chance. Then, also, there is the indication of the results of an infinitely great number of grazes in the shape of lines of metals which we see at the temperature of the oxy-hydrogen flame, but which we do not see so well at the temperature of the arc and the spark; and, on the other hand, there are indications of the results of high temperature which we can study in the sun, and such obvious indications of high temperature that we get the two lines which I have referred to, neither of which has ever been seen so far in any terrestrial laboratory, although they are very familiar indeed to students of solar physics.

The total result of all this inquiry has been that the mean temperature of the meteoritic phenomena brought before us by the nebula of Orion is distinctly low. That is a result of extreme interest and importance, because, remembering what was said about the objection to Laplace's view of high temperature gas because it violated the laws of thermodynamics, we have now, after minute study, come to a conclusion regarding the structure of these nebulæ, which is quite in harmony with the laws of thermodynamics.

When the series of lines associated with high temperatures was first recorded in the spectrum of the nebulæ, I stated that possibly this might be due to the fact that in regions of space where the pressure always operative is extremely low, we might be in the presence of chemical forms which are unfamiliar to us here, because all that we know of here chemically is the result probably of considerable temperature, and not very low pressure. It was therefore supposed that these lines might represent to us the action of unfamiliar conditions in space. Thus, if we have a compound chemical substance, and increase its temperature sufficiently, the thing goes to pieces—is dissociated; but imagine a condition of things in which we have that same chemical substance for a long time exposed to the lowest possible pressure. Is it possible that that substance will ever get pulled to bits? If so, we may imagine parts of space which will contain these substances pulled to bits which really constitute finer forms of matter than our chemical substances. So that we may logically expect to get the finest possible molecules as distinct entities in the regions where the pressure is the lowest possible. These forms are, of course, those we should expect to be produced by a very high temperature brought on by end-on collisions; hence the line of thought is not greatly changed in both these explanations, and I think that probably future research may show that we are justified in looking to both of these possible causes as those which produce for us those so-called "chromospheric lines" which we find in the spectrum of the nebulæ.

However that may be, we have arrived finally at the conclusion that the temperature of these nebulæ is low on the meteoritic hypothesis.

I have already referred in my previous lectures to Dr. Huggins's views connected with the nebulæ and stars, and you will therefore quite understand that I am delighted to find that Dr. Huggins has now come to the conclusion that in nebulæ we have distinctly a relatively low temperature. In 1889 Mr. Huggins wrote:[1] "They [the nebulæ] consist probably of gas at a high temperature," but in the address of 1891, to which I have already had occasion to refer, he gives this view up, and refers to "the much lower mean temperature of the gaseous mass *which we should expect at so early a stage of condensation*" *!!*[2]

I am also glad to say that Dr. Keeler is also perfectly prepared to accept the view I have been insisting on. So that, if the opinion of astronomers of repute is worth anything, we do seem to have arrived at very solid ground indeed on this point, so far as a consensus of opinion can make any ground solid.

J. NORMAN LOCKYER.

(*To be continued.*)

[1] *P.R.S.* vol. xlvi. p. 59.

[2] In this printing of the passage, the italics and notes of exclamation are mine.—J. N. L.

THE RARER METALS AND THEIR ALLOYS.[3]

THE study of metals possesses an irresistible charm for us, quite apart from its vast national importance. How many of us made our first scientific experiment by watching the melting of lead, little thinking that we should hardly have done a bad life's work if the experiment had been our last, provided we had only understood its full significance. How few of us forget that we wistfully observed at an early age the melting in an ordinary fire of some metallic toy of our childhood; and the experiment has, like the "Flat iron for a farthing," in Mrs. Ewing's charming story, taken a prominent place in literature which claims to be written for children. Hans Andersen's fairy tale, for instance, the "History of a Tin Soldier," has been read by children of all ages and of most nations. The romantic incidents of the soldier's eventful career need not be dwelt upon: but I may remind you that at its end he perished in the flames of an ordinary fire, and all that could subsequently be found of him was a small heart-shaped mass. There is no reason to doubt the perfect accuracy of the story recorded by Andersen, who at least knew the facts, though his statement is made in popular language. No analysis is given of the tin soldier; in a fairy tale it would have been out of place, but the latest stage of his evolution is described, and the record is sufficient to enable us to form the opinion that he was composed of both tin and lead, certain alloys of which metals will burn to ashes like tinder. His uniform was doubtless richly ornamented with gold lace. Some small amount of one of the rarer metals had probably—for on this point the history is silent—found its way into his constitution, and by uniting with the gold, formed the heart-shaped mass which the fire would not melt, as its temperature could not have exceeded 1000°; for we are told that the golden rose, worn by the *artiste* who shared the soldier's fate, was also found unmelted. The main point is, however, that the presence of one of the rarer metals must have endued the soldier with his singular endurance, and in the end left an incorruptible record of him.

