Students' simple apparatus for determining the mechanical equivalent of heat was exhibited by Prof. Ayrton. The apparatus enables the heat equivalent of a watt-second to be experimentally ascertained with an error of less than 1 per cent., without any allowance having to be made for heat lost by conduction, convection, or radiation. It will give the result when 2000 c.c. of water are warmed for two minutes with a current of about 30 amperes, at a pressure of about 10 volts. The conductor consisted of 10 feet of manganin rolled into a thin strip to give off heat rapidly, and formed into a double grid so as to be used as an efficient water stirrer. The cross section of the flexible leads was such that practically no flow of heat occurred between them and the grid when a current of about 30 amperes is used.

Photographs of sections of gold nuggets etched to show crystalline structure, were exhibited by Prof. A. Liversidge. Gold nuggets, on being cut through or sliced and polished, and etched by chlorine water, were found to exhibit well-marked crystalline structure, closely resembling the Widmanstatt figures shown by most metallic meteorites, except that, in the nuggets, the crystals are more or less square in section, and show faces which evidently belong to the octahedron and cube.

Phenomena associated with the formation of cloud were experimentally illustrated by Mr. W. N. Shaw. Clouds formed by mixture of two currents of air of different temperatures were shown in a large glass globe. The currents were due to convection. The motion of the clouds gave an indication of the motion of the air. Under suitable conditions the motion assumed a gyratory or "cyclonic" character. A second globe was arranged to show the formation of a cloud by the dynamical cooling of air, consequent upon a sudden expansion equivalent to an elevation of about 10,000 feet. The water globules could be seen to fall slowly. A light was arranged at the back of the globe to show (under favourable circumstances) coloured coronæ surrounding a central bright spot. Two other globes were used in conjunction to demonstrate the modification which cloud formation introduces into the dynamical cooling of air. In one of the pair condensation diminished the fall of temperature incidental to sudden expansion, and the difference was indicated by the final pressure-difference between the globes.

There were two barometric exhibits, one a mechanical device for performing temperature corrections in barometers, by Dr. John Shields, and a new form of barometer, exhibited by Dr. J. Norman Collie.

The preparation of acetylene from calcic carbide was shown by Prof. V. B. Lewes. The combustion of acetylene for illuminating purposes attracted great attention. Calcic carbide, formed by the action of carbon on lime at the temperature of the electric furnace, was decomposed by water with evolution of acetylene. The remarkable brilliancy of the flame produced may be judged by the fact that the acetylene when consumed in suitable burners develops an illuminating value of 240 candles per 5 cubic feet of gas.

Generalised frequency curves were exhibited by the Applied Mathematics Department of University College, London, and also compound frequency curves, a harmonic analyser, and a biprojector.

Mr. T. Clarkson showed his circlographs for drawing and measuring circular curves of any large radius without requiring the centre, with examples of curves. The construction of these instruments is based upon a recent discovery that it is possible to cut a flat plate of steel (of uniform thickness and temper) into a certain form, which imparts to it the property of bending always into circular curves.

Mr. R. Inwards had on view examples of curious mortise joints in carpentry, all made without compression or veneering, and Mr. Hermann Kühne exhibited Junkers' patent calorimeter.

The radial cursor, a new addition to the slide rule, was shown by Mr. F. W. Lanchester. This cursor added to the slide rule makes the rule applicable at once to the calculation of whole or fractional powers, and renders it specially useful for the solution of problems in thermodynamics.

The Cambridge Scientific Instrument Company showed a new form of rocking microtome and a new form of spectrometer, and an improved form of Donkin's harmonograph. This was a modification of Donkin's harmonograph, and draws, on a moving strip of paper, a curve compounded of two simple harmonic motions.

During the evening demonstrations by means of the electric lantern took place in the meeting room.

Prof. A. C. Haddon showed lantern slides illustrating the ethnography of British New Guinea. The slides illustrated the physical characters of different tribes inhabiting British New Guinea, some of the occupations of the people, several kinds of dances, and the distribution of dance-masks. Evidence was given in support of the view that British New Guinea is inhabited by true dark Papuans, and by two distinct lighter Melanesian peoples, one of whom may have come from the New Hebrides, and the other from the Solomon Islands.

