ELECTRIC FURNACES AND
THEIR INDUSTRIAL
APPLICATIONS

J. WRIGHT

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By

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WITH 57 ILLUSTRATIONS

NEW YORK

THE NORMAN W. HENLEY PUBLISHING CO

132 NASSAU STREET

1905

INTRODUCTION

THE development of the electric furnace, and the various industries with which it is associated, as a necessary auxiliary to the processes involved, is making vast strides, and is regarded with ever-increasing interest by the electro-chemist and metallurgist, who see in it possibilities, far beyond those offered, until some few years back, by the blast furnace on a commercial scale, and the oxy-hydrogen flame in the laboratory.

The limitations of temperature imposed by the methods available prior to the introduction of electricity as a heating agent, were such as to render commercially impossible many of the processes now carried out by its aid. On the other hand, the introduction of the electric furnace with its vast possibilities in the field of exceedingly high tempera-tures, gave rise at first to misuse of the power available ; i.e. the temperatures required for the various reactions were over, rather than under estimated, and, as a result, the sub-stances which should have been produced by the furnace were again split up into constituent elements, or built up into compounds other than those which it was originally intended to produce. Many of the early failures were due to this cause, especially in furnaces of the "arc" type, but experience has taught the usual lesson, and it is now possible to regulate the temperature of an electric furnace within far narrower limits than is possible with furnaces of the ordinary type, consuming coke and coal fuel.

There is hardly an electro-metallurgical process to which the electric furnace has not been applied, either experi-

mentally, or on a commercial scale, and, though many of the experimental attempts have, thus far, proved abortive, the success of the remainder justifies the hope that perseverance, aided by the incentive to progress in the shape of much valuable material, such as low-grade ores, so-called "waste products," etc., at present unworkable, may lead to increased research in this promising field, in which it is fairly safe to predict that the indefatigable worker will not go unrewarded.

The introduction of acetylene gas for illuminating purposes, has of course, been responsible for the great advance in the carbide industry, which at present constitutes the largest branch of electric furnace work, although at one time the boom, and consequent over production, threatened ruin to many works. So great, in fact, was the reaction consequent upon an overstocked market, that many factories possessing furnaces and plant for the manufacture of calcium carbide, turned their attention to other substances, which, with a little adaptation, their furnaces could be made to produce. Alloys of the ferro-chrome type are amongst the substituted products, being largely used in hardening armour plates, etc.

Electric smelting furnaces for the reduction of iron and other ores to the metallic state, have also provided a subject for extensive research, with no small measure of success, it having been found possible to apply the electric smelting process in many cases where the blast furnace, either from scarcity of fuel or similar causes, was out of the question.

It is naturally impossible at the present stage of our knowledge concerning the generation of electrical energy from coal and other fuels, for the electric smelting furnace to compete with smelting furnaces using fuel direct, but there are many instances in which the electrical process can be introduced with advantage, and a fair promise of profit to the metallurgist.

Metalliferous ores frequently abound in localities where fuel of any description is scarce, but water power plentiful;

in such cases, a hydro-electric generating plant, though expensive to instal, frequently provides a ready way out of the difficulty. Water power has, in fact, been the salvation of the electro-chemical and electro-metallurgical industries which for the greater part involve a vast expenditure of power within a comparatively small compass. Hence we find almost all the large works concerned in the foregoing allied industries, confined to America and the Continent, and frequently to localities where fuel is comparatively scarce but water power plentiful.

Niagara, with its 50,000 H.P. derived from the celebrated Falls, is a case in point, and it is worthy of note that by far the greater proportion of this huge power is utilized in the two industries enumerated above.

It is unnecessary to enlarge further, at this point, upon the many applications of the electric furnace in modern industry, in that the various processes will be alluded to in connexion with the several furnaces to be described later.

There is also a type of furnace which the author proposes to include in this work, with the object of rendering it complete, and that is the electrolytic type. Although not, strictly speaking, furnaces, in the ordinary acceptation of the term, there are several forms of apparatus which depend for their action on a combination of thermal, electrolytic, and chemical effects. Since the office of the furnace proper, viz., that of heating the raw materials, is an essential auxiliary in such cases, it has been resolved to include them in the pages which follow, the necessary line of demarcation between a thermal and an electrolytic process pure and simple being determined by the presence of an aqueous solution. Only such methods and apparatus will be dealt with as involve the presence of a fused electrolyte.

Several of the types of electric furnace construction, described in detail in the pages which follow, have never progressed beyond the experimental stage. Their descriptions are included with a view to showing the extraordinary

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amount of ingenuity which has been expended upon electric furnace design, with a view to rendering them efficient, and, as far as possible, automatic in action. It is this very ingenuity, entailing a certain elaboration of detail which has militated against the commercial success of several very promising furnace inventions. To put the matter in a nutshell, the aspiring designers of some electric furnaces have attempted to apply principles of construction and operation comparable with the delicate mechanism and controlling principles of the self-regulating arc lamp.

It is obviously a mistaken feature in electric furnace design, this elaboration of detail. In an apparatus whose parts may be, and frequently are, subjected to extremely high temperatures, it is necessary that every part shall possess stability, in order to resist the destructive tendency of such great heat, a stability which the nature of some of these inventions, renders impossible of attainment.

The illustrations in this book are essentially in the nature of sectional diagrams, representing "principles of construction" rather than views of the objects as they actually appear to the observer. Photographs of the majority of electric furnaces would convey little or no information to the reader; a mass of brickwork, with perhaps some iron plates; a series of heavy cables leading in; and one or two flues for carrying off the gaseous products: that is all.

J. W.

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SECTION I

HISTORICAL AND GENERAL

Definition.—Strictly speaking, an electric furnace is an apparatus for bringing about a physical or chemical change in materials by the aid of heat obtained from the transformation of electrical energy. There is, however, another class of apparatus, which the writer has seen fit to include, under the title " Electrolytic Furnaces," in which the action is in part electro-thermal, as in the electric furnace pure and simple, and, for the rest, electrolytic. This class of furnace is mainly employed for the electrolysis of fused salts, as, for instance, in the manufacture of aluminium, where heat is a necessary auxiliary if the requisite fusion of the electrolyte is to be maintained.

Historical.—As early as 1853 a form of arc furnace construction, devised by Pichon, was described in the *Practical Mechanics' Journal*. It consisted of a series of arcs, set up between electrodes of large size, and through the several independent heat zones of which, metallic ores, mixed with carbon, were passed, with the object of reduction. There is no record of such a furnace having ever existed, except on paper.

Sir William Siemens may justly be credited with having been the first to suggest the employment of electric furnaces on a commercial scale. For some time (1878–1879) he conducted experiments, with a view to determining the possibilities of the arc furnace as an auxiliary to certain industrial processes, and in June, 1880, embodied the results of his researches in a paper which he read before the then

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Society of Telegraph Engineers. In the course of his experiments with the furnace described below, he succeeded in obtaining an efficiency of 33 per cent., and summed up his conclusions as follows :—

1. The degree of temperature attainable in the electric furnace is theoretically unlimited.

2. Fusion may be effected in a perfectly neutral atmosphere.

3. Furnace operations can be carried on in a laboratory,
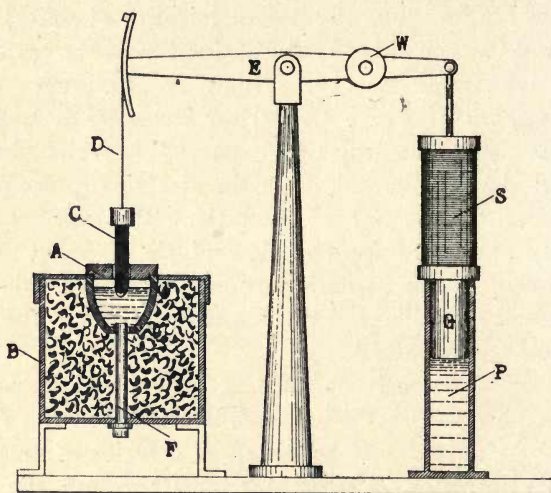
Fig. 1.

without much preparation, and under the eye of the operator.

4. The limit of heat practically obtainable, with the use of ordinary refractory materials is very high, because, in the electric furnace, the fusing material is at a higher temperature than the crucible, whereas, in ordinary fusion, the temperature of the crucible exceeds that of the material fused within it.

The historical furnace used in connexion with these early experiments is depicted in Fig. 1, and consisted of a

refractory crucible A, of plumbago, magnesia, lime, or other suitable material, which may be varied according to the nature of the substance to be treated within it. It is supported at the centre of a cylindrical jacket B, and is packed around with broken charcoal, which, being a poor conductor of heat, isolates it from the surrounding atmosphere, and conserves the heat developed within the crucible to such an extent that there is very little loss due to radiation or diffusion. The negative electrode consists of a massive carbon rod C, passing axially through the centre of the crucible lid, and free to move vertically therein, the clearance opening being, for obvious reasons, very small.

The cathode, C, is suspended from the lower extremity of a copper strap D, which conducts the current from it, being attached at its upper end to the curved extremity of a horizontal beam E. The positive electrode F, which may be of iron, platinum or carbon, consists of a cylindrical rod of one or other of these materials, passing up through the centre of the crucible base. The other side of the beam, E, carries, suspended from its extremity by a hinged joint, a hollow soft iron cylinder G, forming the core of the solenoid S. The core G works in a dash-pot P, the tendency of the solenoid S, when active, being to raise it against the counteracting force of the adjustable counterweight W, thus lowering the cathode G into the crucible. The solenoid winding is connected in shunt to the two electrodes.

The furnace was originally designed by Siemens for the fusion of refractory metals, and their ores ; consequently, once the action is started, electrical connexion is established between the lower electrode F and the semi-metallic mass in the crucible, and the arc continues to play between the surface of the mass and the movable carbon rod C. As the current through the furnace increases, that through the shunt winding of the solenoid diminishes, and the weight W, coming into play, causes its end of the beam to descend, thus raising the cathode C, and restoring equilibrium.

To Moissan we are, of course, indebted for much valuable information to as the possibilities opened up by the introduction of the electric furnace, and the results of his researches into the subject, duly assembled in convenient form in his book *Le Four Electrique*, are well worthy of careful study by those interested in the subject of high temperatures.

Moissan's most valuable researches into the chemistry of high temperatures, rendered possible by the introduction of the electric furnace, were carried out during 1893 and 1894. Many conclusions may be drawn from an exhaustive study of Moissan's work, and those having, or promising to have an industrial importance are well summarized by Blount, in his book *Practical Electro-Chemistry*, as follows—

" The stable form into which carbon, whether amorphous, or crystallized as diamond, tends to pass, is graphite. Under ordinary conditions, carbon does not melt, but passes directly into the gaseous state ; if subjected to high pressure, as it may be by suddenly cooling a liquid, e.g. iron, in which it is dissolved, it may be liquefied, and then may crystallize as diamond.