This has been taken as the starting-point of the lecture, because we shall see that the ordinary metals so often owe remarkable qualities to the presence of a rarer metal which fits them for special work.

This early love of metals is implanted in us as part of our "unsquandered heritage of sentiments and ideals which has come down to us from other ages," and future generations of children will know far more than we did; for the attempt will be made to teach them that even psychology is a branch of molecular physics, and they will therefore see far more in the melted toy than a shapeless mass of tin and lead. It is really not an inert thing; for some time after it was newly cast, it was the scene of intense molecular activity. It probably is never molecularly quiescent, and a slight elevation of temperature will excite in it rapid atomic movement anew. The nature of such movement I have indicated on previous occasions when, as now, I have tried to interest you in certain properties of metals and alloys.

This evening I appeal incidentally to higher feelings than interest, by bringing before you certain phases in the life-history of metals which may lead you to a generous appreciation of the many excellent qualities they possess.

Metals have been sadly misunderstood. In the belief that animate beings are more interesting, experimenters have neglected metals, while no form of matter in which life can be recognised is too humble to receive encouragement. Thus it happens that bacteria, with repulsive attributes and criminal instincts, are petted and watched with solicitude, and comprehensive schemes are submitted to the Royal Society for their development, culture, and even for their "education,"[1] which may, it is true, ultimately make them useful metallurgical agents, as certain micro-organisms have already proved their ability to produce arseniuretted hydrogen from oxide of arsenic.[2]

It will not be difficult to show that methods which have proved so fruitful in results when applied to the study of living things, are singularly applicable to metals and alloys, which really present close analogies to living organisms. This must be a new view to many, and it may be said, "it is well-known that uneducated races tend to personify or animate external nature," and you may think it strange that the attempt should be made to trace analogies which must appear to be remote, between moving organisms and inert alloys, but "the greater the number of attributes that attach to anything, the more real that thing is."[3] Many of the less known metals are very real to me, and I want them to be so to you; listen to me, then, as speaking for my silent metallic friends, while I try to secure for them your sympathy and esteem.

First, as regards their origin and early history. I fully

[3] A Friday evening discourse, delivered at the Royal Institution on March 15, by Prof. Roberts-Austen, C.B., F.R.S.

[1] Dr. Percy Frankland specially refers to the "education" of bacilli for adapting them to altered conditions. *Roy. Soc. Proc.*, vol. lvi., 1894, p. 539.

[2] Dr. Brauner. *Chem. News*, Feb. 15, 1895. P. 79.

[3] Lotze, "Metaphysic," § 49, quoted by Illingworth. "Personality, Human and Divine." Bampton Lectures, 1894, p. 43.

share Mr. Lockyer's belief as to their origin, and think that a future generation will speak of the evolution of metals as we now do of that of animals, and that observers will naturally turn to the sun as the field in which this evolution can best be studied.

To the alchemists metals were very living indeed; they treated them as if they were, and had an elaborate pharmacopœia of "medicines" which they freely administered to metals in the hope of perfecting their constitution. If the alchemists constantly draw parallels between living things and metals, it is not because they were ignorant, but because they recognised in metals the possession of attributes which closely resemble those of organisms. "The first alchemists were gnostics, and the old beliefs of Egypt blended with those of Chaldea in the second and third centuries. The old metals of the Egyptians represented men, and this is probably the origin of the *homunculus* of the middle ages, the notion of the creative power of metals and that of life being confounded in the same symbol."[1]

Thus Albertus Magnus traces the influence of congenital defects in the generation of metals and of animals, and Basil Valentine symbolises the loss of metalline character, which we now know is due to oxidation, to the escape from the metal of an indestructible spirit which flies away and becomes a soul. On the other hand, the "reduction" of metals from their oxides was supposed to give the metals a new existence. A poem[2] of the thirteenth century well embodies this belief in the analogies between men and metals, in the quaint lines:—

> "Homs ont l'estre comme metaulx,
> Vie et augment des vegetaulx,
> Instinct et sens comme les bruts,
> Esprit comme ange en attributes."

"Men have being"—constitution—like metals; you see how closely metals and life were connected in the minds of the alchemists.

