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ADVANCE PROOF—*(Subject to revision.)*

THE ELECTROTHERMIC PRODUCTION OF IRON AND STEEL.

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The commercial possibility of producing iron and steel in the electric furnace is a question of considerable interest at the present time in view of the attempts which have recently been made in this direction. These attempts, which are still being continued, include the production of iron and steel by processes similar to those usually adopted, but in which the heat necessary for enabling the chemical reactions to take place and for fusing the metal and accompanying slag is furnished by means of electric power instead of by the combustion of carbonaceous fuel as at present.

At first sight this idea appears to be quite absurd in view of the high degree of efficiency already attained in the metallurgy of iron and steel, and of the much greater cost of electrical heat than of coal heat; but the fact that commercial attempts to produce iron and steel electrically have actually been undertaken shows us that it is advisable to reconsider this conclusion.

Although the electric furnace is still in its infancy and its full powers are unknown, it is quite obvious that the possibility of applying heat exactly at the required point, of producing a temperature which may be as high as that of the electric arc, and of doing this without being obliged to blow through the furnace a stream of air and other gases is one that, in certain cases, may outweigh the greater cost of electrical energy. A very high temperture can easily be produced by electrical heating in a furnace containing strongly reducing gases, and this fact has already been utilized in the production of certain alloys of iron such as ferro-chrome, ferro-tungsten, ferro-silicon, etc.,* in which cases the value of the alloy and

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* Keller, Journ. Iron and Steel Inst., 1903, I., p. 161.

the difficulty and expense of producing it by ordinary furnace methods has led to the use of the electric furnace in preference to cupola or crucible furnaces, in spite of the greater cost of electrical heat.

Is it possible, however, that the expensive electrical energy should ever be used commercially for the production of iron or steel, metals which are produced with ease and economy by ordinary furnace methods.

The answer to this question must depend mainly upon the relative cost of fuel and electrical energy. There are at present no electrical iron or steel smelting furnaces equal in size to a modern blast furnace or even an open hearth furnace, so that satisfactory demonstrations of their efficiency on a large scale are still lacking, but the great efficiency of electrical heating enables us to predict with a fair degree of accuracy the amount of energy that such furnaces would require, and such calculations are supported by the working results of small furnaces already in operation.

Taking first the direct production of pig iron from the ore, Albert Keller,* of Paris, states that he has determined, experimentally, that one ton † of pig iron requires ¼ of a kilowatt year, that is 2,190 kilowatt hours for its reduction in addition to the 350 kilos. of coke needed to effect the chemical changes.

Dr. Goldschmidt ‡ in reporting on the Stassano process, which was producing nearly pure iron from the ore, calculates that the production of one metric ton of carbon free iron from a 65% ore would require, assuming an efficiency of 80%, 3,364 horse power hours, or 2,510 kilowatt hours, which is of the same order as the previous figures. In the operation of a small Stassano furnace of about 100 kilowatt's capacity a charge of 70 kilograms of ore mixture was reduced in two hours with an expenditure of electrical power equal to 121.5 kilowatt hours, or 3,945 kilowatt hours per metric ton of iron, a figure which is 57% greater than the calculation, but the discrepancy is not surprising in view of the smallness of the test.

It should be remembered that the production of one ton of pig iron would require somewhat less heat than that of one ton of carbon free iron, both on account of the smaller amount of iron to be reduced and of the lower temperature of its melting point.

In order to realize what these figures mean, we must enquire into the price to be paid for electrical energy.

The cost of electrical energy is, indeed, the most important

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* Journ. Iron and Steel Inst., 1903, vol. I., p. 170.

† One metric ton or 2,205 lbs.

‡ Electro-chemical Industry, March, 1903, p. 247.

factor in determining the possibility of the electrical smelting of iron ores. It is by no means easy to obtain satisfactory figures. One Canadian writer states that an electrical horse power can be produced hydraulically in America for 0.05 cents per hour, while the small consumers of electric light in Montreal pay 10½ cents for the same amount, a figure which is 200 times as great as the other.