" Lime, magnesia, molybdenum, tungsten, vanadium, and zirconium may be fused. Silica, zirconia, lime, aluminium, copper, gold, platinum, iron, uranium, silicon, boron and carbon may be volatilized. The oxides among these substances may be deposited in a crystalline form. Oxides usually regarded as irreducible, e.g., alumina, silica, baryta, strontia and lime, uranium oxide, vanadium oxide, and zirconia may be reduced by carbon in the electric furnace. Many metals which are reduced with difficulty in ordinary furnaces, such as manganese, chromium, tungsten, and molybdenum, may be prepared in quantity. Moreover, in the electric furnace, these metals may be obtained of approximate purity, in spite of their great tendency to unite with the oxygen and nitrogen of the air. It often happens that, when a metallic oxide is reduced with excess of carbon in the electric furnace, a carbide of the metal is

first formed. From this the pure metal can usually be prepared by fusing the carbide with the oxide of the metal. The carbon is oxidized and an equivalent of the metal reduced. The behaviour of such metals in dissolving carbon at high temperatures, in rejecting it on cooling, and in losing it when subjected to selective oxidation, in general resembles that of iron, which is well known. One class of bodies is particularly stable at the high temperatures attainable by the electric furnace—to wit, that comprising the carbides, borides, and silicides. These substances are usually of simple composition : SiC (silicon carbide), CaC_2 (calcium carbide), Mn_3C (manganese carbide), Fe_2Si (iron silicide), FeB (iron boride), CB_6 (carbon boride), will serve as examples. Some members of the group are extremely hard. Thus carbon silicide (or silicon carbide) is harder than emery, while boron carbide and titanium carbide may actually serve to cut a diamond—not merely to polish it, as does silicon carbide, but to produce definite facets. Others of the carbides have another claim to interest from an industrial as well as from a scientific standpoint. Everyone knows nowadays that calcium carbide is decomposed by water and yields acetylene ; but it is not always realized that the property of thus giving rise to a hydrocarbon is general for a large number of similar bodies, e.g. the carbides of lithium, aluminium, thorium, and cerium. Lithium carbide (Li_2C_2) yields acetylene ; aluminium carbide (Al_4C_3) gives methane ; cerium carbide (CeC_2), a mixture of the gases acetylene, ethylene, and methane, and a notable proportion of liquid hydrocarbons. This brief catalogue of facts will show how large a field for industrial research exists, and how well mapped are the paths by which it may be entered."

Passing record of the earlier researches into the possibilities of the electric furnace as an industrial auxiliary may be gleaned from the Report of the Franklin Institute, July, 1898, on the researches of M. Henri Moissan.

The electric furnace utilized by Moissan for conducting

these researches was devised by him, and is of very simple construction. It belongs to that class known as "Indirect arc furnaces," so called from the fact that the arc itself is not brought into actual contact with the material under treatment, which receives its heat, instead, by reflection from the furnace walls or roof. It is represented in Fig. 2, and consists of two blocks of chalk, A, A, so hollowed out that, when placed together, they form a cavity for the reception of the carbon crucible C, which contains the material to be treated, and constitutes, in point of fact, the hearth of the furnace. Two carbon electrodes E E project through the sides of the blocks, and meet, with the exception of an arcing space, at a point just above the mouth
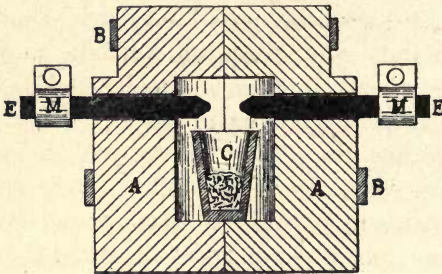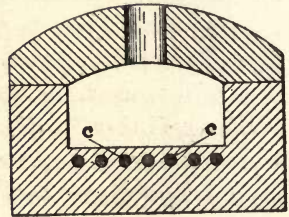

FIG. 2.   FIG. 3.

of the crucible C. Electrical connexion with the source of current is secured through the metal clamps M M. Metal bands B serve to hold the chalk blocks together whilst the furnace is active.

As a laboratory type, this simple furnace has many advantages; it is built up of refractory material, and comprises comparatively few parts, which are easily taken to pieces and reassembled. Furthermore, the centre of activity, surrounded as it is, on all sides, by a considerable thickness of refractory and non-conducting material, can be brought to an extremely high temperature, with very little accompanying loss of energy.

One of the earliest resistance furnaces or muffles, which depended for its action on the heat generated in a conductor of reduced cross-section embedded in the substance of its walls, was that patented by Faure in 1883. It was intended for the manufacture of sodium, and a sectional view is represented in Fig. 3, from which it will be seen that the conductors c c were embedded in the hearth. One or two later modifications of this early type are described in the section dealing with laboratory furnaces.

The commercial resistance furnace is the outcome of the inventive genius of Messrs. Eugene H. and Alfred H. Cowles, who, after numerous experiments, selected coarsely powdered carbon as a suitable material for the resistance core, whilst, at the same time, a necessary ingredient, for the reduction of oxides.

From an historical point of view, the following extract from a paper read before the American Association for the Advancement of Science, in 1885, by Professor Chas. F. Mabery, may prove of interest :

" A short time since, Eugene H. Cowles, and Alfred H. Cowles, of Cleveland, conceived the idea of obtaining a continuous high temperature, on an extended scale, by introducing into the path of an electric current, some material that would afford the requisite resistance, thereby producing a corresponding increase in the temperature. After numerous experiments, that need not be described in detail, coarsely pulverised carbon was selected as the best means for maintaining a variable resistance, and at the same time the most available substance for the reduction of oxides. When this material, mixed with the oxide to be reduced, was made a part of the electric circuit in a fire-clay retort, and submitted to the action of a current from a powerful dynamo machine, not only was the reduction accomplished, but the temperature increased to such an extent that the whole interior of the retort fused completely. In other

experiments, lumps of lime, sand, and corundum were fused, with indications of a reduction of the corresponding metal; on cooling, the lime formed large, well-defined crystals, the corundum, beautiful red, green, and blue, hexagonal crystals.

"Experiments already made show that aluminium, silicon, boron, manganese, magnesium, sodium, and potassium can be reduced from their oxides with ease. In fact there is no oxide that can withstand temperatures attainable in this electrical furnace. Charcoal in considerable quantities is changed to graphite; whether this indicates fusion, or solution of carbon in the reduced metal, has not been fully determined.

"As to what can be accomplished by converting enormous electrical energy into heat within its limited space, it can only be said that it opens the way into an extensive field for pure and applied chemistry. It is not difficult to conceive of temperatures limited only by the capability of carbon to resist fusion."

The Cowles furnace made its first appearance in public in 1885, its initial application to the needs of industry being in the reduction of oxides (*vide* the zinc furnace, in which a graphite crucible forms one electrode).

In 1887, the Cowles Brothers took out a patent on a furnace with an arrangement for continuous feeding of the charge.

Temperatures Attainable in the Electric Furnace.—The maximum temperature attainable by the combustion of fuel, either in solid, liquid, or gaseous form, and under the most favourable conditions for the conservation of the heat developed, is in the neighbourhood of 2,000°C. =3,632°F., although Heraeus, in a paper before the German Bunsen Society in 1902, claimed that he had succeeded in constructing a non-electric furnace, in which temperatures up to 2,200 C. =3,992°F. could be produced. He employs an

iridium tube, suitably mounted in a furnace, and heated by means of an oxy-hydrogen flame. The temperature was measured by the aid of a thermo-couple, consisting of absolutely pure iridium, and an alloy of 90 per cent. iridium with 10 per cent. ruthenium. Up to $1,650°C. = 3,002°F.$ a direct comparison was made between this thermo-couple, and a standard calibrated by the Reichsanstalt. Above this temperature the several values were arrived at by calculation.

The temperature of the electric arc itself has never been determined, the only available data on the subject of such high temperatures being the results of temperature or calorimetric measurements, made on the active extremities of the carbons. Thus, in 1893, Violle tested the temperature of the positive carbon crater by photometric methods, and found it to be $3,500°C. = 6,332°F.$, and independent of the magnitude of the current producing it, between 10 and 400 ampères. This estimate is only subject to error through a corresponding miscalculation of the specific heat of carbon, and was subsequently modified by the investigator to $3,600°C. = 6,512°F.$, as the result of assigning a slightly different value to this specific heat.

It is probable that the temperature of the arc itself is slightly higher than the above figure, which may nevertheless be taken as the approximate limiting temperature of furnaces operating on the arc principle, at atmospheric pressure, and with carbon electrodes. Assuming this to be the temperature at which carbon vaporizes, it is obvious that a limit is similarly set upon the temperature obtainable in furnaces of the " resistance " type, in which a carbon core is employed.

Basing his deductions upon an interesting and instructive experiment performed by Moissan, Townsend (*Electrical World*, April 6, 1901), suggests defining the limiting temperature of the arc between carbon electrodes, as that temperature at which the complex carbon molecule breaks down ;

and that of the resistance furnace, with carbon core, as the true point of vaporization of carbon, the former temperature being distinctly lower than the latter.

The experiment referred to as having been performed by Moissan is mentioned in *Comptes Rendus*, vol. cxix, p. 776, and consisted in exposing to the direct heat of a 2000 ampère, 80 volt arc, a carbon tube having an internal diameter or bore, of one centimetre. The experiment served to demonstrate the volatilization and condensation of carbon, the interior of the tube becoming filled, under the intense heating effect of the arc, with carbon vapours, which subsequently condensed upon its walls in the form of graphite. Crystallized silicon, placed at the lower extremity of the tube, fused and volatilized, with the result that its ascending vapour, meeting the descending carbon vapour, combined with it to form transparent needle-like crystals of silicon carbide (carborundum).

Townsend argues that, since silicon carbide was formed in this manner the temperature of the vapours was below that at which this compound is decomposed, e.g. below that of the Acheson graphite furnace ; hence his deductions as to the relative limiting temperatures of arc and resistance furnaces as set forth above.

The heat intensity, or temperature attainable, in an electric furnace depends, among other things, on the heat-conserving qualities of the materials of which the furnace is constructed. In furnaces of the Moissan type, but lined with blocks of pure carbon, and reinforced, on the outside, with a refractory non-conductor of heat, such as chalk or magnesia, it is possible, therefore, to obtain a temperature of approximately $4,000°C. = 7,232°F.$ whilst temperatures ranging from $2,000° - 3,500°C. = 3,632° - 6,332°F.$, are easily reached and maintained in the commercial electric furnace.