Lord Armstrong showed some of the results of his recent experiments on the electric discharge in air. The figures exhibited by means of the lantern, showed various phases, hitherto unobserved, of the brush discharge accompanying the electric spark. They showed also the remarkable modifying effect of induction on the results obtained. The luminous effects were delineated by instantaneous photography, and the mechanical effects by the electric action on dust plates. The spark itself had to be taken in a dark box on a shunt line, as its strong light and violent action would otherwise have been incompatible with the photographic and mechanical methods used in the experiments; but nearly the same tensions were obtained outside the box as within.

THE RARER METALS AND THEIR ALLOYS.[1]

II.

NOW turn to more complex curves taken on one plate by making the sensitised photographic plate seize the critical part of the curve, the range of the swing of the mirror from hot to cold being some sixty feet. The upper curve (Fig. 4) gives the freezing point of bismuth, and you see that surfusion, *a*, is clearly marked, the temperature at which bismuth freezes being 268°. The lower point represents the freezing point of tin, which we know is 231° C., and in it surfusion, *b*, is also clearly marked. The lowest curve of all contains a subordinate point in the cooling curve of standard gold, and this subordinate point, *c*, which you will observe is lower than the freezing point of tin, is caused by the falling out of solution of a small portion of bismuth, which alloyed itself with some gold atoms, and "fell out" below the freezing point not only of bismuth itself but of tin. Now gold with a low freezing point in it like this is found to be very brittle, and we are in a fair way to answer the question why $\frac{2}{10}$ per cent of zirconium doubles the strength of gold, while $\frac{2}{10}$ per cent of thallium, another rare metal, halves the strength. In the case of the zirconium the subordinate point is very high up, while in the case of the thallium it is very low down. So far as my experiments have as yet been carried, this seems to be a fact which underlies the whole question of the strength of metals and alloys. If the subordinate point is low, the metal will be weak; if it is high in relation to the main setting point, then the metal will be strong, and the conclusion of the whole matter is this.—The rarer metals which demand for their isolation from their oxides either the use of aluminium or the electric arc, never, so far as I can ascertain, produce low freezing points when they are added in small quantities to those metals which are used for constructive purposes. The difficultly fusible rarer metals are never the cause

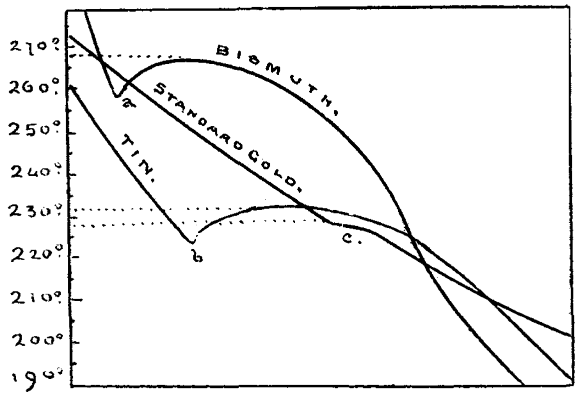

FIG. 4.

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[1] A Friday evening discourse, delivered at the Royal Institution on March 15, by Prof. Roberts-Austen, C.B., F.R.S. (Continued from p. 18.)

of weakness, but always confer some property which is precious in industrial use. How these rarer metals act, why the small quantities of the added rare metals permeate the molecules, or, it may be the atoms, and strengthen the metallic mass, we do not know; we are only gradually accumulating evidence which is afforded by this very delicate physiological method of investigation.

As regards the actual temperatures represented by points on such curves, it will be remembered that the indications afforded by the recording pyrometer are only relative, and that gold is one of the most suitable metals for enabling a high, fixed point to be determined. There is much trustworthy evidence in favour of the adoption of 1045° as the melting point hitherto accepted for gold. The results of recent work indicate, however, that this is too low, and it may prove to be as high as 1061·7, which is the melting point given by Heycock and Neville[1] in the latest of their admirable series of investigations to which reference was made in my Friday evening lecture of 1891.