"Who said these old renowns, dead long ago, could make me forget the living world?" are words which Browning places in the lips of Paracelsus, and we metallurgists are not likely to forget the living world; we borrow its definitions, and apply them to our metals. Thus nobility in metals as in men, means freedom from liability to tarnish, and we know that the rarer metals, like the rarer virtues, have singular power in enduing their more ordinary associates with firmness, elasticity, strength, and endurance. On the other hand, some of the less known metals appear to be mere "things" which do not exist for themselves, but only for the sake of other metals to which they can be united. This may, however, only seem to be the case because we as yet know so little about them. The question naturally arises, how can the analogies between organic and inorganic bodies be traced? I agree with my colleague at the École des Mines of Paris, Prof. Urbain le Verrier, in thinking that it is possible[3] to study the biology, the anatomy, and even the pathology of metals.

The anatomy of metals—that is, their structure and framework—is best examined by the aid of the microscope, but the method of autographic pyrometry, which I brought before you in a Friday evening lecture delivered in 1891, is rendering admirable service in enabling both the biology and pathology of metals to be studied, for, just as in biological and pathological phenomena vital functions and changes of tissue are accompanied by a rise or fall in temperature, so molecular changes in metals are attended with an evolution or absorption of heat. With the aid of the recording pyrometer we now "take the temperature" of a mass of metal or alloy in which molecular disturbance is suspected to lurk, as surely as a doctor does that of a patient in whom febrile symptoms are manifest.

It has, moreover, long been known that we can submit a metal or an alloy in its normal state to severe stress, record its power of endurance, and then, by allowing it to recover from fatigue, enable it to regain some, at least, of its original strength. The human analogies of metals are really very close indeed, for, as is the case with our own mental efforts, the internal molecular work which is done in metals often strengthens and invigorates them. Certain metals have a double existence, and, according to circumstances, their behaviour may be absolutely harmful or entirely beneficial. The dualism we so often recognise in human life becomes allotropism in metals, and they, strangely enough, seem to be restricted to a single form of existence if they are absolutely free from contamination, for probably an absolutely pure metal cannot pass from a normal to an allotropic state. Last, it may be claimed that some metals possess attributes which are closely allied to moral qualities, for, in their relations with other elements, they often display an amount of discrimination and restraint that would do credit to sentient beings.

Close as this resemblance is, I am far from attributing consciousness to metals, as their atomic changes result from the action of external agents, while the conduct of conscious beings is not determined from without, but from within. I have, however, ventured to offer the introduction of this lecture in its present form, because any facts which lead us to reflect on the unity of plan in nature, will aid the recognition of the complexity of atomic motion in metals upon which it is needful to insist.

The foregoing remarks have special significance in relation to the influence exerted by the rarer metals on the ordinary ones. With exception of the action of carbon upon iron, probably nothing is more remarkable than the action of the rare metals on those which are more common; but their peculiar influence often involves, as we shall see, the presence of carbon in the alloy.

Which, then, are the rarer metals, and how may they be isolated? The chemist differs somewhat from the metallurgist as to the application of the word "rare." The chemist thinks of the "rarity" of a compound of a metal; the metallurgist, rather of the difficulty of isolating the metal from the state of combination in which it occurs in nature.

The chemist in speaking of the reactions of salts of the rarer metals, in view of the wide distribution of limestone and pyrolusite, would hardly think of either calcium or manganese as being among the rarer metals. The metallurgist would consider pure calcium or pure manganese to be very rare, I have only recently seen comparatively pure specimens of the latter.

The metals which, for the purposes of this lecture, may be included among the rarer metals are: (1) those of the platinum group, which occur in nature in the metallic state; and (2) certain metals which in nature are usually found as oxides or in an oxidised form of some kind, and these are chromium, manganese, vanadium, tungsten, titanium, zirconium, uranium, molybdenum (which occurs, however, as sulphide). Incidental reference will be made to nickel and cobalt.

Of the rare metals of the platinum group I propose to say but little; we are indebted for a magnificent display of them in the library to my friends Messrs. George and Edward Matthey and to Mr. Sellon, all members of a great firm of metallurgists. You should specially look at the splendid mass of palladium, extracted from native gold of the value of £2,500,000, at the melted and rolled iridium, and at the masses of osmium and rhodium. No other nation in the world could show such specimens as these, and we are justly proud of them.

These metals are so interesting and precious in themselves, that I hope you will not think I am taking a sordid view of them by saying that the contents of the case exhibited in the library are certainly not worth less than ten thousand pounds.