Classification.—There are two leading types of electric furnace, distinguished from one another by the method in which the heat energy is produced. They are known

respectively as " Arc " and " Resistance " furnaces. The former performs its work by virtue of the intense heat generated by the arc set up between two or more electrodes, one of which is frequently constituted by the lining, or base, of the furnace chamber itself. The latter derives its heating power from the passage of a heavy current through an attenuated conductor of high resistance, such as a carbon pencil.

These two main classes may be subjected to further subdivision, depending upon the principle of their construction and working. The arc furnaces, for example, may be divided into those in which the raw material to be heated is subjected to the direct heat of the arc, and is brought into actual contact with it, and those in which the heating is effected indirectly, either by conduction, or reflection from the roof or walls. In this latter type, to which belongs the Moissan furnace already described, the charge does
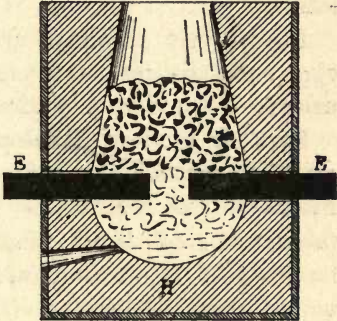
Fig. 4.

not come into contact with the electrodes at all, but is situated below the plane of the arc, and sometimes partially protected from it, thus reducing the chances of contamination by particles which might become detached therefrom, a very necessary precaution in some processes, such as glass manufacture, for example.

Another way of classifying furnaces, adopted by some writers, is according to their construction, and the arrangement of the electrodes. Thus arc furnaces may be subdivided under separate headings, according to whether the electrodes are horizontal, vertical, or parallel. A typical arc furnace, with horizontal electrodes, is shown

in diagram in Fig. 4, E E being the electrodes, and H the refractory hearth, or crucible, provided with a tap-hole, as shown, at its lowest point, for drawing off the molten products of the reaction.

Resistance furnaces, sometimes called " Incandescent Furnaces," may be similarly subdivided, according to whether the heating is directly or indirectly effected ; a further distinction also arises out of the nature of the resistance itself ; in some cases, this is independent, and takes the form of a carbon pencil, or even a glower of the Nernst type, whilst in others it is constituted by a poorly conducting column of the unconverted charge itself.

Electrolytic furnaces are essentially of the resistance type, the resistance in this case being the electrolyte, usually a fused salt, under treatment.

Another modern development of the resistance furnace principle is that class of apparatus known as " Induction Furnaces," of which the Kjellin furnace, for the manufacture of steel, is a typical example, and will be described later on. These induction furnaces depend for their action upon the heating effect of a current induced in them by a neighbouring conductor through which an alternating current is flowing. They are, in effect, transformer furnaces, the furnace itself, or rather its contents, forming a closed-circuit secondary winding, in which is induced a heavy current, by the comparatively small current flowing through a neighbouring primary winding of many turns. The principal advantage of this class lies in the complete absence of troublesome electrodes ; no minor consideration, as will be seen when dealing with the various electric furnace processes.

There is yet another type, which is, however, confined, for the greater part, to small units and laboratory apparatus, and is known as the " Tube Furnace." A cylindrical or tubular construction offers several advantages, more

especially for laboratory work and experimental research. Tube furnaces operate either on the resistance principle, or a combination of both arc and resistance heating, and are dealt with in a special section.

Two qualifying terms often used in connexion with electric furnace work are " Intermittent " and " Continuous." An intermittent furnace is one in which only one charge, equal to the capacity of the furnace, can be dealt with at a time, without interrupting the operation for the purpose of removing the product. A continuous furnace, on the other hand, is so constructed with regard to its tapping and feed arrangements, that a process can be carried on continuously without shutting down, the material under treatment either passing through at a regular rate, or the furnace being partially relieved of its contents at regular intervals without necessitating a stoppage of the current. Continuous furnaces are sometimes referred to as " Tapping " furnaces.

As regards the relative advantages and disadvantages of the arc and resistance principles of electric furnace working, it may be stated in general that the intense and more or less concentrated heat developed in the arc is unsuitable for many commercial processes, which call for a less violent and more readily controllable source of heat, such as is provided in the resistance principle of construction.

Here, again, we are confronted with further difficulties, for, if the resistance core be composed of the material itself under treatment, such, for example, as a mixture of ore and slag, in an electric smelting furnace, the current, and therefore the heating effect, will be subject to extreme variations, depending upon the changes brought about in the conductivity of the core as the operation proceeds, and the liberated metal asserts its presence. To mitigate this drawback to a certain extent, the molten product must be continually tapped off, such that a constant cross-

sectional area of resistance core may be, as far as possible, maintained.

Better conditions for the control and regulation of the temperature obtain in resistance furnaces with independent cores, i.e. furnaces in which the resistance column does not form part and parcel of the charge under treatment, but is independent of it, and maintains its shape and cross-section, within reasonable limits, throughout the process. The main drawback to their use is, of course, the extra expense involved by the introduction of such a core, and its subsequent periodical renewal.

Rasch (*Zeit. f. Elektrochemie*, February 19, 1903) deprecates the use of the arc furnace, with carbon electrodes, for the majority of processes. He cites the following requirements as essential to the success of pyrochemical reactions in general—

" The electrodes must be capable of withstanding a high energy density, and a high temperature ; they must not be oxidized, and must not exercise a reducing action on the reaction to be obtained."

He suggests the substitution of conductors of the second class for carbon ; e.g., rods, or tubes, of magnesia, aluminium oxide, etc., which require to be pre-heated, after the manner of a Nernst lamp glower, before they become conductors. This principle has already been applied to laboratory furnaces, and small units, but its adoption on a more extensive scale is at present limited by the cost of the material, and the difficulties incidental to the construction of a tube furnace of any magnitude.

General Remarks.—Employed for heating purposes, electricity is only capable of evolving that quantity of thermal energy represented by Joule's equivalent of the energy originally consumed in generating the current. In the case of a steam-driven plant, the heat energy available at the furnace terminals is only a small fraction (from $\frac{1}{10}$ to $\frac{1}{20}$) of the calorific value of the coal used in the boiler

furnaces. Of this latter about one-fifth is lost in the flues during combustion : the waste gases account for a considerable proportion, of far greater value, from a heating point of view, than the electricity generated ; whilst some 75 per cent. of fuel energy is present in the exhaust steam.

It will readily be seen, therefore, that electric heat, derived from steam-driven plant, is only commercially applicable in special cases, involving especially high temperatures, which are unattainable by ordinary combustion methods, concentrated heating effect, or where the value of the substances under treatment, and the necessity for maintaining them in a pure state, outweigh the cost of the heating itself, and render it a secondary consideration.

With natural water power, however, the matter assumes a different aspect. Here we have a frequently unlimited supply of energy, which is only costing the interest on capital outlay for plant and maintenance, so that the comparatively wasteful transformation of water power into thermal energy becomes a minor consideration.

In nearly all electro-chemical and electro-metallurgical processes, the cost of the electrical energy constitutes a considerable percentage of the total cost of operation ; usually 25 per cent. or more, sometimes as much as 90 per cent. Cheap electrical energy is therefore an essential requirement for the economical working of an electric furnace process.

The principal advantages of the electric furnace, from an industrial standpoint, may be summarized as follows :—

1. The time required for a reaction is reduced, and the yield increased for a given time.

2. Reactions take place more completely.

3. The heating effect is concentrated at the point where it is most required.

4. It is capable of bringing about high temperature reactions impossible at ordinary temperatures.

5. Operations may be readily conducted in the presence

of various gases, bringing their chemical action into play on other substances at high temperatures, or causing one or more gases to react together.

In laying out an electric furnace plant, it is essential that the furnaces be as near to the source of current as is compatible with the safety of the generators, and accessibility of the former. No undue loss of energy is then likely to take place in the main connecting cables, whilst the quantity of copper required for the latter is reduced to a minimum. Some appreciable separation between the two is, of course, essential, owing to the intense heat which prevails in the immediate neighbourhood of the furnace, and which would prove prejudicial to the dynamos. M. Keller advocates a separation of two metres, with a dividing wall between generator and furnace. The cables would then be from 18 to 20 metres long, and the power factor as high as 0·9.

For electric furnace work, in the absence of electrolytic action, an alternating current is more easily regulable, and yields better heating effect than a direct current.

According to Mr. J. B. C. Kershaw (*Electrical Review,* July 7, 1899), the first instance of three-phase currents being commercially employed in electric furnace work was in the manufacture of calcium carbide, at Langenthal, in Switzerland. The furnaces are of the movable hearth type, and three are worked simultaneously, each taking current of one phase, viz. 1,000 to 1,500 ampères at 75 volts.

The repulsion exerted by a strong magnetic field upon the electric arc has not been without its attractions for the furnace inventor, as instance a patent granted in 1897 to W. H. Monk. The principle of the invention is equally applicable to either arc or resistance furnaces, and consists in the provision of a rotating magnetic field in the neighbourhood of the arc or heating current, whereby the latter is also caused to rotate or circulate through the mass of

the material to be heated, and thereby extend its sphere of influence.

In one form of arc furnace on this principle, detailed in the published specification, arcs were set up between concentric tubular carbons, which also served as feed passages, and a solid electrode, mounted on an iron plate. Surrounding this was an iron ring, suitably protected from the intense heat, and wound continuously, with four branch connexions, whereby it could be supplied with two alternating currents in quadrature, to produce the rotating field.

A rotating field is similarly produced around the central resistance core or cores in a furnace working on the latter principle:

The project is an ingenious one, and worthy of mention, but it is questionable whether the extra expense involved in the furnace construction, to say nothing of the power consumed in producing the required magnetic field, is overset by the attendant advantages. At all events, there is no record of the principle having been adopted in practice.

Another inventor, I. L. Roberts, adopts the travelling belt, or conveyor principle, with a view to securing continuity of furnace action. His invention relates to a delivery hopper, and flue, or casing, covering a slowly travelling belt, woven from asbestos coated wire, on which the raw material to be treated is deposited from the hopper, and carried into the heat zone created by the arc set up between two carbon electrodes, held in adjustable clamps and projecting through the walls of the flue.

In 1898, Messrs. Siemens Bros. & Co. took out a patent solely on a form of furnace construction which prevented the ingress or egress of atmospheric air either to or from the interior of the furnace. To this end the raw material under treatment was built up in the form of a thick layer, capable of preventing the permeation of air, whilst the upper carbon electrode was given a tubular form and utilized for the secondary purpose of carrying off the gases

produced in the reaction, without permitting combustion. This tubular construction for the upper electrode has since been applied in many different designs of furnace, and is used, not only as a flue for the gases, but also as a feed channel for the raw materials to be treated.