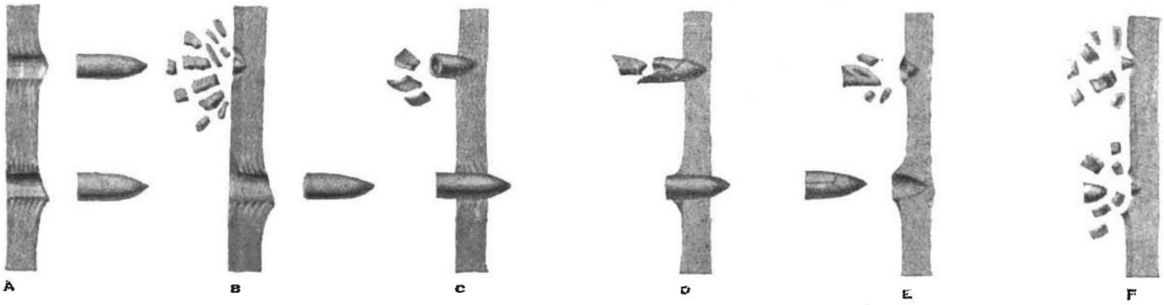
It may be well to point to a few instances in which the industrial use of such of the rarer metals, as have been available in sufficient quantity, is made evident. Modern developments in armour-plate and projectiles will occur to many of us at once. This diagram (Fig 5) affords a rapid view of the progress which has been made, and in collecting the materials for it from various sources, I have been aided by Mr. Jenkins. The effect of projectiles of approximately the same weight, when fired with the same velocity against six-inch plates, enables comparative results to be studied, and illustrates the fact that the rivalry between artillerists who design guns, and metallurgists who attempt to produce both impenetrable armour-plates and irresistible projectiles, forms one of the most interesting pages in our national history. When metallic armour was first applied to the sides of war vessels, it was of wrought iron, and proved to be of very great service by absolutely preventing the passage of ordinary cast-iron shot into the interior of the vessel, as was demonstrated during the American Civil War in 1866. It was found to be necessary, in order to pierce the plates, to employ harder and larger projectiles than those then in use, and the chilled cast iron shot with which Colonel Palliser's name is identified proved to be formidable and effective. The point of such a projectile was sufficiently hard to retain its form under impact with the plate, and it was only necessary to impart a moderate velocity to a shot to enable it to pass through the wrought-iron armour (A, Fig. 5).

It soon became evident that in order to resist the attack of such projectiles with a plate of any reasonable thickness, it would be necessary to make the plate harder, so that the point of the projectile should be damaged at the moment of first contact, and the reaction to the blow distributed over a considerable area of the plate. This object could be attained by either using a steel plate in a more or less hardened condition, or by employing a plate with a very hard face of steel, and a less hard but tougher back. The authorities in this country during the decade, 1880-90, had a very high opinion of plates that resisted attack without the development of through-cracks, and this led to the production of the compound plate. The backs of these plates (B, Fig. 5) are of wrought iron, the fronts are of a more or less hard variety of steel, either cast on, or welded on by a layer of steel of an intermediate quality cast between the two plates. Armour-plates of this kind differ in detail, but the principle of their construction is now generally accepted as correct.

Such plates shown by plate B, resisted the attack of large Palliser shells admirably, as when such shells struck the plate they were damaged at their points, and the remainder of the shell was unable to perforate the armour against which it was directed. An increase in the size of the projectiles led, however, to a decrease in the resisting power of the plates, portions of the hard face of which would at times be detached in flakes from the junction of the steel and the iron. An increase in the toughness of the projectiles by a substitution of forged chrome-steel for chilled iron (see lower part of plate B), secured a victory for the shot, which was then enabled to impart its energy to the plate faster than the surface of the plate itself could transmit the energy to the back. The result was that the plate was overcome, as it were, piecemeal; the steel surface was not sufficient to resist the blow itself, and was shattered, leaving the projectile an easy victory over the soft back. The lower part of plate, B (in Fig. 5), represents a similar plate to that used in the *Nettle* trials of 1888.[1] It must not be forgotten in this connection, that the armour of a ship is but little likely to be struck twice by heavy projectiles in the same place, although it might be by smaller ones.