As regards the rarer metals which are associated with oxygen, the problem is to remove the oxygen, and this is usually effected either by affording the oxygen an opportunity for uniting with another metal, or by reducing the oxide of the rare metal by carbon, aided by the tearing effect of an electric current. In this crucible there is an intimate mixture, in atomic proportions, of oxide of chromium and finely divided metallic aluminium. The thermo-junction (A, Fig. 1) of the pyrometer which formed the subject of my last Friday evening lecture here, is placed within the crucible, B, and the spot of light, C, from the galvanometer, D, with which it is connected, indicates on the screen that the temperature is gradually rising. You will observe that as soon as the point marked 1010° is reached, energetic action takes place: the temperature suddenly rising above the melting-point of platinum, melts the thermo-junction, and the spot of light swings violently; but if the crucible be broken open, you will see that a mass of metallic chromium has been liberated.

The use of alkaline metals in separating oxygen from other metals is well known. I cannot enter into its history here, beyond saying that if I were to do so, frequent references to

[1] Berthelot, *Les origines des alchimie*, 1885, p. 60.

[2] *Les Remonstrances ou la complaint de nature a l'alchimist errant.* Attributed to Jehan de Meung, who with Guillaume de Lorris wrote the *Roman de la Rose.* M. Méon, the editor of the edition of 1814 of this celebrated work, doubts, however, whether the attribution of the *complaint de nature* to Meung is correct.

[3] "La Metallurgie in France," 1894, p. 2.

the honoured names of Berzelius, Wöhler, and Winkler would be demanded.[1]

Mr. Vautin has recently shown that granulated aluminium may readily be prepared, and that it renders great service when employed as a reducing agent. He has lent me many specimens of rarer metals which have been reduced to the metallic state by the aid of this finely-granulated aluminium; and I am indebted to his assistant, Mr. Picard, who was lately one of my own students at the Royal School of Mines, for aid in the preparation of certain other specimens which have been isolated in my laboratory at the Mint.

The experiment you have just seen enables me to justify a statement I made respecting the discriminating action which certain metals appear to exert. The relation of aluminium to other metals is very singular. When, for instance, a small quantity of aluminium is present in cast-iron, it protects the silicon, manganese, and carbon from oxidation.[2] The presence of silicon in aluminium greatly adds to the brilliancy with which aluminium itself oxidises and burns.[3] It is also asserted that aluminium, even in small quantity, exerts a powerful protective action against the oxidation of the silver-zinc alloy which is the result of the desilverisation of lead by zinc.

Moreover, heat aluminium in mass to redness in air, where oxygen may be had freely, and a film of oxide which is formed will protect the mass from further oxidation. On the other hand, if finely divided aluminium finds itself in the presence of an oxide of a rare metal, at an elevated temperature, it at once acts with energy and promptitude, and releases the rare metal from the bondage of oxidation. I trust, therefore, you will consider my claim that a metal may possess moral attributes has

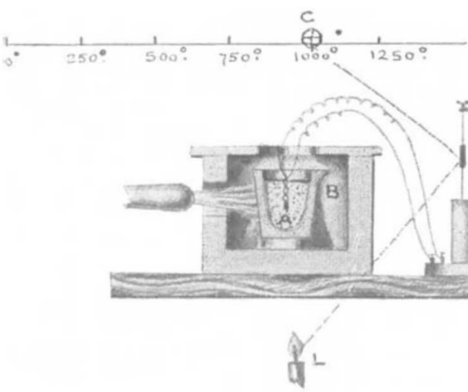

FIG. 1

been justified. Aluminium, moreover, retains the oxygen it has acquired with great fidelity, and will only part with it again at very high temperatures, under the influence of the electric arc in the presence of carbon.

[A suitable mixture of red-lead and aluminium was placed in a small crucible heated in a wind furnace, and in two minutes an explosion announced the termination of the experiment. The crucible was shattered to fragments.]

The aluminium loudly protests, as it were, against being entrusted with such an easy task, as the heat engendered by its oxidation had not to be used in melting a difficultly fusible metal like chromium, the melting point of which is higher than that of platinum.

It is admitted that a metal will abstract oxygen from another metal if the reaction is more exothermic than that by which the oxide to be decomposed, was originally formed. The heat of formation of alumina is 391 calories, that of oxide of lead is 51 calories; so that it might be expected that metallic aluminium, at an elevated temperature, would readily reduce oxide of lead to the metallic state.

The last experiment, however, proved that the reduction of oxide of lead by aluminum is effected with explosive violence, the temperature engendered by the reduction being sufficiently high to volatilise the lead. Experiments of my own show that the explosion takes place with much disruptive power when aluminium reacts on oxide of lead *in vacuo*, and that if coarsely ground, fused litharge be substituted for red lead, the action is only accompanied by a rushing sound. The result is, therefore, much influenced by the rapidity with which the reaction can be transmitted throughout the mass. It is this kind of experiment which makes us turn with such vivid interest to the teaching of the school of St. Claire Deville, the members of which have rendered such splendid services to physics and metallurgy. They do not advocate the employment of the mechanism of molecules and atoms in dealing with chemical problems, but would simply accumulate evidence as to the physical circumstances under which chemical combination and dissociation take place, viewing these as belonging to the same class of phenomena as solidification, fusion, condensation, and evaporation. They do not even insist upon the view that matter is minutely granular, but in all cases of change of state, make calculations on the basis of work done, viewing changed "internal energy" as a quantity which should reappear when the system returns to the initial state.