Statistics.—In the words of an old saw, " The proof of the pudding is in the eating," and, despite the somewhat wasteful transformation of energy entailed by the industrial application of the electric furnace, a few statistics from various sources will serve to show that in many cases, and for various processes, the advantages of the electric furnace have so far outweighed this drawback as to warrant their installation on a scale of considerable magnitude.

According to Prof. Borchers, the aggregate power utilized in electro-chemical and electro-metallurgical industries employing electric furnaces in 1900 was—

For Calcium carbide manufacture	.	.	180,000 h.p.
„ Aluminium „	.	.	27,000 „
„ Carborundum „	.	.	2,600 „
Total			209,600 h.p.

The total output of electrical power at Niagara in 1901 was 50,000 H.P., of which 23,000 H.P. was consumed in electro-chemical and electro-metallurgical processes. Among the principal consumers for electric furnace operations are the following, the statistics being taken from *Cassier's Magazine* for May, 1901—

The Acheson International Graphite Company—1,000 H.P., utilized in the conversion of anthracite into graphite, at a pressure of 80 volts.

The Pittsburg Reduction Company—5,000 H.P., utilized in the extraction of aluminium from bauxite by the Hall process. Direct current at 160 volts.

The Carborundum Company—2,000 H.P., utilized in the manufacture of silicon carbide. Alternating current at 110 volts.

The Niagara Electro-Chemical Company—500 H.P., utilized in the production of sodium, and sodium peroxide from caustic soda by the Castner process; 165 volts, continuous current.

The Union Carbide Company—10,000 H.P., utilized in the manufacture of calcium carbide. Each furnace 200 H.P. Alternating current at 110 volts and 25 alternations per second.

French statistics (1904) show that out of a total of 238,703 H.P., available from the falls of the Alps, 22,536 H.P. is employed in the manufacture of aluminium; 20,485 H.P. in other metallurgical industries; and 104,466 H.P. in calcium carbide manufacture.

Scientific Deductions.—The principle of the electrical furnace, and the reactions brought about by the extremely high temperatures produced within it, have been advanced in explanation of many geological facts, hitherto unexplained, e.g., the formation of natural gases, petroleum, bitumen, graphite, corundum, etc., all of which occur in nature, and can be artificially produced, under similar conditions, by the direct, or indirect aid of the electric furnace.

In a paper before the French Académie des Sciences (*Comptes Rendus*, 134, pp. 1185–1188), MM. Sabatier and Sendereus, writing on the synthetic production of petroleum, incidentally call attention to the existence of the carbides of the alkaline earth metals in nature. In addition to opening up possibilities of artificial petroleum becoming an electric furnace product, this fact also lends colour to the oft-suggested theory that processes analogous to those of the high temperature reactions brought about in the electric furnace also take place as the result of natural phenomena.

Moissan's original theory of the natural formation of petroleum, which is supported by the results obtained by the above investigators, is that it results from the action of water upon natural carbides, under certain conditions

involving the presence of metals, and a temperature not exceeding 149°C=300°F.

The above authorities summarize their results as follows. A liquid, resembling Caucasian petroleum, in all its physical properties is obtained by passing a mixture of acetylene gas and hydrogen, in certain proportions, over finely divided nickel, or a metal belonging to the same chemical group, maintained at a temperature of from 200°–300°C=392°–572°F.

Variations in the physical conditions of the experiment resulted in the formation of an oil resembling Galician petroleum, and, like it, containing aromatic hydrocarbons, whilst lowering the temperature to 180°C=356°F. furnished a liquid resembling American petroleum.

The passage of acetylene gas *per se* over the finely divided metals resulted in the formation, by exothermic reactions, of hydrocarbons of the unsaturated series, which, when mixed with hydrogen, and again passed over the heated metal, led to the formation of a similar product to the first, resembling Caucasian oil.

SECTION II

ARC FURNACES.

An indirect arc furnace, for the treatment of metallic oxides and metalloids, such as silica, ferrous chromate, bauxite, etc., and converting them into a vitreous and homogeneous product of commercial value, is represented in Fig. 5. The process in its entirety consists in subjecting the raw materials to the radiated or luminous heat of an arc, which fuses them, and then subsequently cooling the resultant fused mass. The furnace in which the fusion is effected is of simple construction, its design being such that the charge never comes in actual contact with the arc, but is heated solely by radiation and reflection. The materials to be treated are fed in through a central chimney or flue F, fitted with a gas-tight valve V, and a connexion, C, for producing a vacuum in the furnace chamber. On reaching the bottom of F, the charge divides between the two inclined chutes B B, which form a bridge or dome immediately over the arc A. In passing down these, it receives a preliminary heating, the fusion being completed when it reaches the hearth, H, of the chamber, by the direct radiant heat from A.

An indirect arc furnace devised by G. de Chalmont comprises a refractory crucible, supported on one carbon electrode, which passes vertically up through the base of the furnace chamber, whilst the remaining electrode is horizontally disposed, in the shape of four radial sections which bear on the outer surface of the wall of the crucible. The charge is thus screened from the direct heat of the arcs, which play over the exterior of the crucible.

The de Chalmont furnace, invented by the late Dr. de Chalmont, and employed by him in his researches on metallic silicides, presents several novel and interesting features in furnace construction. It is represented in diagrammatic
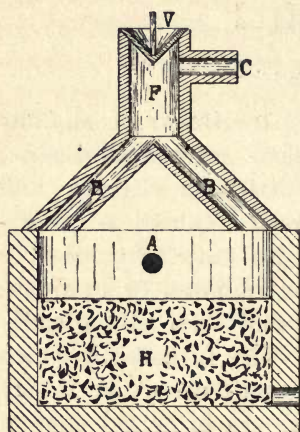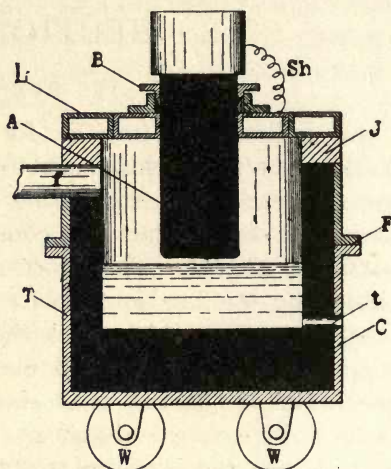

FIG. 6.

section by Fig. 6, and consists of a cast-iron trough, T, made in two sections, upper and lower respectively, which are connected by a flanged joint at F. The whole is mounted on wheels, W, for portability. A carbon lining, C, constitutes one electrode and also the hearth of the furnace proper, which is provided with the usual tapping hole t, and flue f. J is a layer of refractory insulating material, supporting the lid L, which, as represented in the figure, is given a sectional construction, each separate portion being furnished with a distinct conduit for water-cooling purposes. The upper adjustable electrode A, also of carbon, enters through a stuffing box B, in the centre of the cover, which effectually prevents ingress of air, whilst at the same time permitting the necessary adjustments of the movable electrode. *Sh* is a shunt interposed between the upper electrode and the cover itself, its object being to prevent accidental arcing

between them, by maintaining them both at the same potential, thus protecting the lid from injury.

The Denbergh arc furnace, invented by Dr. F. P. van Denbergh, is specially adapted to a variety of operations, chief among which may be cited the manufacture of sulphuric and phosphoric acids, and alkaline silicates, such as "water-glass." The furnace is represented in sectional elevation in Fig. 7. It comprises a fire-brick structure F, contracted below, as shown, to form a crucible for the reception of the molten products. The upper chamber where the actual fusion takes place is lined interiorly with a refractory layer R, which remains unaffected by the gases and vapours produced. E E are carbon electrodes, each mounted in a species of universal ball joint, built into the furnace wall, which permits a longitudinal or feed adjustment, and, at the same time, a swivelling motion of the electrodes, whereby the

FIG. 7.

position of the arc may be regulated at will. The base B is removably rabbited into the furnace walls, and supported in position by the loose bricks *b, b*. A flue, the opening to which is shown at *o*, leads up from the base of the furnace within the walls to a point which determines the level of the molten mass within; its position, *within* the heated walls, effectually prevents "freezing" and consequent stoppage of the outlet. A is an outlet at the top of the furnace, for gaseous products. The raw material is fed in at a regular rate, from the hopper H, by a reciprocating, piston-feed mechanism P, driven by the belt D, and falls vertically through the central heat zone of the arc.
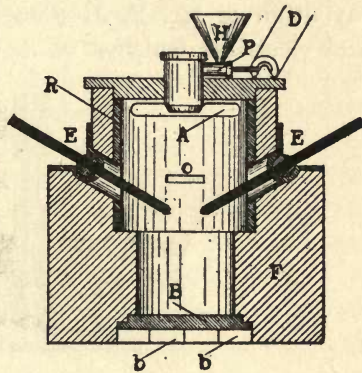
In this furnace, the inventor manufactures phosphoric acid from apatite, etc. The mineral is first crushed, and a quantity of sand added to it to serve as a flux. Under the heat of the arc, phosphorus is liberated from the mixture. The atmosphere of the furnace is rich in oxygen, with which the phosphorus immediately enters into combination, forming oxides. These latter are subsequently hydrated by steam, which is introduced into the furnace chamber for the purpose.

A somewhat ingenious continuous arc furnace is the invention of Mr. F. J. Patten. The principal mechanical and electrical features of its construction are represented
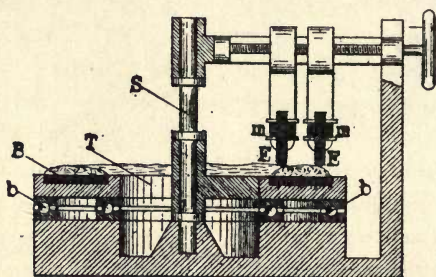

FIG. 8.

in Fig. 8. It consists, in the main, of a vertical centre spindle S, suitably supported for free rotation, in bearings, and carrying a flat annular table T, which, protected by a refractory bed B, constitutes the moving hearth or floor of the furnace, upon which is spread the raw material to be subjected to the action of the arc. The revolving table is additionally supported on ball bearings $b\ b$. The two carbon electrodes E E are carried by vertical supports, capable of lateral adjustment by means of a screw carriage, mounted on a radial arm, which also permits of their rotation independently of the hearth. A greater number of electrode carriers may be added, if it be wished to increase the capacity of the furnace.

An additional feature in the construction consists of

electro-magnets *m m* attached to the electrode terminals, which, when active, deflect the arcs down on to the charge after the manner of a blow-pipe.