Plates made entirely of steel, on the other hand, were found, prior to 1888, to have a considerable tendency to break up completely when struck by the shot. It was not possible, on that account, to make their faces as hard as those of compound plates; but while they did not resist the Palliser shot nearly so well as the rival compound plate, they offered more effective resistance to steel shot (see lower part of plate C, Fig. 5).

ATTACK OF 6-INCH ARMOUR-PLATES BY 4.72-INCH SHELLS, WEIGHING 57.2 LBS.



Wrought iron. 1888.

Compound plate. 1888.

Steel. 1888.

Steel. 1894.

Nickel-steel. 1894.

Harveyed, nickel-steel. 1894.

FIG. 5.—The upper series of projectiles are Palliser chilled-iron shells, and the lower are chrome-steel. In each case the velocity of the projectile is approximately 1640 foot-seconds, and the energy 1070 foot-tons.

It appears that Berthier recognised, in 1820, the great value of chromium when alloyed with iron; but its use for projectiles, although now general, is of comparatively recent date, and these projectiles now commonly contain from 1·2 to 1·5 per cent. of chromium, and will hold together even when they strike steel plates at a velocity of 2000 feet per second,[2] (see lower part of plate D); and unless the armour-plate is of considerable thickness, such projectiles will even carry bursting charges of explosives through it. [The behaviour of a chromium-steel shell, made by Mr. Hadfield, was dwelt upon, and the shell was exhibited.]

It now remained to be seen what could be done in the way of toughening and hardening the plates so as to resist the chrome steel shot. About the year 1888, very great improvements were made in the production of steel plates. Devices for hardening and tempering plates were ultimately obtained, so that the latter were hard enough throughout their substance to give them the necessary resisting power without such serious cracking as had occurred in previous ones. But in 1889, Mr. Riley exhibited, at the meeting of the Iron and Steel Institute, a thin plate that owed its remarkable toughness to the presence of nickel in the steel. The immediate result of this was that plates could be made to contain more carbon, and hence be harder, without at the same time having increased brittleness; such plates, indeed, could be water hardened and yet not crack.

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[1] "Trans. Chem. Soc.," vol. lxvii., 1895, p. 160.

[1] *Proceedings.* Institution of Civil Engineers, 1889, vol. xcviii. p. 1, *et seq.*

[2] *Journal* U.S. Artillery, 1893. Vol. .p. 497

The plate E (Fig. 5) represents the behaviour of nickel-steel armour. It will be seen that it is penetrated to a much less extent than in the former case; at the same time there is entire absence of cracking.

Now as to the hardening processes. Evrard had developed the use of the lead bath in France, while Captain Tressider[1] had perfected the use of the water-jet in England for the purpose of rapidly cooling the heated plates. The principle adopted in the design of the compound plates has been again utilised by Harvey, who places the soft steel or nickel-steel plate in a furnace of suitable construction, and covers it with carbonaceous material such as charcoal, and strongly heats it for a period, which may be as long as 120 hours. This is the old Sheffield process of cementation, and the result is to increase the carbon from 0·35 per cent. in the body of the plate to 0·6 per cent., or even more at the front surface, the increase in the amount of carbon only extending to a depth of two or three inches in the thickest armour.

The carburised face is then "chill-hardened," the result being that the best chrome-steel shot are shattered at the moment of impact, unless they are of very large size as compared with the thickness of the plate. The interesting result was observed lately[2] of shot doing less harm to the plate, and penetrating less, when its velocity was increased beyond a certain value, a result due to a superiority in the power of the face of the plate to transmit energy over that possessed by the projectile, which was itself damaged, when a certain rate was exceeded. At a comparatively low velocity the point of the shot would resist fracture, but the energy of the projectile is not then sufficient to perforate the plate, which would need the attack of a much larger gun firing a projectile at a lower velocity.