A verse, of some historical interest, may appeal to them. It occurs in an old poem to which I have already referred as being connected with the *Roman de la Rose*, and it expresses nature's protest against those who attempt to imitate her works by the use of mechanical methods. The "argument" runs thus:—

> "Comme nature se complaint,
> Et dit sa douleur et son plaint,
> A ung sot soffleur sophistique,
> Qui n'use que d'art méchanique."

If the "use of mechanical art" includes the study of chemistry on the basis of the mechanics of the atoms, I may be permitted to offer the modern school the following rendering of nature's plaint:—

> "How nature sighs without restraint,
> And grieving makes her sad complaint
> Against the subtle sophistry
> Which trusts atomic theory."

An explosion such as is produced when aluminium and oxide of lead are heated in presence of each other, which suggested the reference to the old French verse, does not often occur, as in most cases the reduction of the rarer metals by aluminium is effected quietly.

Zirconium is a metal which may be so reduced. I have in this way prepared small quantities of zirconium from its oxide, and have formed a greenish alloy of extraordinary strength by the addition of $\frac{2}{10}$ per cent. of it to gold, and there are many circumstances which lead to the belief that the future of zirconium will be brilliant and useful. I have reduced vanadium and uranium from its oxide by means of aluminium as well as manganese, which is easy, and titanium, which is more difficult. Tungsten, in fine specimens, is also before you, and allusion will be made subsequently to the uses of these metals. At present I would draw your attention to some properties of titanium which are of special interest. It burns with brilliant sparks in air; and as few of us have seen titanium burn, it may be well to burn a little in this flame. [Experiment performed.] Titanium appears to be, from the recent experiments of M. Moissan, the most difficultly fusible metal known; but it has the singular property of burning in nitrogen—it presents, in fact, the only known instance of vivid combustion in nitrogen.[1]

Titanium may be readily reduced from its oxide by the aid of aluminium. Here are considerable masses, sufficiently pure for many purposes, which I have recently prepared in view of this lecture.

The other method by which the rarer metals may be isolated is that which involves the use of the electrical furnace. In this connection the name of Sir W. Siemens should not be forgotten. He described the use of the electric arc-furnace in which the carbons were arranged vertically, the lower carbon being replaced by a carbon crucible, and in 1882 he melted in such a furnace no less than ten pounds of platinum during an experiment at which I had the good fortune to assist. It may fairly be claimed that the large furnaces with a vertical carbon in which aluminium and other metals are now reduced by the combined electrolytic action and tearing temperature of the arc, are the direct outcome of the work of Siemens.

In the development of the use of the electric arc for the isolation of the rare, difficultly fusible, metals Moissan stands

[1] An interesting paper, by H. F. Keller, on the reduction of oxides of metals by other metals, will be found in the *Journal* of the American Chemical Society, December 1894, p. 833.
[2] *Bull. Soc. Chim.* Paris, vol. xi. 1894, p. 377.
[3] "Ditte Leçons sur les Métaux," part ii. 1891, p. 206.

[1] Lord Rayleigh has since stated that titanium does not combine with argon; and M. Guntz points out that lithium in combining with nitrogen produces incandescence.

in the front rank. He points out[1] that Deprez[2] used in 1849, the heat produced by the arc of a powerful pile; but Moissan was the first to employ the arc in such a way as to separate its heating effect from the electrolytic action it exerts. This he does by placing the poles in a horizontal position, and by reflecting their heat into a receptacle below them. He has shown, in a series of classical researches, that employing 800 amperes and 110 volts a temperature of at least 3500° may be attained, and that many metallic oxides which until recently were supposed to be irreducible may be readily made to yield the metal they contain.[3]

A support or base for the metal to be reduced is needed, and this is afforded by magnesia, which appears to be absolutely stable at the utmost temperatures of the arc. An atmosphere of hydrogen may be employed to avoid oxidation of the reduced metal, which, if it is not a volatile one, remains at the bottom of the crucible almost always associated with carbon—forming, in fact, a carbide of the metal. I want to show you the way in which the electric furnace is used, but unfortunately the reductions are usually very tedious, and it would be impossible to actually show you much if I were to attempt to reduce before you any of the rarer metals; but as the main object is to show you how the furnace is used, it may be well to *boil* some silver at a temperature of some 2500°, and subsequently to melt chromium in the furnace (Fig. 2). This furnace consists of a clay receptacle, A, lined with magnesia, B. A current of 60 amperes and 100 volts is introduced by the carbon poles, C, C; an electro-magnet, M, is provided to deflect the arc on to the metal to be melted. [By