A patent, dated July 17, 1897, granted to C. Bertolus, covers the application of polyphase currents to electric furnace working on the arc principle.

The advantages of three-phase currents for electric furnaces of the arc type are—

1. More uniform distribution of heat throughout the mass of material under treatment.

2. Accidental extinction of the arc a very remote contingency.

3. Polyphase generators are of simpler construction, and less liable to breakdown, consequent upon the sudden variations in load, incidental to arc furnace working.

Koller's arc furnace construction is very simple, and was devised with a view to securing better distribution of the heating effect throughout the charge, whilst at the same time rendering the furnace suitable for use on circuits of higher voltage than usual. It consists of a longitudinal chamber, with massive carbon blocks, projecting through the end walls. A series of carbon blocks, supported in line with these terminal electrodes, are arranged along the furnace chamber at regular intervals, their number varying according to the voltage. The arc is thus split up into a series, and a number of heated regions are secured in the centre of the mass of raw material, which is packed around the blocks.

A rather ingenious application of the arc furnace principle to the carbonizing of electric lamp filaments is the outcome of a patent granted to W. L. Voelker, the inventor of the Voelker Carbide Lamp. The device consists of a fire-proof crucible, enclosing the arcing space between two vertical carbon electrodes, which constitute the terminals of the furnace. The untreated filament is reeled off from a drum, through orifices in the walls of the crucible, on to

another receiving drum, its line of passage through the crucible being so disposed as not to pass through the axis of the arc itself, but to one side of it, the arc being deflected on to it. The crucible is kept charged, either with carbon vapour, or a hydrocarbon reducing gas, during the treatment.

A patent for a similar method of procedure in the manufacture of filaments for incandescent lamps, has been granted to R. A. Nielsen, and is applicable to oxides of the rare earths, such as are utilized in Nernst lamp glowers. These oxides are subjected to the heat of the arc, whilst shielded from its electrolytic action by a tube of refractory material, until they melt or soften, whereupon they are drawn out into threads of the required diameter.

Action of the Arc Furnace.—A paper by MM. Gin and Leleux, before the Paris Academy of Science in 1898, discussed the action of the electric arc furnace, from a theoretical standpoint, as compared with the results obtained in actual practice. We may regard the fall of potential between the electrodes of an arc furnace as taking place through the resistance column of gas which lies between them, and is the product of the volatilization of either the electrodes themselves, or a portion of the raw material under treatment. Regarding this column of gas as a theoretically perfect cylinder, having a sectional area equal to that of the electrodes, and surrounded by a perfect heat-conserving screen or jacket, we can prove that the temperature would increase in direct proportion to the square of the current density, and the ratio of the resistivity to the specific heat per unit volume, of the atmosphere of the arc.

In actual practice, however, this result is never obtained ; the arc forms a species of pocket or envelope, with a small orifice in its upper portion, through which the various gases, resulting from the reaction, make their escape. The size of this envelope, or cavity, increases, until a point is reached, at which the resultant heat of the arc is equivalent to the heat dissipated in the surrounding raw material.

SECTION III

RESISTANCE FURNACES AND TYPICAL PROCESSES

The heat developed in a conductor, such as the core of a resistance furnace, by the passage of an electric current through it, depends upon—

1. The ohmic resistance of the conductor.
2. The magnitude of the current.
3. The duration of its flow.

All three quantities are open to regulation in the majority of resistance furnaces, hence the facility with which this type lends itself to exact temperature regulation and control.

The temperature of a heating resistance core depends upon the rate of development of heat within it, and upon the rate at which it is capable of dissipating that heat by radiation and conduction. The ultimate fixed temperature of a resistance furnace core is attained when the above two quantities are exactly equal, i.e. when the rate at which heat is dissipated or given off by the conductor is equal to the rate at which it is developed.

The limit of temperature attainable in such a conducting core depends, of course, upon the fusing point of the material of which it is composed.

An excellent example of the various possibilities of a suitably designed resistance furnace, in which the temperature regulation is well under control, and can be altered with a fair degree of accuracy over an extended range, is to be seen in the various Acheson furnace processes, in which

silicon and carbon constitute the raw materials under treatment.

By certain variations in the conditions and temperatures at which the reactions are brought about, it is possible to produce carborundum, " white stuff," silicon, siloxicon, or graphite, at will.

With resistance furnaces generally, and those of the Acheson type, with only a partially independent core, in particular, the question of efficient temperature regulation is an important one, in that it cannot be effected by any change in the internal conditions of the furnace charge, or core ; the latter, once the operation is started, is unalterable, and it is only by external means that the current, and consequently the temperature, can be governed and regulated.

A feature peculiar to this type of furnace is a high internal resistance, which gradually falls during working, until, at the end of an operation, it is fairly low, a condition of things which can only be compensated by corresponding regulation of the voltage at the furnace terminals.

The actual resistance which a furnace is desired to have, can only be procured, or reproduced, by experiment, a process in which the choice of many different grades of core carbon, together with a variation in the size and shape of the constituent particles, provides a wide field for initial adjustment.

Herr Otto Vogel, a German authority, has made the following suggestions with regard to resistance furnaces. The heating resistance or core should be given the largest possible surface area, in order to facilitate the transference of its heat to the materials of the furnace charge.

Assuming, for the sake of example, three distinct cores, each of 1,200 square millimetres cross-sectional area, but having different formations, viz., circular, square, and rectangular ; their efficiencies, from the point of view of heat transference, will vary considerably.

Taking the diameter of the first (circular) core as 39 m.m., its effective surface area, per metre of length, will be 132,000 square m.m. The second (square), with 35 m.m. side, will expose an area of 140,000 square m.m., for the same length, whilst the third (rectangular), 80 m.m. by 15 m.m., will, under similar conditions, have a surface area of 190,000 square m.m. Their efficiencies will therefore stand in the ratio 6 : 7 : 9.

Again, by constructing the circular electrode in the form of a hollow cylinder, 30 m.m., internal, and 46 m.m. external diameter, its effective surface area will, for the same cross-section as formerly, be increased to 146,000 square m.m. for one metre of length, whilst its mechanical strength will be superior to that of the original solid cylinder.

The same authority quotes the results of tests made on independent carbon resistance cores, with a view to ascertaining their rate of oxidation, or combustion, in air.

To this end, a current of 500 ampères was passed through a rectangular carbon core, 400 by 80 by 15 m.m., which, with a gradually increasing current density, consequent on the reduction of its cross-sectional area by combustion, was raised, during a period of five hours, to a white heat.

Current was then switched off and the block examined, when it was found that the original dimensions of 80, and 15 m.m., had decreased to 60, and 7 m.m. respectively, whilst the under side of the block had been reduced to a knife edge ; the original cross-sectional dimension of 1,200 square m.m. had been reduced to 210 square m.m., with a corresponding increase in current density, from 0·41 to 2·38 ampères per square m.m.

A further test was then made with a view to ascertaining the temperature limitations imposed by this method of resistance heating with independent carbon core. A second carbon block, having the same dimensions as the first, was totally embedded in powdered lime, with the exception of its flat upper surface, which was left exposed to the atmosphere.

A current of 300 ampères was first applied for a period of 15 minutes, thus bringing the temperature of the carbon up to a point suitable for the commencement of the tests, after which the current was increased by regular increments, at intervals of five minutes, the temperature resulting from each augmentation of current being measured by the collapse of Seger cones placed upon its exposed surface.

The following results were obtained :—

CURRENT DENSITY IN AMPÈRES PER SQ. M.M.	SEGER CONE No.	RESULTANT CENTIGRADE.	TEMPERATURE. FAHRENHEIT.
0·25	0·22	590	1,094
0·33	0·18	710	1,310
0·45	0·8	990	1,814
0·54	0·2	1,110	2,030
0·66	4	1,210	2,210
1·2	24	1,600	2,912
1·6	36	1,850	3,362
2·0	—	2,300	4,172

The block was then replaced by one of circular section, having a diameter of 30 m.m. With this, the current density was increased to as much as 4 to 6 ampères per square m.m., without disturbing its solidity.
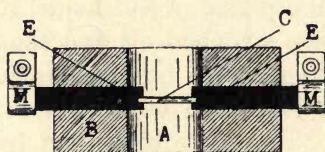
At 8 ampères per square m.m., however, the carbon

FIG. 9.

commenced to volatilize, though no intermediate fluid state was noticed. Its original diameter was reduced, by this treatment, to 8 m.m.

Furnaces.—An early form of electric furnace devised by Borchers may be taken as typical of the resistance principle of construction. It consists (Fig. 9), of a cavity A in the centre of a block of refractory material B, through the sides of which pass two large carbon electrodes E E.

These latter are fitted with metal terminal clamps M for attachment to the source of current, and extend to a point just within the cavity A, where their extremities are bridged by a thin carbon pencil C, which becomes heated by the passage of the current, and imparts its heat to the raw material, which is either placed within, or caused to pass through the cavity.

A modification of what is more familiarly known as the " Cowles Furnace " is represented in Fig. 10. It consists of a rectangular fire-brick structure F, with hearths sloping to a central tapping hole T. L is a lid, fitted with feed hoppers H H. The current enters by way of the end
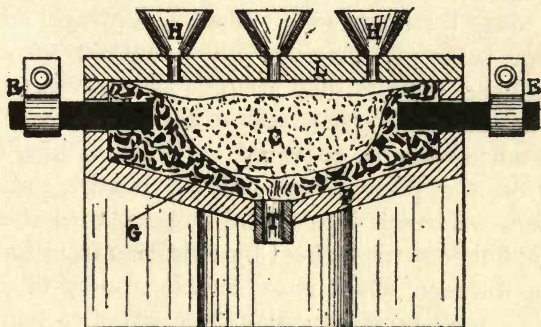

Fig. 10.

electrodes E E, and passes through the core C, which consists of a mixture of the ore, or other material to be treated, with carbon. The latter, in this instance, fulfils the double office of conductor and reducing agent. The core is surrounded by a layer of granular charcoal G, which conserves the heat generated, and is, at the same time, highly refractory. The hopper openings in the lid L enable a constant and evenly distributed charge to be maintained within the furnace.

L. S. Dumoulin's improved construction for furnaces of the independent resistance type relates to the resistances

31

themselves, and consists in a means for protecting them, and thereby prolonging their useful life.

To this end, the heating resistances, which are of the usual carbon rod type, with a reduced central cross-section, where they come within the furnace, and enlarged extremities by which they are supported within the furnace walls, and to which the terminal connexions with the external circuit are effected, are completely encased in a fire-clay jacket, which is applied in a plastic state, and moulded around the resistance rod so as to act as a complete protection from the disintegrating effects of the charge under treatment.