The author had obtained a number of figures for the cost of production and the selling price of electrical power, and these placed the cost of producing an electrical horse power under very favourable conditions from water power as 0.13 cents per hour while the price at which it might be bought would be 0.16 or 0.17 cents, and in exceptionally favourable cases even lower figures might be obtained, it being understood that very large outputs are considered, that these are to be employed near the source of power and that the power is to be used continuously 24 hours a day and 365 days a year.

The problem may be considered in two ways, either as a simple iron smelting proposition in which electric power is purchased with the other supplies, or as a scheme for the utilization of a water power in which the iron smelting is merely considered as a means to that end, and the price charged for electrical power would probably be different in these two cases.

Let us suppose that the iron smelter purchases power at 0.15 cents per E.H.P. hour or 0.2 cents per kilowatt hour.

If 2,500 kilowatt hours are required for the production of 1 metric ton of pig iron the cost for electrical energy would be $5.00.

Against the cost of the electrical power may be set the cost of the fuel that is saved by using electrical heat. About 0.6 of a ton of coke is saved per ton of iron produced and this at $2.50 a ton * would amount to $1.50 per ton of iron.

Dr. Goldschmidt considers that the carbon electrodes used in the electric furnace will cost about 70 cents per ton of iron, and against this figure should be set the saving effected by the absence of blowing engines and hot blast stoves.

We may, therefore, consider that the prices of fuel and of electrical power are the main factors to be considered as determining the relative cost of the two methods of smelting iron ores. It is quite clear that electrical smelting of iron ores cannot compete with the blast furnace using coke at $2.50 a ton, even in places where very cheap water power is available, but if the price of coke were $8.00 instead of $2.50, the saving of coke and blast would about equal the cost of the electrical heat, so that in localities where furnace coke cost upwards of $8.00 a ton and where cheap

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* Mineral Industry, vol. XI., page 135, average price at ovens in the United States during 1902.

water power could be obtained, it might be better to smelt iron ores electrically than by means of coke. Mr. Keller,* in his paper read before the Iron and Steel Institute, considers that in Brazil, Chile and New Zealand electrical smelting of iron ores would be possible and he quotes prices of coke in Brazil and Chile that would be prohibitive for the blast furnace smelting of iron ores, but it would be necessary also to consider at what price iron could be imported from outside sources, before deciding that electrical smelting of iron ores would be financially possible in any locality.

The above considerations apply to the smelting of iron ores that are equally suitable for the blast furnace and the electric furnace, but there are some ores such as iron sands and titaniferous iron ores which can only be smelted in the blast furnace with considerable difficulty † while in the electric furnace owing to the absence of a blast and to the higher temperature attainable less difficulty may be experienced. It is obvious that cases may occur in which the electric furnace, although more expensive when treating an ordinary iron ore may yet be less expensive than the blast furnace when treating certain refractory ores, and the possibilities of treating these ores at all may depend upon the possibility of smelting them electrically.

The possibility of the electrical smelting of charcoal iron should be considered as in this case, owing to the greater value of the product and the higher cost of the fuel there is a greater probability that electrical smelting may be commercially possible.

Leaving now the smelting of iron ores for the production of pig iron, let us consider the electric furnace methods of producing steel, including in this term both structural steel and the more valuable varieties such as crucible steel.

Mild steel can be made in the electric furnace by the direct reduction of pure iron ores, using only just enough carbon in the charge to reduce the oxide of iron to the metallic state.

Dr. Goldschmidt states that Stassano can produce, in his furnace, steel containing less than 0.1% of carbon, 0.01% of phosphorous and 0.06% of sulphur from ores containing nearly 0.06% each of phosphorous and sulphur. The amount of sulphur in the coal used in the charge is not mentioned.

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* Loc. cit.

† See, however, a paper by Rossi (Trans. Am. Inst. of Min. Eng., vol. XXXIII., 1903, p. 179), on the "Metallurgy of Titanium," in which he states that iron ores with 20% or 30% of titanic acid can be smelted with no more difficulty than iron ores containing that amount of silica, provided that the charges are suitably arranged, and that the resulting pig iron is of especially good quality.

As the cost of production of this steel is about the same as that of producing cast iron in the Stassano furnace, it would appear that electrically smelted steel can be obtained directly from the ore at a price that would compare with that of open hearth or Bessemer steel. For such a purpose it would probably be advisable to use particularly pure ores and coal, but as there is no need (as in the blast furnace) to have more coal or coke than is required for the reduction of the iron oxide, it might be possible to provide an excess of oxide sufficient to carry off in the slag the bulk of the phosphorous and sulphur from ordinary ores unless they were highly siliceous.