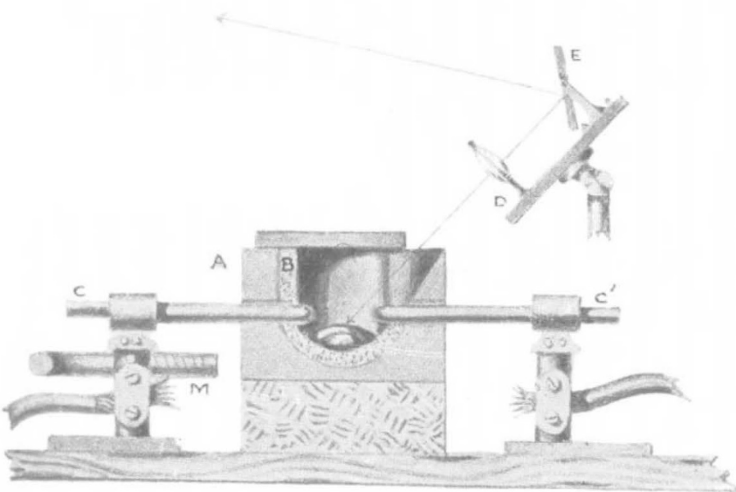

FIG. 2.

means of a lens and mirror, D, E, the image of the arc and of the molten metal was projected on to a screen. For this purpose it was found convenient to make the furnace much deeper than would ordinarily be the case.]

It must not be forgotten that the use of the electric arc between carbon poles renders it practically impossible to prepare the rare metals without associating them with carbon, often forming true carbides; but it is possible in many cases to separate the carbon by subsequent treatment. Moissan has, however, opened up a vast field of industrial work by placing at our disposal practically all the rarer infusible metals which may be reduced from oxides, and it is necessary for us now to consider how we may best enter upon our inheritance. Those members of the group which we have known long enough to appreciate are chromium and manganese, and these we have only known free from carbon for a few months. In their carburised state they have done excellent service in connection with the metallurgy of steel; and may we not hope that vanadium, molybdenum, titanium, and uranium will render still greater services? My object in this lecture is mainly to introduce you to these metals, which hitherto few of us have ever seen except as minute cabinet specimens, and we are greatly indebted to M. Moissan for sending us beautiful specimens of chromium, vanadium, uranium, zirconium, tungsten, molybdenum, and titanium. [These were exhibited.]

The question naturally arises: Why is the future of their usefulness so promising? Why are they likely to render better service than the common metals with which we have long been familiar? It must be confessed that as yet we know but little what services these metals will render when they stand alone; we have yet to obtain them in a state of purity, and have yet to study their properties, but when small quantities of any of them are associated or alloyed with other metals, there is good reason to believe that they will exert a very powerful influence. In order to explain this, I must appeal to the physical method of inquiry to which I have already referred.

It is easy to test the strength of a metal or of an alloy; it is also easy to determine its electrical resistance. If the mass stands these tests well, its suitability for certain purposes is assured; but a subtle method of investigation has been afforded by the results of a research entrusted to me by a committee of

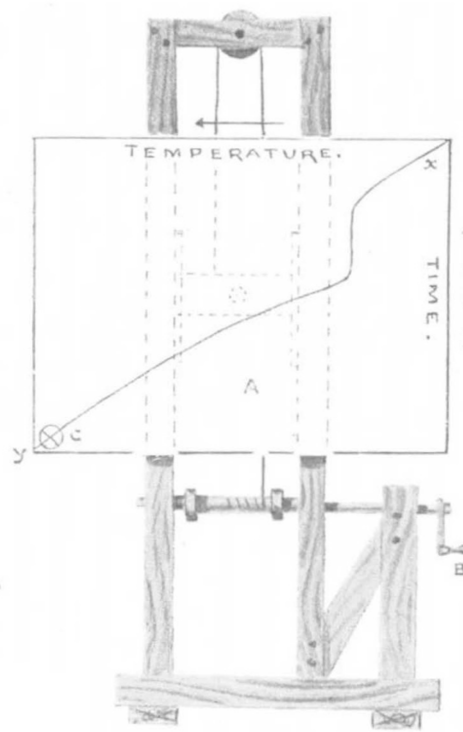

FIG. 3.

the Institution of Mechanical Engineers, over which Dr. Anderson, of Woolwich, presides. We can now gather much information as to the way in which a mass of metal has arranged itself during the cooling from a molten condition, which is the necessary step in fashioning it into a useful form; it is possible to gain insight into the way in which a molten mass of a metal or an alloy, molecularly settles itself down to its work, so to speak, and we can form conclusions as to its probable sphere of usefulness.