If necessary, additional protection is secured by threading the rods, thus previously coated, through additional jackets, or tubes of fire-clay, which extend through the furnace proper, and are, like the rods themselves, supported at their extremities by the walls of the structure.

A resistance furnace, patented by W. T. Gibbs, Canada, is based on the principle of indirect heating, where the charge does not come into actual contact with the heated resistance, but receives its heat by reflection from the domed roof. The furnace, which is too simple to need illustration, consists of a built-up rectangular structure of carbon blocks, or fire-brick, and having, as already stated, a domed roof for reflecting the heat downwards on to the charge. Suitable inlet and outlet orifices are provided, both for solids and gases, while the heating resistances consist of carbon rods, placed transversely across the furnace, about two-thirds up, and clamped between massive carbon terminal blocks, which are held, in turn, by cast iron sockets, let into the walls, and connected to the source of current.

The heating capacity of the Gibbs furnace is governed by its size, and the number of carbon rod heaters employed, whilst its adaptability to currents of varying character lies in the external means for changing the connexions of the

rods, which may be either in series, parallel, or a combination of the two.

The resistance furnace invented by M. Girod, is capable of a wide range of application, whilst, at the same time, of comparatively simple construction. It consists of a crucible of graphite, or refractory earths, encased on the outside by a graphite sheathing, which serves the purpose of a high resistance path between the electrodes, and in which heat is developed by the passage of a suitable current. The structure is mounted on a horizontal shaft, so as to admit of tipping, or canting, during operation, after the manner of a Bessemer converter. The voltage necessary ranges from 20 to 80, and the temperature can be regulated between 500° and 3,500° C. = 932° and 6,332° F., or even higher, if necessary. A simple furnace, such as the above appears to be, should be readily adapted to foundry operations, where refractory metals have to be dealt with.

In the light of Dr. Nernst's discoveries regarding the conducting power of certain solids, when raised to a high temperature, the question of a satisfactory material for the construction of the walls of resistance furnaces is an important one, in that, if the material chosen be in the nature of a " solid electrolyte," considerable loss of energy is likely to arise from the passage of useless currents through the walls of the structure, when raised to the temperatures necessary to bring about a re-action.

Fröhlich seems to have recognized the need for investigation in this direction, and, in an article in *Zeitschrift für Elektrochemie*, August 6, 1903, he describes his investigations in search of a suitable material.

The necessary properties for such are a high melting point, chemical indifference, high electrical resistance, and plasticity, enabling the substance to be moulded into various shapes and sizes.

He (Fröhlich) claims to have discovered a number of chemical compounds which fulfil these conditions, their

electrical resistance being much higher than that of carbon, whilst they are decomposed but little, if at all, by unidirectional currents.

His sugggestion, which he has since carried into practice, is to construct conducting plates of these materials, which, furnished with suitable electrodes, would constitute the heating units of a resistance furnace of any required shape or form. The composition of the material is not stated.

In Dr. O. Fröhlich's lately patented resistance furnace, constructed on this principle, the walls of the structure itself constitute the heating resistances, rendering the employment of an independent core superfluous. The material used in the construction of the resistance walls, the composition of which is not divulged, is said to have sixteen times the resistivity of carbon when hot, and twenty-five times its resistivity when cold. A suitable material has also been discovered for insulating the semi-conducting walls, the principal merit of which is that it fails to become a conductor, even when raised to a white heat.

The furnace is surrounded by a refractory heat-conserving jacket, an air-space being left between the two.

Experimental trials have demonstrated the possibility of attaining a temperature of at least $1,600°C. = 2,912°F.$, by means of this furnace. The resistance material itself does not fuse until a temperature well above $2,000°C. = 3,632°F.$, has been reached.

The application of polyphase currents to electric resistance furnaces is the subject of a patent, of which the details were published in 1897 by Messrs. H. Maxim and W. H. Graham. The projected furnace is of fire-brick with a series of parallel horizontal electrodes projecting through one of its walls. These are connected individually, through metres and switches, with the several circuits of a polyphase generator. Opposite their inner extremities, on the other side of the furnace, is arranged a common electrode, to act as a return conductor.

For the manufacture of calcium carbide in this furnace, small resistance rods or pencils of carbon are so disposed as to bridge the space between each individual electrode, and the common return, whilst the raw mixture of coke and lime is packed around them. These rods become heated with the passage of the current, and convert the mixture into coherent masses of calcium carbide, which are subsequently removed with the aid of tongs.

The electrodes are carried on threaded rods, passing through suitable handles, which permit the necessary withdrawal of the electrodes pending the insertion of new carbon pencils, and, when in place, an even pressure is maintained by springs.

If so desired, the return, or common electrode, may be subdivided, and each pair enclosed within a separate compartment of the furnace.

A novel type of resistance, or, as it is sometimes termed, " Induction " furnace, patented independently, with some slight variation of detail, by Colby, Ferranti, and Kjellin, consists of an annular, or helical channel, in a refractory base, filled with a conducting, or semi-conducting medium which constitutes the furnace charge, and has a heavy current induced in it by a surrounding coil of many turns, carrying an alternating current.

The device, in point of fact, acts as the closed-circuit secondary of a step-down transformer, and is said to be admirably adapted for the fusing of such metals as platinum, which, if exposed to the atmosphere during the process, as in the ordinary type of furnace, occlude oxygen, and other gases in their mass, which lead subsequently to blow holes, and other imperfections in the casting. The Kjellin patent has since been considerably developed, and is now applied to the smelting of iron ore and the manufacture of a special quality of crucible steel, at Gysinge, Sweden.

The process is worked on a commercial scale, and further

particulars will be found in the section devoted to steel production.

The Acheson Furnace Group.—One of the most indefatigable workers in the field represented by the industrial application of the resistance furnace is E. G. Acheson, of Niagara. The many processes with which his name is associated as inventor and originator are all capable of being conducted, with some slight modifications, in the same type of furnace, which has, in fact, come to be generally known as the " Acheson Furnace."

The form of construction is unique in being of a temporary nature. The whole structure is built up afresh, of loose fire-bricks, for each operation, and pulled down again at the conclusion of a run. Such a furnace construction offers several advantages ; it is not costly to construct, is devoid of all considerations implied by the terms, wear and maintenance, and is, moreover, simplicity itself, a very important desideratum in electric furnace construction.

Carborundum.—The manufacture of carborundum, or carbide of silicon, is one of the simplest industrial applications of the resistance principle. The furnace itself, is not a permanent structure, but built up loosely of firebrick for each run, only to be pulled down again at the end of the operation. The process is purely synthetic, carbon, in the form of coke, being caused to combine, under stress of electrical heat, with the silicon contained in sand as an oxide. The oxygen of the silica combines with the excess of carbon present, forming carbon monoxide gas, which is given off, and burns at the various openings in the furnace wall, with a blue flame. The silicon thus set free combines with more carbon to form the carbide.

The furnace, Fig. 11, is built in the form of a species of trough T, with massive electrode clamps, E E, projecting through the end walls, and carrying each a bundle of carbon rods C, which establish electrical connexion with the

core proper R running through the centre of the mass. The core may consist of granular carbon, coke, or the carbon rods themselves. The furnace is well stacked with the raw mixture M of powdered coke and sand, to which are also added sawdust and a small quantity of common salt, the actual proportions of each ingredient contained in a ten ton charge, which is the usual quantity dealt with in one operation at Niagara, being coke, 34·2 per cent. ; sand, 54·2 per cent. ; sawdust, 9·9 per cent. ; and common salt, 1·7 per cent.

The object of the sawdust is to secure porosity of the furnace charge, and that of the salt to act as a flux.
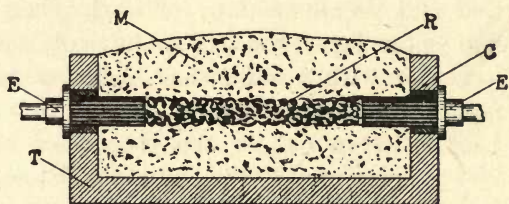

Fig. 11.

The subsequent conversion, which occupies about thirty-six hours, results in some two tons of carborundum, as against a theoretical yield of four tons, from which it will be seen that the process is anything but efficient.

The carborundum furnaces in use at Niagara are 15 by 7 by 7 ft. The electrodes consist of bundles of sixty 3-in. carbon rods, each 2 ft. long. These are mounted in heavy bronze sockets, supported by the brickwork. The coke resistance core is 9 ft. long by 2 ft. in diameter, and the grains of coke utilized in its formation vary from $\frac{1}{4}$ to $\frac{3}{8}$ in. in diameter. An alternating current is employed.

The initial voltage at the furnace terminals is 200, which, however, falls to 80 or thereabouts as the operation proceeds and the charge becomes heated. Regulation is

effected by varying the voltage so as to keep the furnaces working at their full capacity of 1,000 h.p. apiece.

The charge, when broken up at the end of the run, is found to consist of several layers, the centre one of which is graphite, into which the original coke, or carbon of the core, has been partially converted. Immediately surrounding this is a layer, about 16 in. in thickness, of crystallized carborundum, which constitutes the useful portion of the charge, and consists approximately of 70 per cent. silicon, and 30 per cent. carbon. Next to this will be found a greenish layer of amorphous silicon carbide, mixed with unconverted portions of the charge ; this layer is known as " white stuff," and it is presumable that its temperatures of formation and decomposition are fairly near together. The extreme outer layer consists mainly of unconverted material, together with a somewhat higher percentage of common salt, than before, that substance having been volatilized, and driven out in the process of conversion. These latter layers are worked up again into the next charge.

In connexion with the low efficiency of the process, it is stated that the electrical energy necessary for producing carborundum has been reduced from 15·5 to 8·6 kilowatt hours per kilogramme.

The temperature at which the operation is conducted needs very careful regulation, in that, if allowed to reach too high a value, the carborundum is again decomposed and the silicon volatilized.

Pure carborundum is a colourless, crystalline compound, having the formula, SiC ; the commercial article is dark brown or black ; its specific gravity is 3·12, and it consists of 70 per cent. silicon and 30 per cent. carbon.

Its formation in the electric furnace by the simultaneous reduction of silica, and synthesis of the resulting elements, is represented by the equation :

$$SiO_2 + 3C = SiC + 2CO.$$
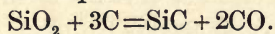
The furnace charge, which is packed around the core of

granulated coke, and fills up the entire furnace cavity, weighs about ten tons, as already intimated.

Carborundum was first discovered by Acheson in 1893. In that year, only 6¾ tons were manufactured, but, in 1901, this figure had been increased to 1,690 tons, whilst an extension of the plant (1902) from 2,000 to 3,000 h.p. raises the possible output to 2,690 tons. It is largely employed as an abrasive, a refractory lining for steel, and cement furnaces, and a deoxidiser in steel manufacture.