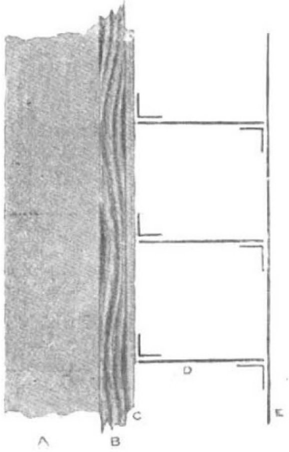

FIG. 6.—Section of Barbette of the *Majestic*.

The tendency to-day is to dispense with nickel, and to use ordinary steel, "Harveyed;"[3] this gives excellent six-inch plates, but there is some difference of opinion as to whether it is advantageous to omit nickel in the case of very thick plates, and the problem is now being worked out by the method of trial. Probably, too, the Harveyed plates will be much improved by judicious forging after the process, as is indicated by some recent work done in America. The use of chromium in the plates may lead to interesting results.

Turn for a moment to the "*Majestic*" class of ships, the construction of which we owe to the genius of Sir William White, to whom I am indebted for a section representing the exact size of the protection afforded to the barbette of the *Majestic*. [This section was exhibited and is shown as reduced to the diagram Fig. 6.] Her armour is of the Harveyed steel, which has hitherto proved singularly resisting to chromium projectiles.

In this section, A represents a 14-inch Harveyed steel armour-plate; B, a 4-inch teak backing; C, a 1¼-inch steel plate; D, ½-inch steel frames; and E, ¼-inch steel linings.

It will, I trust, have been evident that two of the rarer metals, chromium and nickel, are playing a very important part in our national defences; and if I ever lecture to you again, it may be possible for me to record similar triumphs for molybdenum, titanium, vanadium, and others of these still rarer metals.

Here is another alloy, for which I am indebted to Mr. Hadfield. It is iron alloyed with 25 per cent. of nickel, and Hopkinson has shown that its density is permanently reduced by two per cent. by an exposure to a temperature of – 30°, that is the metal expands at this temperature.

Supposing, therefore, that a ship-of-war was built in our climate of ordinary steel, and clad with some three thousand tons of such nickel-steel armour, we are confronted with the extraordinary fact that if such a ship visited the Arctic regions, it would actually become some two feet longer, and the shearing which would result from the expansion of the armour by exposure to cold would destroy the ship. Before I leave the question of the nickel-iron alloys, let me direct your attention to this triple alloy of iron, nickel and cobalt in simple atomic proportions. Dr. Oliver Lodge believes that this alloy will be found to possess very remarkable properties; in fact, as he told me, if nature had properly understood Mendeléef, this alloy would really have been an element. As regards electrical properties of alloys, it is impossible to say what services the rarer metals may not render; and I would remind you that "platinoid," mainly a nickel-copper alloy, owes to the presence of a little tungsten its peculiar property of having a high electrical resistance which does not change with temperature.

One other instance of the kind of influence the rarer metals may be expected to exert is all that time will permit me to give you. It relates to their influence on aluminium itself. You have heard much of the adoption of aluminium in such branches of naval construction as demand lightness and portability. During last autumn Messrs. Yarrow completed a torpedo boat which was built of aluminium alloyed with 6 per cent. of copper. Her hull is 50 per cent. lighter, and she is 3½ knots faster than a similar boat of steel would have been, and, notwithstanding her increased speed, is singularly free from vibration.