Thus the absence of fuel in the electric furnace enables it to be used for the production of either cast iron or steel directly from the ore.

The methods usually adopted by electro-metallurgists for the production of steel resemble more closely the open-hearth and crucible processes. Cast iron, obtained electrically or in the blast furnace, is melted electrically together with steel scrap and pure iron ores, the impurities in the charge are eliminated, mainly as oxides in the slag, and a metal is obtained which may retain the desired amount of carbon, or may be recarburized by suitable additions in the furnace or the casting ladle.

The electrothermic production of steel from intermediate products such as pig iron and steel scrap with the usual additions of iron ore has been attempted by several experimenters.

Kjellin's electric induction furnace is stated to be capable of producing molten steel from cold pig iron and scrap at the rate of 1 metric ton of tool steel for 800 E.H.P. hours,* the cost for power being, in this case, about one-fourth of that incurred in the production of pig iron from the ore—that is about $1.25 per metric ton of steel.

The conditions were exceptionally favourable as charcoal iron was used, but, on the other hand, the use of molten pig iron would have further reduced the expense for power. The steel was said to be exceptionally good and this was attributed to the absence of dissolved gases. Very little exact information is available in this connection, but it is considered that the superiority of open hearth steel over Bessemer steel and of crucible steel over open hearth steel is due, not entirely to a greater degree of freedom from the ordinary metalloids present in steel, but in part, at least, to the degree of freedom from dissolved gases, such as oxygen, nitrogen

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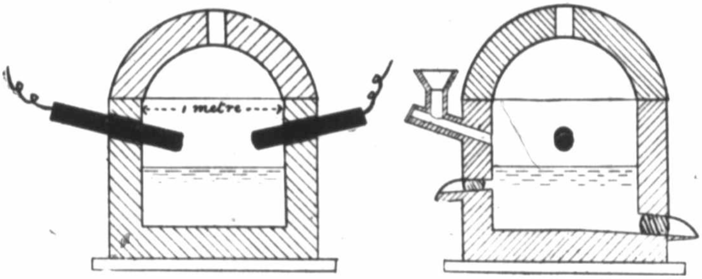
* This figure is an estimate of the output from a 1,000 H.P. furnace, the actual results obtained with a furnace of 200 H.P. were considerably more costly. Electro-Chemical Industry, vol. I., 1903, p. 576.

or hydrogen ; these gases being likely to be most abundant in Bessemer steel and least abundant in crucible steel.

Probably the greatest field of usefulness of the electric furnace in the metallurgy of iron and steel will be in the production of crucible steel. As it still pays to fuse this material in small amounts in crucibles, in order to protect it from the gases unavoidably present in an open hearth furnace, it seems probable that the electric furnace which can fuse steel more cheaply than the crucible process and can protect it quite as effectually from any gases that may be found objectionable, must replace the crucible furnace.

It may also be expected to partly replace the open hearth furnace, in the production, for example, of the more expensive varieties of steel in which the expense of fusing is of less importance than the soundness of the product.

Very many different types of furnace have been used for the electro-thermic smelting of iron ores or the production of steel, but they may all be placed in one of two classes :—(1) furnaces heated by means of an electric arc and (2) furnaces heated by the passage of an electric current through the charge itself or through some poorly conducting part of the furnace.



THE STASSANO FURNACE.*

Fig. 1.

The Stassano and Heroult furnaces are examples of arc furnaces, and the Keller, Harmet and Kjellin furnaces depend upon the heating effect of an electric current flowing through the charge itself.

A few of these furnaces will now be shortly described with the aid of diagramatic illustrations. More detailed information can be obtained from the original papers to which references are given.

The Stassano furnace is constructed of masonry and is lined with magnesite bricks. The working chamber is rectangular and is one metre square and one metre in height with an arched roof or lid.