In connexion with its use for lining furnaces, Dr. W. Engels has lately (1900) patented a method of applying carborundum to the interior walls of furnaces in the form of a paint. To this end, powdered carborundum is mixed with one-third its weight of water glass, and water added to the mixture until it assumes the consistency of cream, in which form it is applied by means of a stiff brush to the surfaces it is required to protect. If the furnace is to be employed in the treatment of basic substances, e.g. basic slag, fire-clay is substituted for the water-glass. It is then made up of 85 per cent. carborundum, and 15 per cent. clay, and applied in the same manner, viz., with a brush, the surfaces to be protected having been previously dried thoroughly by gentle heating, the presence of moisture being fatal to adhesion of the coat. 1,200 grams of carborundum are said to be required per square metre of surface to be covered.

The manufacture of what is known as "white stuff," a material largely consisting of silicon and carbon, which is formed, to a limited extent, in the ordinary carborundum furnace, as a thin layer between the carborundum and the unconverted charge, has been made the subject of a patent by Acheson. The respective temperatures of formation and decomposition of this substance are comparatively near to one another, rendering it necessary to devise a process of manufacture in which these upper and lower tempera-

ture limits should be the limiting temperatures of the reaction. Acheson achieves this result in a resistance furnace with subdivided core, consisting of a number of equally spaced carbon rods, distributed throughout the mass of the furnace charge. The success and efficiency of the process depend, of course, upon the spacing of these several cores, which are so disposed that the temperature attained in their immediate vicinity is not in excess of the maximum whilst that at intermediate points does not fall below the minimum temperature necessary for the formation of the compound. The result of such a disposition is the conversion of the entire charge into " white stuff."

Fitzgerald prepares refractory carborundum articles, such as crucibles, furnace bricks, etc., by moulding crystallized carborundum into the desired form, and subsequently subjecting the articles to such a temperature, in the electric furnace, that the mass re-crystallizes.

F. J. Tone, of Niagara Falls, has adopted " white stuff," or amorphous carborundum, to a similar purpose, the product, owing to its greater porosity, being especially suitable for furnace construction, where it will be subjected to sudden and excessive temperature changes. A temporary binder of glue, or water-glass, is added to the mass previous to moulding, and the articles may be conveniently heated by embedding them in the usual charge of a carborundum furnace.

Siloxicon is the name given to a new class of compounds, the commercial value and mode of preparation of which have been recognized and patented by Acheson, and assigned to the Acheson Company of Niagara Falls.

Generally speaking, it consists of carbon, silicon, and oxygen in chemical combination, and is described as amorphous, grey-green, when cold, and light yellow when heated to $149°C. = 300°F.$ or above; density 2.75; very refractory to heat; insoluble in molten iron; neutral towards acid and basic slags; indifferent to all acids save

hydrofluoric ; unattacked by hot alkaline solutions, and self-binding to such a degree that the use of a separate binding agent is not essential in forming it into crucibles, furnace-linings, fire-bricks, and such other articles as may be manufactured from it. The articles may be formed by merely moistening the pulverulent material with water, moulding, and firing, or, if desired, a carbonaceous or other binding material may be used.

It is a by-product of the process of carborundum manufacture, and is prepared in an Acheson resistance furnace with multiple core. The manufacture of siloxicon bears a striking resemblance to that of carborundum. The process is patented by E. G. Acheson, and is being worked by the Acheson International Graphite Company. The raw materials are ground coke and sand, mixed in the proportion of one part carbon to two parts silicon, with a certain quantity of sawdust to impart porosity to the mass. In adding the latter, due regard is paid to its carbon content ; the correct apportioning of the carbon percentage in the furnace charge is of great importance, as, if it be present in excess, the silica will be completely reduced, and no formation of siloxicon will take place. Siloxicon has a chemical composition approximately represented by the formula Si_2C_2O.

As in the case of carborundum manufacture, the furnace is loosely built of fire-brick, its approximate dimensions being : length, 30 ft. ; width, 8 ft. ; and depth, 6 ft. To operate a siloxicon furnace of this capacity 1,000 e.h.p. are required.

The original siloxicon furnace had a double flat heating core, but the writer understands that later furnaces have been constructed with three cores.

The temperature at which the reaction takes place is lower than that required for the production of carborundum, the formation of siloxicon occurring at a temperature between 2,480° and 2,757°C. = 4,500° and 5,000°F., whereas

carborundum manufacture entails a temperature of approximately $3,876°C. = 7,000°F.$

Freshly made siloxicon is a greyish green, loosely coherent mass, and, on leaving the furnace, it is subjected to a milling process which reduces it to such a grade that it will pass through a No. 40 sieve.

It is a self-binding material, and only needs forming into a paste with water, when it can be moulded into any desired form, which is rendered permanent by subsequent firing. For some purposes, an admixture of 25 per cent. clay may be introduced into the mass, prior to moulding, or, if preferred, additional binding materials, such as liquid tar, asphaltum, pitch, molasses or glue ; in fact, any similar carbonaceous binding material may be employed, in which case the siloxicon powder and agglutinant are thoroughly mixed whilst hot, after which the mixture is moulded into the desired form and burned, or, as an alternative, may be used without burning, the subsequent heating to which it is subjected in use being sufficient for the purpose.

It has a promising future in the manufacture of all kinds of refractory articles, such as furnace linings, crucibles, fire-bricks, etc.

For lining furnaces, the paste or mixture, prepared as above, is applied to the surface to be protected, and well rammed into place, where subsequent burning converts it into a homogeneous refractory layer.

Siloxicon, when heated to a temperature of $1,466°C. = 2,674°F.$, or above, in an atmosphere containing free oxygen in excess, decomposes, presumably, according to the equation :

$$Si_2C_2O + 7O = 2SiO_2 + 2CO_2.$$
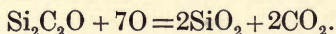
If the siloxicon thus heated be agglomerated or moulded into a coherent mass, the reaction is confined to the surface of the latter, and produces a vitreous glaze, tinged light green by the presence of iron as an impurity. In the absence

of free oxygen, or in a reducing atmosphere, no decomposition occurs at the above temperature, and the siloxicon may be heated to the formation temperature of carborundum, approximately $3,867°C. = 7,000°F.$, without change. At this point, however, it dissociates ; the equation representing its decomposition is supposed by Acheson to be :

$$Si_2C_2O = SiC + Si + CO.$$
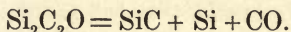
Solid carborundum is left behind, whilst siloxicon vapour and carbon monoxide gas are driven off. Carborundum, subjected to the same treatment, behaves similarly.

Artificial Graphite.—The electric furnace devised by E. G. Acheson for the manufacture of graphite is, like the other designs which owe their origin to his inventive genius, of the resistance type. It takes the form of a trough-like structure, in which is placed the rough charge of anthracite coal, or coke, which it is required to convert into graphite. The core is independent of the charge itself, and consists of a series of carbon rods, extending through the mass to be heated, and forming a bridge for the current between two end electrodes. The raw charge itself is, at first, a non-conductor, and the current, when switched on, passes entirely through the carbon rods, raising them to a high temperature. The heat thus evolved converts the layer of coal or coke, immediately surrounding the core, into graphite, which, in turn, becomes a conductor, and performs a similar office for the next layer of raw material, and so on until the whole charge has been converted.

A study of the various allotropic modifications of carbon, and the changes they severally undergo when subjected to high temperatures, provides a wide and interesting field for the investigator, and many scientists, past and present, recognizing the possibilities opened up by a more advanced knowledge of the subject, have, from time to time, devoted considerable attention to it. The principal results of their experiments, in so far as they bear upon

the artificial production of graphite, have been assembled in the form of a very interesting article by C. P. Townsend, which appeared in the *Electrical World*, April 6, 1901, and to which the reader is directed for the original references. The writer has taken the liberty of extracting therefrom the following interesting and salient points in the history of the manufacture of artificial graphite.

Scheele, as far back as 1778, discovered the solvent power of molten iron for carbon, and also the additional fact that a portion of the carbon so dissolved separates out on cooling in the form of graphite, a discovery which has since exercised an important influence upon the iron industries.

This knowledge was further supplemented in 1896 by Moissan, who showed that the purity of the graphite thus formed by separation on the cooling of the iron solvent is proportional to the temperature to which the solvent metal has been raised, and to the pressure exerted by the iron in cooling. Moreover, it has been demonstrated that graphite, from whatever source, invariably contains hydrogen as a constituent, though not, apparently, in chemical combination with it.

In 1849 Despretz commenced a series of careful investigations into the changes undergone by carbon at high temperatures, his apparatus consisting of a closed cast-iron furnace, through the walls of which, and rendered airtight by leather stuffing boxes, projected two carbon electrodes.

Inlet and outlet pipes for the introduction and withdrawal of gases were provided, and the effects of variations in the pressure duly noted.

This experimental furnace was operated both on the " arc " and " resistance " principles, by the current from 600 Bunsen cells, in series of 25, 50, or 100, as occasion determined.

Various forms of carbon were experimented upon, and

Despretz thus summarized the results of his investigations—

(1) Carbon, in a vacuum, volatilizes at temperatures produced by 500 to 600 Bunsen cells. Under pressure of nitrogen at $2\frac{1}{2}$ atmospheres, volatilization occurs more slowly.

(2) Carbon, at these temperatures, may be bent, welded, or fused.

(3) Carbon from all sources becomes progressively softer, finally turning to graphite.

(4) Graphite volatilizes slowly.

(5) Diamond is converted into graphite.

Strangely enough, this early investigator appears to have actually applied the modern principles of artificial graphite manufacture, and yet failed to produce it, for he asserts, in the course of his report :—" I have enveloped, I have impregnated, acicular rods of carbon, with more fusible materials, silica, alumina, magnesia, to determine whether the presence of a more fusible body would render the fusion of the carbon more easy. The silica, magnesia, and alumina, escaped as vapours and the carbon remained unmodified."

In the case of anthracite coal, however, Despretz appears to have met with a measure of success, for he speaks of its conversion into " well characterized graphite," the conversion having been effected in a crucible by the heat of an arc struck between an independent electrode and the anthracite under treatment.

In 1870 Berthelot studied the direct combination and conversion of carbon ; he was unable to effect the conversion of amorphous carbon into graphite by any other heat save that of the arc, nor could he convert graphite into amorphous carbon. Berthelot was responsible for the discovery that graphite could be obtained as the result of decomposing a carbide. He heated boron carbide in an atmosphere of dry chlorine gas, and found that at a temperature below the softening point of glass, carbon separates

out as amorphous graphite, and, at the fusing point of porcelain as hexagonal crystals.