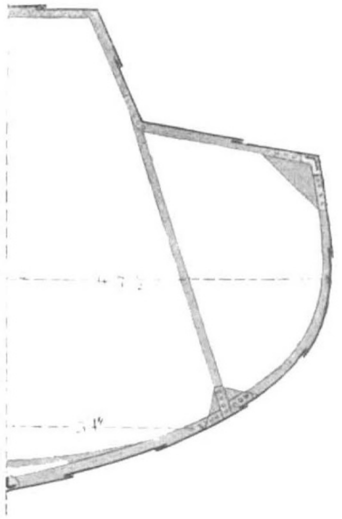

FIG. 7.—Half-section Midship of Aluminium Torpedo-boat

Her plates are $\frac{1}{10}$th inch thick, and $\frac{1}{8}$th inch where greater strength is needed. It remains to be seen whether copper is the best metal to alloy with aluminium. Several of the rarer metals have already been tried, and among them titanium. Two per cent. of this rare metal seems to confer remarkable properties on aluminium, and it should do so according to the views I have expressed, for the cooling curve of the titanium-aluminium alloy would certainly show a high subordinate freezing point.

Hitherto I have appealed to industrial work, rather than to abstract science, for illustrations of the services which the rarer metals may render. One reason for this is that at present we have but little knowledge of some of the rarer metals apart from their association with carbon. The metals yielded by treatment

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[1] Weaver, "Notes on Armour." *Journal* U.S. Artillery. Vol. iii. 1894, p. 417.

[2] Brassey's *Naval Annual*, 1894, p. 367.

[3] *Engineering*, vol. lvii., 1894, pp. 465, 530, 595.

of oxides in the electric arc are always carbides. There are, in fact, some of the rarer metals which we, as yet, can hardly be said to know except as carbides. As the following experiment is the last of the series, I would express my thanks to my assistant, Mr. Stansfield, for the great care he has bestowed in order to ensure their success. Here is the carbide of calcium which is produced by heating lime and carbon in the electric arc. It possesses great chemical activity, for if it is placed in water the calcium seizes the oxygen of the water, while the carbon also combines with the hydrogen, and acetylene is the result, which burns brilliantly. [Experiment shown.] If the carbide of calcium be placed in chlorine water, evil smelling chloride of carbon is formed.

In studying the relations of the rarer metals to iron, it is impossible to dissociate them from the influence exerted by the simultaneous presence of carbon; but carbon is a protean element—it may be dissolved in iron, or it may exist in iron in any of the varied forms in which we know it when it is free. Matthiessen, the great authority on alloys, actually writes of the "carbon-iron alloys." I do not hesitate therefore, on the ground that the subject might appear to be without the limits of the title of this lecture, to point to one other result which has been achieved by M. Moissan. Here is a fragment of pig iron highly carburised: melt it in the electric arc in the presence of carbon, and cool the molten metal suddenly, preferably by plunging it into molten lead. As cast iron expands on solidification, the little mass will become solid at its surface and will contract; but when, in turn, the still fluid mass in the interior cools, it expands against the solid crust, and consequently solidifies under great pressure. Dissolve such a mass of carburised iron in nitric acid to which chlorate of potash is added; treat the residue with caustic potash, submit it to the prolonged attack of hydrofluoric acid, then to boiling sulphuric acid, and finally fuse it with potash, to remove any traces of carbide of silicon, and you have carbon left, but—in the form of *diamonds*.

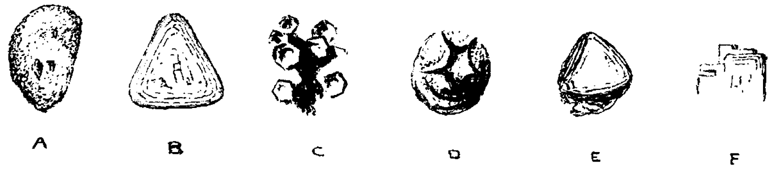

FIG. 8.—Preparations for the microscope of diamonds and other forms of carbon obtained from carburised iron.

If you will not expect to see too much, I will show you some diamonds I have prepared by strictly following the directions of M. Moissan. As he points out, these diamonds, being produced under stress, are not entirely without action on polarised light, and they have, sometimes, the singular property of flying to pieces like Rupert's drops when they are mounted as preparations for the microscope. [The images of many small specimens were projected on the screen from the microscope, and (Fig. 8, E) shows a sketch of one of these. The largest diamond yet produced by M. Moissan, is 0·5 millimetre in diameter.]