The position of the carbon electrodes and the charging and tap-

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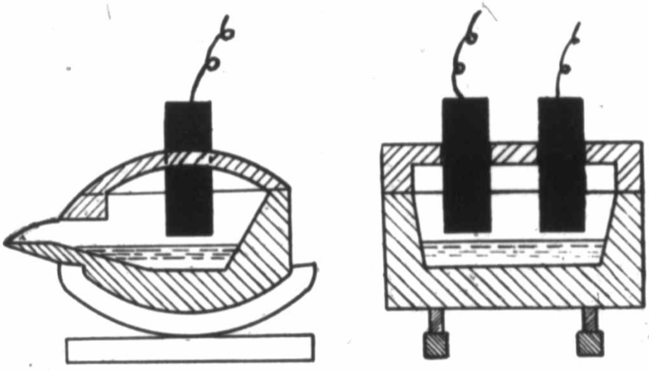
* Electro-Chemical Industry, vol. I. (1903), p. 247.

ping openings is clearly shown in figure 1, while a pipe through the lid removes the carbon monoxide resulting from the reaction.

An alternating current arc is maintained between the carbons which can be drawn apart by suitable mechanism, and the ore mixed with coal or charcoal is fed in at the side of the furnace and lies below the arc. The ore must therefore be heated by conduction and radiation from the intensely hot arc which occupies the upper part of the furnace, the method of heating being like that in the open hearth furnace.

An alternating current of 2,000 ampères at 170 volts is used in the arc which, when the furnace has become hot, traverses the whole width of the furnace and consumes about 450 horse power.

While the use of the elctric arc has certain points in its favour it seems unlikely that the greatest economy can be obtained in this way. Thus, for example, the heat can only penetrate the ore by conduction through the mass and, meanwhile, heat is being lost by conduction through the upper walls of the furnace. Also the ore is not pre-heated before entering the fusion chamber and the waste gases by passing through the arc on their way out, tend to escape at a very high temperature and so to waste heat which might have been employed in pre-heating the ore charge.



THE HEROULT FURNACE.*

Fig. 2.

In fact, both the pre-heating and the partial reduction of the ore might be effected by the hot carbon monoxide escaping from the furnace. The furnace was working in Italy on local iron ores and produced steel directly from the ores. Dr. Goldschmidt concluded that the steel would cost $18.80 per metric ton and that the process could not be economically introduced into Germany.

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* Electro-Chemical Industry, vol. I., 1903, p. 449.

The Heroult furnace is like a tilting open hearth furnace and has two vertical carbon electrodes as shown in figure 2. The current flows from one of these into the charge of ore or metal to be melted and back on to the other carbon, thus producing two arcs between the carbons and the charge which is also heated to a certain extent by the passage of the current through the molten slag and metal.

The furnace was used at first for the direct reduction of iron ores, but has been found to be more suitable for the production of steel from scrap and pig.

Heroult constructed a 400 H.P. furnace which took a charge of three tons but he gives no details as to the current employed.

The transmission of heat from the arc to the charge will probably be better in this furnace than in the Stassano furnace, but considerable losses of heat must take place through the holes in the roof through which the electrodes enter.

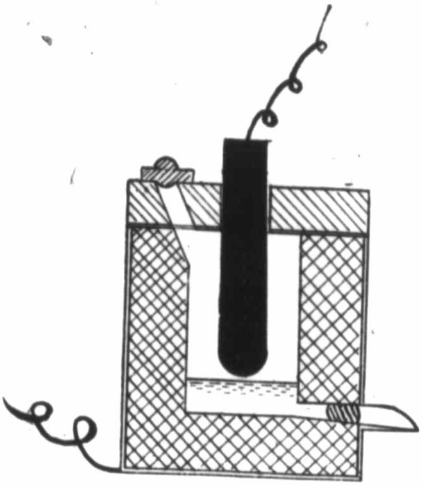

Fig. 3.

THE SIEMENS FURNACE (fig. 3), has been frequently used for the reduction of metallic oxides and for melting metals. It consists of a crucible composed wholly or in part of carbon which is connected to one of the leads, while a carbon electrode which dips into the crucible is connected to the other. An arc is formed between this electrode and the contents of the crucible, and fresh quantities of the ore can be charged in from above until the crucible is full of the molten metal and slag.

The Siemens furnace is very convenient for experimental work on the reduction of difficultly fusible metals such as chromium, tungsten, titanium, etc., and A. J. Rossi * has employed it on a larger scale for the production of ferro-titanium and similar alloys.