The method is a graphic one, such as this audience is familiar with, for Prof. Victor Horsley has shown in a masterly way that traces on smoked paper may form the record of the heart's action under the disturbing influence caused by the intrusion of a bullet into the human body. I hope to show you by similar records the effect, which though disturbing is often far from prejudicial, of the introduction of a small quantity of a foreign element into the "system" of a metal, and to justify a statement which I made earlier, as to the applicability of physiological methods of investigation to the study of metals. In order that the nature of this method may be clear, it

1 *Ann. de Chim. et de Phys.* vol. iv. 1895, p. 365.
2 *Comptes rendus*, vol. xxix. 1849, p. 48, 545, 712.
3 The principal memoirs of M. Moissan will be found in the *Comptes rendus*, vol. cxv. 1892, p. 1031; *ibid.* vol. cxvi. 1893, pp. 347, 349, 549, 1222, 1225, 1429; *ibid.* vol. cxix. 1894, pp. 15, 20, 935; *ibid.* vol. cxx. 1895, p. 290. The more important of the metals he has isolated are uranium, chromium, manganese, zirconium, molybdenum, tungsten, vanadium, and titanium. There is an important paper by him on the various forms of the electric furnace in the *Ann. de Chim. et de Phys.* vol. iv. 1895, p. 365

must be remembered that if a thermometer or a pyrometer, as the case may be, is plunged into a mass of water or of molten metal, the temperature will fall continuously until the water or the metal begins to become solid; the temperature will then remain constant until the whole mass is solid, when the downward course of the temperature is resumed. This little thermo-junction is plunged into a mass of gold; an electric current is, in popular language, generated, and the strength of the current is proportional to the temperature to which the thermo-junction is raised; so that the spot of light from a galvanometer to which the thermo-junction is attached enables us to measure the temperature, or, by the aid of photography, to record any thermal changes that may occur in a heated mass of metal or alloy.

It is only necessary for our purpose to use a portion of the long scale, and to make that portion of the scale movable. Let me try to trace before you the curve of the freezing of pure gold. It will be necessary to mark the position occupied by the movable spot of light at regular intervals of time during which the gold is near 1045°, that is, while the metal is becoming solid. Every time a metronome beats a second, the white screen A (Fig. 3), a sheet of paper will be raised a definite number of inches by the gearing and handle, B, and the position successively occupied by the spot of light, C, will be marked by hand.

You see that the time-temperature curve, x, y, so traced is not continuous. The freezing point of the metal is very clearly marked by the horizontal portion. If the gold is very pure the angles are sharp, if it is impure they are rounded. If the metal had fallen below its freezing point without actually becoming solid, that is, if superfusion or surfusion had occurred, then there would be, as is often the case, a dip where the freezing begins, and then the temperature curve rises suddenly.

If the metal is alloyed with large quantities of other metals, then there may be several of these freezing points, as successive groups of alloys fall out of solution. The rough diagrammatic method is not sufficiently delicate to enable me to trace the subordinate points, but they are of vital importance to the strength of the metal or alloy, and photography enables us to detect them readily.

Take the case of the tin-copper series; you will see that as a mass of tin-copper alloy cools, there are at least two distinct freezing points. At the upper one the main mass of the fluid alloy became solid: at the lower, some definite group of tin and copper atoms fall out, the position of the lower point depending upon the composition of the mass.

(To be continued.)

THE INSTITUTION OF MECHANICAL ENGINEERS.

THE ordinary spring meeting of the Institution of Mechanical Engineers was held on Wednesday and Friday evening of last week, April 24 and 26, the President, Prof. Alexander B. W. Kennedy, F.R.S., occupying the chair both evenings. The following was down on the agenda of the meeting: Adjourned discussion on Captain H. Riall Sankey's paper on "Governing of Steam Engines by Throttling and by Variable Expansion"; the "Third Report to the Alloys Research Committee," by Prof. W. C. Roberts-Austen, C.B., F.R.S., "Appendix on the Elimination of Impurities during the Process of making 'Best Selected' Copper," by Mr. Allan Gibb; "Appendix on the Pyrometric Examination of the Alloys of Copper and Tin," by Mr. Alfred Stansfield.