A (Fig. 8) represents the rounded, pitted surface of a diamond, and B a crystal of diamond from the series prepared by M. Moissan, drawings of which illustrate his paper.[1] The rest of the specimens, C to F, were obtained by myself by the aid of his method as above described. C represents a dendritic growth apparently composed of hexagonal plates of graphite, while D is a specimen of much interest, as it appears to be a hollow sphere of graphitic carbon, partially crushed in. Such examples are very numerous, and their surfaces are covered with minute round graphitic pits and prominences of great brilliancy. Specimen E (which, as already stated, was one of a series shown to the audience) is a broken crystal, probably a tetrahedron, and is the best crystallised specimen of diamond I have as yet succeeded in preparing. Minute diamonds, similar to A, may be readily produced, and brilliant fragments, with the lamella structure shown in F, are also often met with.

The close association of the rarer metals and carbon and their intimate relations with carbon, when they are hidden with it in iron, enabled me to refer to the production of the diamond, and afford a basis for the few observations I would offer in conclusion. These relate to the singular attitude towards metallurgical research maintained by those who are in a position to promote the advancement of science in this country. Statements respecting the change of shining graphite into brilliant diamond are received with appreciative interest; but, on the other hand, the vast importance of effecting similar molecular changes in metals is ignored.

We may acknowledge that "no nation of modern times has done so much practical work in the world as ourselves, none has applied itself so conspicuously or with such conspicuous success to the indefatigable pursuit of all those branches of human knowledge which give to man his mastery over matter."[1] But it is typical of our peculiar British method of advance to dismiss all metallurgical questions as "industrial," and leave their consideration to private enterprise.

We are, fortunately, to spend, I believe, eighteen millions this year on our Navy, and yet the nation only endows experimental research in all branches of science with four thousand pounds. We rightly and gladly spend a million on the *Magnificent*, and then stand by while manufacturers compete for the privilege of providing her with the armour-plate which is to save her from disablement or destruction. We as a nation are fully holding our own in metallurgical progress, but we might be doing so much more. Why are so few workers studying the rarer metals and their alloys? Why is the crucible so often abandoned for the test-tube? Is not the investigation of the properties of alloys precious for its own sake, or is our faith in the fruitfulness of the results of metallurgical investigation so weak that, in its case, the substance of things hoped for remains unsought for and unseen in the depths of obscurity in which metals are still left?

We must go back to the traditions of Faraday, who was the first to investigate the influence of the rarer metals upon iron, and to prepare the nickel-iron series of which so much has since been heard. He did not despise research which might possibly tend to useful results, but joyously records his satisfaction at the fact that a generous gift from Wollaston of certain of the "scarce and more valuable metals" enabled him to transfer his experiments from the laboratory in Albemarle Street to the works of a manufacturer at Sheffield.

Faraday not only began the research I am pleading for to-night, but he gave us the germ of the dynamo, by the aid of which, as we have seen, the rarer metals may be isolated. If it is a source of national pride that research should be endowed apart from the national expenditure, let us, while remembering our responsibilities, rest in the hope that metallurgy will be well represented in the Laboratory which private munificence is to place side by side with our historic Royal Institution.

ELECTRICITY AND OPTICS.

A MEMOIR of singular interest, and one of which it would be well if the contents could be made more readily accessible to students in this country, has lately been published by Prof. Righi.[2] Among the numerous papers published during the last twenty years by Prof. Righi there are several (on electric discharges, on electric shadows and photo-electric phenomena) which indicate his interest in the relations between light and electricity. Since Hertz succeeded in obtaining rays of electric force, and demonstrated the reflection, refraction and interference of electric radiation, other experimenters have endeavoured to extend and complete the analogy between electromagnetic and luminous vibrations. Thus Lodge and Howard showed that electric radiation could be concentrated by means of large lenses;

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[1] *Comptes rendus*, vol. cxviii., 1894, p. 324.

[1] *The Times*, February 22, 1895.

[2] "Sulle oscillazioni elettriche a piccola lunghezza d'onda e sul loro impiego nella produzione di fenomeni analoghie ai principali fenomeni dell' ottica." (Bologna: 1894).