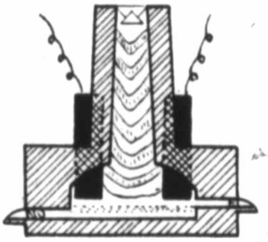

Fig. 4.

THE KELLER FURNACE † for the reduction of iron ores (fig. 4), is of the resistance type. It is similar in construction to an iron blast furnace, except that the crucible of the Keller furnace is larger in section than the stack. Four carbon electrodes are inserted vertically into this enlarged crucible and dip into the slag. The current is carried by the fused slag and metal from one electrode to another and, in this way, the charge is heated. The gases resulting from the reduction of the oxides in the ore pass up through the descending column and give up their heat to the ore and also effect the reduction of a part of the iron. The molten iron and slag are tapped out at intervals in the usual manner.

The method of heating adopted in this furnace is more conducive to economy than is the heating by electric arc as in the Stassano furnace.

The Keller furnace, moreover, is suited to continuous introduction of fresh charges of ore while the Stassano furnace is worked intermittently, which must tend to a waste of heat. Furnaces of the resistance type are also able to supply heat more or less uniformly through a large mass of ore and are, therefore, better suited than arc furnaces to large scale operations. In the Keller furnace, however, it seems probable that the current would be carried from one electrode to the other, largely through the molten iron in the crucible, and as this is a relatively good conductor, most of the heat

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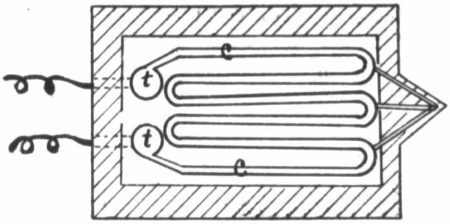
* Electro-Chemical Industry, vol. I., 1903, p. 523.

† Journ. Iron and Steel Inst., 1903, vol. I., p. 161.

would be developed in the molten slag immediately surrounding each electrode, while the middle of the furnace would tend to be cooler.

In the manufacture of steel an intermittent method of smelting must be adopted in order to adjust the composition of the steel, and such furnaces as the Stassano and Heroult would appear to be suited to this, while the reduction of ore would be best effected in the Keller or similar furnaces in which continuous smelting and pre-heating of the charge is provided for.

THE HARMET FURNACE * is similar in construction to the Keller furnace. The Keller and Harmet furnaces are employed to produce pig iron direct from the ore, and the pig iron is then tapped into a furnace of the Heroult type and converted into steel.



GIN FURNACE (Sectional plan.)
Fig. 5.

THE KJELLIN † AND THE GIN FURNACES ‡ are remarkable because in them the heat is produced by the passage of the current through the molten metal itself instead of through the fused slag or through the air above the charge.

In this method a difficulty arises on account of the low specific resistance of the metal, because an enormous current would be required to heat up a bath of moderate size. Gin endeavours to overcome this difficulty by making his furnace in the form of a canal *cc* (see fig. 5), which is folded on itself and contains the metal ; the current is introduced through water cooled metallic terminals of large section *tt*.

It is intended to tap the steel from the three loops of the canal simultaneously. The canal is formed in some neutral refractory material like chrome iron ore.

The numerous difficulties which are likely to occur in connection with the use and maintenance of such a furnace are too obvious to

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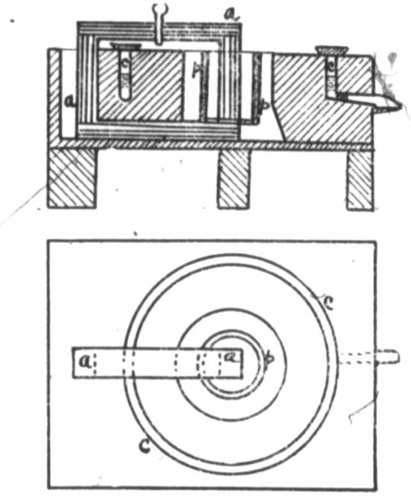
* Electro-Chemical Industry, vol. I., 1903, p. 422.

† Electro-Chemical Industry, vol. I., 1903, p. 576.