In the discussion on Captain Sankey's paper a number of members spoke. As a general result it may be stated that the position taken by the author in his paper was supported, viz.: that for certain purposes, governing by means of the throttle valve was to be preferred; whilst under other conditions variable expansion governors would have advantages over the other method. Captain Sankey in his contribution impartially discussed both systems, and his paper may be taken as a good model of what a memoir of the kind should be, no undue bias being shown on either side.

The report of Prof. Roberts-Austen was perhaps of even greater interest than those which have preceded it; whilst the two appendices of Messrs. Gibb and Stansfield discussed important practical details. A request had been made that the investigations of Warburg and Tegetmeier on molecular porosity, and their observations on the "Electrolysis of Glass"[1] should be repeated. It will be remembered that atoms of sodium were made to pass through glass at a temperature of 200° C. under the influence of the electric current. Lithium atoms were then made to follow along the tracks or molecular galleries left by the sodium, the lithium having a lower atomic volume and weight than the sodium. When potassium, having a higher atomic weight and volume, was substituted, it was not found possible to trace out the sodium. We are thus, the author said confronted with a molecular porosity which can in a sense be gauged, and the mechanical influence of the volume of the atom is thus made evident. It will also be evident that there is a direct connection between the properties of a mass and the volume of its atoms. The results previously obtained were entirely confirmed and somewhat extended in the experiments the author had undertaken. The septa, or dividing partitions, in these fresh experiments, were made mostly of soda glass, of which thick bulbs were blown from barometer tube. In most of the experiments the glass was electrolysed, using mercury and an amalgam of some metal as cathode and anode respectively. The temperature was from 250° to 350° C. The electromotive force employed was 100 volts, and the current in the case of the sodium experiments averaged about one-thousandth of an ampere, and was sometimes as high as one-fiftieth of an ampere. When the glass bulbs were employed they soon became cracked, and the free passage of the current fused the glass, forming a well-rounded hole. In each experiment a safety fuse was placed in series, to stop the current in case of breakage. In experiments in which sodium amalgam had been placed in the bulb and pure mercury outside, sodium passed into the mercury to the extent of 0·03 gramme or 0·46 grain. In one experiment, which lasted eighteen hours, the amount of sodium found in the mercury was 0·0131 gramme, or 0·2022 grain. The quantity of electricity which passed through the glass was measured by the aid of an electrolytic cell placed in series, in which copper was deposited to the amount of 0·0206 gramme, or 0·3179 grain. Calculating the number of coulombs of electricity passed by means of the electrolysis of glass, the number 55 is found, and by the electrolysis of copper sulphate, 62; thus showing, as well as a rough approximate experiment could, that the passage of sodium into the mercury follows the ordinary law of electrolysis. It is doubtful whether the sodium from the amalgam actually penetrated right through the glass; but there can be no question that it replaced a considerable proportion of the sodium which the glass contained. An attempt to pass potassium through the same glass failed. Gold was then used, both in the form of amalgam and dissolved in metallic lead, but in the latter case the temperature employed was, of course, higher. No gold was found to have been transmitted through the glass; but the glass employed became coloured by gold, and minute spangles of the metal were found embedded in it. The same result was obtained when copper was used as an amalgam; and in this case minute nodules of copper were deposited below the surface of the glass, an effect which is highly suggestive in connection with the formation of mineral veins by earth currents. Sodium amalgam placed in a bulb and surrounded with mercury, but with no current, gave negative results, showing that simple diffusion did not play any important part in the results obtained. The fact that a current passes at all through glass is a proof that electrolytic action has taken place; so that, even if a metal be not actually transmitted through glass, the passage of a current indicates that sodium, potassium, or other metallic constituent of the glass, must be leaving it, and is probably replaced by one or more of the metals in the metallic bath which constitutes the anode.

The author next referred to an addition made to the recording pyrometer by means of which increased sensitiveness was obtained. The galvanometer, which affords the means of measuring the temperatures of the masses of metal or alloy under examination, may occupy one of two positions: it may either be nearer to the slit through which the ray of light falls upon the photographic plate, or it may be further away from it. It will be evident that two galvanometers may be used simultaneously, with the light from their respective mirrors playing

[1] E. Warburg, "Ueber die Elektrolyse des festen Glases," *Wiedemann's Annalen*, vol. xxi. 1884, p. 622. E. Warburg and F. Tegetmeier, "Ueber die elektrolytische Leitung des Bergkrystalls," *Wiedemann's Annalen*, vol. xli., 1890, page 18. E. Warburg, "Ueber eine Methode Natrium Metall in geisslersche Rühren einzuführen," *Wiedemann's Annalen*, vol. xl. 1890, page 1.