was reached; it then suddenly clouded over, and a granular mass began to form. The results were remarkable from the fact that the atomic fall was found to be only one-half that obtained in most other cases; thus there is reason to conclude that manganese exists in this particular instance as a diatomic molecule.

The effect of aluminum was also studied, on account of the interest it possesses in connection with the metallurgy of iron. The gold combined with this metal with avidity, and when cold the fracture showed very marked granular structure. A study of the curve indicates that an almost chaotic state is produced in the gold by the addition of aluminum; not only is the point of initial freezing lowered, but the metal only partially solidifies during a very long range of temperature, and could easily be poured at several hundred

degrees lower than the initial freezing point. This in all probability is the reason for the conflict of opinion as to the amount and nature of the change produced in the freezing point of wrought iron by the presence of aluminum, as in the case of the well known "mitis" castings. The long pasty stage which aluminum sets up is very deceptive, and renders it difficult to determine which is the true freezing point. Aluminum has a low atomic weight, and causes a very considerable fall in the freezing point of gold; this fall, however, is only one-third of that produced per atom by other impurities.

Silver occupies a remarkable position in the series. Very pure silver was used, which had been tested by Stas; but it required nearly 5 per cent. of silver to cause any appreciable lowering of the freezing point. Whether solid gold is capable of dissolving silver cannot yet be proved; but it opens an extremely interesting field for research.

#### STEEL.

From the engineer's point of view the most interesting information which the pyrometer has as yet afforded is connected with the measurement of internal stresses in iron and steel. Osmond's work has shown that molecular changes take place in steel; and it is evident that the occurrence of these changes must be of vital importance when the metal is subjected at high temperatures to mechanical operations such as a rolling or forging. The question naturally arises, Do the molecular changes in the iron take place at one moment throughout the mass of metal? that is, is the rate of cooling approximately uniform throughout the mass? Or does the external portion of a hot ingot cool so much more rapidly than the center as to allow the molecular changes in the iron, and the alterations in the relation between the carbon and the iron, to become completed near the surface long before they take place in the interior of the mass? The experimental difficulties in the way of obtaining information upon these points have hitherto appeared to be insuperable; but the pyrometric method used in this research affords most important evidence, as a brief description of the following experiments will show:

Two thermo-junctions made from adjacent pieces of the same coils of wire, and both insulated in the ordinary way by means of pipe clay tubes, were carefully prepared. A miniature ingot of mild steel, 4 in. diameter and 8 in. long, shown in section in Fig. 8, was provided by the Director-General of Ordnance Factories; one hole,  $\frac{1}{8}$  in. diameter was drilled from the center of one end to a depth of 4 in., and another hole of the same diameter was drilled near the edge of the same end to a depth of 1 in. The ingot was then heated to bright redness in a furnace; and when it had been withdrawn, the two thermo-junctions were inserted, one in each of the holes. Then, by means of a special switch, they were alternately connected for short but measured periods of time with the galvanometer of the photographic recording apparatus. Curves were thus obtained from both the thermo-junctions simultaneously, each curve being made up of short dashes. In the case of mild steel the evidence as to molecular change was but slight, but with a single ingot of moderately hard steel the results, which are shown in Figs. 13, 14 and 15, are very interesting. This ingot contained 0.799 per cent. of carbon, 0.084 per cent. of silicon and 0.412 per cent. of manganese.

In Fig. 13, which represents the cooling of the ingot in air, the upper curve records the cooling of the center of the ingot and the lower the cooling of the outer portion. The initial temperature at the center was 1,160° C. or 2,120° F. The molecular change in the iron can be detected at 850° C. or 1,561° F., and the carbon change takes place at 690° C. or 1,285° F. In the lower curve, representing the cooling of the circumference, the carbon change takes place no less than four minutes earlier than at the center, and at the lower temperature of 665° C. or 1,229° F. as compared with 696° C. or 1,285° F. This is a most interesting point, as Osmond has already shown that the rate of cooling has a measurable effect upon the temperatures at which molecular change occurs. The great internal strain which must be set up between the points marked A and B in the upper curve is evident when it is borne in mind that the carbon change is accompanied by a considerable alteration of volume.

In Fig. 14 is shown a pair of curves obtained from the same ingot when cooled by a water spray. These present but few additional points of interest.

In the experiment represented by Fig. 15 the ingot was plunged, when its exterior was at a temperature of 850° C. or 1,560° F., into a tank of cold water. The lower curve, however, representing the rate of cooling of the outer portions of the ingot, is not strictly autographic, as it was slightly defective on the original photographic plate for temperatures below 600° C. or 1,100° F. The upper curve is autographic throughout.

In all these experiments it was found that the flow of heat from the center of such an ingot was not sufficiently rapid to prevent there being considerable variations in temperature within the mass. There can be but little question that such experiments will deserve careful attention, and in the hands of competent observers should be fruitful of results.

#### A NEW ELECTRO-DEPOSITED ALLOY.

It has always been advanced by those who view alloys as true chemical compounds that the fact that certain of them can be deposited electrically lends countenance to their view. Seeing that brass was almost the only alloy of which the deposition was successfully practiced, the position lacked strength from the scanty evidence supporting it. Lately, however, several attempts have been made to deposit other alloys, and that, too, on a commercial scale. The process of plating recently patented by the London Metallurgical Plating Company, under the significant name of "Arcas," has gone through several stages of development, and, according to the *Engineer*, in its newest form presents several features of interest. To begin with, a metal—the use of which has been hitherto confined to the production of an artist's pigment, to the formation of fusible alloys, and to the aid of the photographer—which is similar to zinc, and associated with it in its ores, namely, cadmium, has been made to do duty in a larger field. Instead of the alloy of zinc and

\* *Comptes Rendus*, vol. cx., 1890, p. 346.

† *Annales de Chimie et de Physique*, vol. xx., 1880, p. 66.

‡ *Philosophical Transactions of the Royal Society*, vol. clxxix., 1888, pp. 339-349.

§ Riemdijk, *Journal of the Chemical Society*, vol. lv., 1889, p. 666; vol. lvii., 1890, pp. 376 and 656.

\* *Journal of the Chemical Society*, vol. lv., 1889, p. 521. See also Tam-mann, *Zeitschrift für physikalische Chemie*, 1889, p. 441.