‡ Electro-Chemical Industry, vol. II., 1904, p. 20.

need mentioning, but the principle employed may, perhaps, be developed in a somewhat different form.

The Kjellin furnace (see fig. 6), consists of a circular canal *cc*, containing the metallic charge which forms the secondary winding of a transformer of which *pp* is the primary coil and *aa* the iron core. In this manner an enormous current is produced in the molten metal without the necessity for any terminals to lead in the current. A furnace of this type has been successfully used for the production of steel, but the shape of the furnace would not be conducive to the production of steel of a uniform composition.



KJELLIN FURNACE.

Fig. 6.

The Kjellin furnace has been used for the production of steel from pig and scrap, a certain amount of metal being left in the furnace to carry the current in the early stages of the following charge, but if molten pig iron were employed, this would be unnecessary.

The Gin furnace is intended to be used in the same way, but is still in the experimental stage.

The electric furnace, using carbon electrodes, is especially suited to operations of a reducing character as the electrodes are then protected from loss by oxidation. In the production of steel, however, an oxidising slag is employed to remove the impurities from the pig iron, and this slag would tend to corrode the carbon electrodes and itself to become deoxidised, and, therefore, unfit to refine the iron. This difficulty is met in the Heroult furnace by keeping the electrodes above the surface of the slag, so that the current passes into the charge by means of an arc. In the Gin furnace water cooled metal electrodes are used and in the Kjellin furnace electrodes are dispensed with altogether.

In concluding this paper, it may be worth while to consider in what way the electrothermic production of iron or steel will be likely to be of use in Canada.

The production of crucible steel in the electric furnace may be considered to be possible both technically and financially and furnaces might be installed for the production of tool steel which at present is largely imported, the electric current being produced by means of water power or by gas engines run by blast furnace gas.

The utilisation of titaniferous iron sands is a problem of considerable importance. These sands are difficult to smelt partly because sandy ores are difficult to treat in the blast furnace and partly on account of the titanium which produces a very infusible slag.

A. T. Rossi *, of New York, in a paper already referred to furnishes evidence to show that the difficulty of smelting titaniferous ores has been very much exaggerated.

He states that blast furnaces have been run for seven years in England on ores containing 40% of titanic acid, and that iron slags containing over 30% of titanic acid have been found to be perfectly satisfactory in an experimental blast furnace at Buffalo.

In smelting such ores in the blast furnace the titanium passes almost entirely into the slag, the iron produced carrying not more than a few tenths per cent. of titanium, but even this small amount appears to decidedly improve the quality of the iron for certain purposes.

In the electric furnace more strongly reducing conditions can be obtained than in the blast furnace and it is possible to smelt a titaniferous ore so as to obtain a rich ferro-titanium, the titanium being reduced to the metallic state instead of remaining as oxide in the slag.

Rossi has added such alloys to ordinary cast iron and finds that the addition of 2% or 3% of a 10% ferro-titanium increases the strength of cast iron about 20% or 30%.

In the absence of analyses it is not possible to say whether this increased strength is due to the addition of the titanium or, for example, to some difference in the amount or condition of the car-

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* Trans. Am. Inst. Min. Eng., vol. XXXIII., 1903, p. 179.

bon or other constituents of the iron, but if Mr. Rossi's conclusions are sustained it would appear probable that the electric smelting of titaniferous ores for the production of ferro-titanium may be commercially possible on a moderate scale.

The electrical smelting of these ores for ordinary pig iron has not, I believe, been attempted, and even if it were technically successful it would be difficult to produce the iron sufficiently cheaply to compete with blast furnace iron.

Dr. Stansfield's paper was illustrated by lantern slides of the electric furnaces referred to and was followed by a demonstration of the melting of metals in a Siemens furnace and a Moissan furnace; the last named being similar in construction to the Stassano furnace, and being furnished with a lens and mirror, by means of which a picture of the inside of the furnace was projected upon a screen and the audience was able to watch the metals melting down in the intense heat of the electric arc.

In the Moissan furnace direct currents are usually employed and the electric arc is forced down upon the metals to be melted by the influence of an electro-magnet placed near the furnace. The principle of the resistance type of electric furnace was demonstrated by means of a pencil of carbon, about 6 inches long and ¼ inch diameter, which was raised to a dazzling white heat by the passage of the current.