In 1893 Girard and Street introduced their system of superficially graphitizing electrodes and other carbon articles, by causing an arc or arcs to play over the entire surface of the object, the process being carried out either in an atmosphere of carbon monoxide, nitrogen, or similarly neutral gas, or in a vacuum.

In 1896 Moissan pointed out that diamond, when subjected to the heat of the arc, was converted into graphite, a conclusion previously arrived at by Despretz. Moissan also investigated the solution of carbon by many metals, and its subsequent separation as graphite, on cooling. Among the metals experimented with, were aluminium, silver, manganese, nickel, chromium, tungsten, molybdenum, uranium, zirconium, vanadium, titanium and silicon.

At normal pressures, carbon has no intermediate liquid state.

The results of Moissan's varied and extensive researches on the subject of graphite and its formation have been thus summarized by him (*Comptes Rendus*, vol. 119, p. 980)—

1. Whatever the variety of carbon, elevation of temperature always suffices to convert it into graphite. This graphite may be amorphous, or crystallized, has a specific gravity of 2·10 to 2·25, and a temperature of combustion in oxygen of 660°C. =1,220°F.

2. There are several varieties of graphite, just as there are several varieties of amorphous carbon and of the diamond.

3. The stability of graphite (its resistance to oxidation) increases in proportion to the temperature to which it has been subjected.

4. This fact is clearly shown by the resistance opposed by different graphites to transformation to graphitic oxide. The difficulty of this oxidation increases in proportion to the fusing point of the metal, from solution in which the graphite has been derived. Similarly, a readily oxidizable

graphite, like that of Ceylon, becomes much more resistant after heating.

Acheson, who is associated with the most modern methods of treating carbon and certain of its compounds in the electric furnace, patented, as early as 1895, a process of coke purification, which consists in subjecting it to the direct heat of the current, thus volatilizing the impurities and leaving the carbon in a practically pure state, and, in all probability partially converted into graphite. In the same year, he patented a method for the production of graphite by the decomposition of silicon carbide (carborundum), that compound being heated to such an extent as to volatilize the silicon. Moissan has similarly produced graphite by the high temperature decomposition of calcium carbide, employing a 1,200 ampère, 60 volt, arc furnace.

In 1899 Acheson, who may be regarded as an authority with considerable practical experience of his subject, published in the *Journal of the Franklin Institute* his observations on the yield of graphite, and the conclusions to be drawn therefrom. They run as follows—

1. Comparatively pure petroleum coke produces practically no graphite.

2. Impure bituminous coal coke produces large quantities of graphite.

3. The larger the percentage of impurities in the bituminous coal core, the greater the yield of graphite.

4. Only part of the carbon core of carborundum furnaces is converted into graphite (that part which carries an admixture of slate, or a high ash content). This conversion is not increased, even by repeated use of the same grains in successive furnaces.

The conclusions drawn by Acheson from these observations are—

1. *Graphite*—is the form carbon assumes when freed from chemical associations, under conditions of low pressure and protection from chemical influence.

2. *Diamond*—is the form carbon assumes when freed from chemical associations, under the conditions of high pressure and protection from chemical influence.

And, by " inference "—

3. *Amorphous carbon*—is the form carbon assumes when freed from chemical associations, under conditions of high or low pressure and exposure to chemical influence.

It will have been noted, from the foregoing context, that these various investigators are far from being of one accord as regards the theory of the formation of graphite. Commenting upon this, and basing his deductions upon the fact that Moissan, with an arc furnace, succeeded in converting all forms of carbon into graphite, whereas Acheson, working with his well known resistance type of furnace, failed to effect such conversion in the case of pure carbon, Townsend suggests that the preliminary ionization of the carbon is essential to the formation of graphite ; he thus advances his theory—

" The essential condition for the formation of graphite may be considered to be the presence of carbon in the ionized state, and its separation therefrom. This, so far as we know, may be accomplished by any one of four methods—

" 1. By solution in metals or carbides.

" 2. By the direct ionizing action of the electric discharge, and notably the arc, upon carbon.

" 3. By the action of the electric discharge upon gaseous carbon compounds.

" 4. By the dissociation, by heat, of certain carbon compounds, notably the carbides."

Borchers and Mogenburg, investigating the conversion of amorphous carbon into graphite by electric furnace methods, have also found the process, with pure carbon, very difficult of accomplishment. The conversion is, however, facilitated by the presence of metals or their compounds, notably aluminium. These combine with the

carbon to form carbides, which are subsequently decomposed, and the carbon released from combination in the form of graphite. The quantities of metal thus required are very small, and aluminium has been found most suitable and effective for the purpose.

In the course of his researches into the manufacture of artificial graphite, Acheson has demonstrated that the carbide forming impurities need not be present in proportion sufficient to react at once with the whole of the carbon to be converted, but that the graphite formation may be of a progressive character, small quantities of carbide being formed, decomposed, and the volatilized impurity again combine with an adjacent portion of carbon, to repeat the cycle of transformation.

He also found that the introduction of additional carbide forming impurities, in the case of non-coking coal, and certain kinds of charcoal, was unnecessary, in that they contained sufficient mineral impurities in themselves to effect their conversion into graphite, when raised to the required temperature.

It is not essential that the preliminary mixing in of the impurities with the mass of carbon be thorough, as the metallic vapours formed during the process thoroughly permeate the entire mass.

According to Blount (Paper read before Manchester Section I.E.E., March 4, 1902) there are three methods available for the artificial manufacture of graphite in the electric furnace.

1. By direct conversion at a very high temperature.

2. By crystallization, on cooling, from supersaturated solution of carbon in some suitable metal (e.g., aluminium, manganese, nickel, chromium, tungsten, molybdenum, uranium, zirconium, vanadium and titanium).

3. By crystallization of dissolved carbon from its metallic solution, by the addition of an element, such as silicon or boron, capable of displacing it.

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Blount, in speaking of Acheson's method of manufacturing artificial graphite, criticizes the wording of his patent claims, which nominally cover the production of graphite by the decomposition of a carbide, and points out that, if put to the test in a patent litigation case, they would probably prove untenable, in that they refer to processes discovered and made public many years ago. In this connexion it may be mentioned that Acheson's own theory to account for the conversion of amorphous carbon into graphite at high temperatures is that it follows from the decomposition of a carbide, which is formed in the first instance, the carbon of the latter being deposited in the form of graphite.

A good mixture for the production of artificial graphite is said to consist of 97 parts finely divided amorphous carbon mixed with three parts iron oxide. It is suitable for moulding into any desired form previous to graphitizing.

The output of artificial graphite in America was 81 tons in 1897 ; in 1901, it had increased to 1,200 tons.

The total yearly production of the International Acheson Graphite Co. alone, in 1902, was said to be in the neighbourhood of 500 tons.

Graphitizing Electrodes.—The Acheson resistance furnace for graphitizing electrodes, as employed at the works of the International Acheson Graphite Company, Niagara Falls, is of the usual type, as already described in connexion with the manufacture of carborundum. The process of graphitizing is similar to that already dealt with, and consists in causing the pure carbon, under the influence of electric heat, to combine with certain carbide forming impurities which are present in the mass prior to the process.

The electrodes are first made up in the usual way, from petroleum coke and pitch, like ordinary arc light carbons, the only addition being a certain amount of carbide-forming material such as silica, or iron oxide. They are baked in the usual way, and then subjected to the graphitizing furnace, in which process they are raised to a temperature

well above that of the volatilization of iron, aluminium, or silicon.

The necessary temperature for the reaction is higher than that required for the decomposition of the carbides formed, and is produced in the furnace construction represented in Fig. 12, where F is the outer rectangular structure of fire-brick, through the end walls of which are introduced the electrodes *e e,* which conduct the current to the charge C ; this latter may either consist of cylindrical rods, as represented in transverse section in the figure, or rectangular plates. In the former case the rods are, as shown, packed transversely to the direction of current flow, the necessary
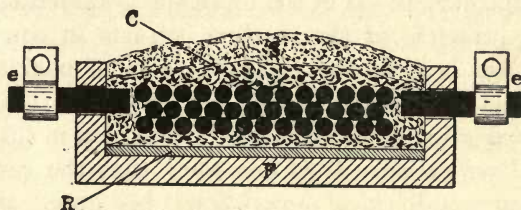

FIG. 12.

high resistance path from one to the other being established along the lines of contact between the cylindrical surfaces.

It is chiefly along these lines that the heat is generated, and this mode of packing the articles to be graphitized gives rise to the evolution of heat exterior to the articles, rather than in the mass itself, as would be the case were they arranged with their axes parallel to the line of direction of the current. This constitutes the principal feature of the invention, and effects considerable economy in the current required for the operation of the furnace.

If the objects to be graphitized are rectangular, they are arranged in a series of regular piles along the path of the current, each pile being separated from its neighbour by a filling of ground or pulverized coke.

The latter is also employed as a filling, in both cases, and

is introduced between the ends of the charge and the electrodes. The base of the furnace is lined with a refractory layer of carborundum R, or similar conducting material, and the whole is covered in at the top with a layer of ground coke and sand S.

One of the latest resistance furnace methods patented by Acheson relates to the manufacture or baking of moulded carbon articles, such as electrodes, arc-light carbons, etc. To this end they are embedded in a heating resistance composed of granular carbon, or a mixture of carbon with silicon, etc. The articles to be baked are placed with their longest dimensions at right angles to the path of the current, as in the foregoing graphitizing furnace, and the principle of the method consists in confining the evolution of heat to the resistance core of packing, rather than to the articles themselves. A very uniform and easily regulable heating effect is said to be obtained in this manner.

Coke Purification.—It is necessary that the carbon used in electro-metallurgical operations be pure, and, more especially, free from silica and the compounds of silicon, which would, if present, combine with the metal under treatment, and result in the re-introduction of like impurities into the finished article.

Mr. C. M. Hall, the patentee of the aluminium process which bears his name, has devised and patented a form of resistance furnace for ridding the coke of these undesirable impurities before it is employed in connexion with the extraction of metals.

The process consists in powdering the coke, and mixing it intimately, whilst thus powdered, with a metallic fluoride, such as sodium fluoride, cryolite, or fluor-spar. This mixture, when subjected to heat in a suitable furnace, becomes pure carbon, owing to the reaction set up between the fluoride and the compounds of silicon, which combine to form silicon fluoride, the latter being driven off in the form of gas.

By adding a suitable proportion of pitch to the mixture, as a binding material, it can be moulded into electrodes of any desired form, and the purification and baking process carried out in one operation of the furnace.

The latter is built of brick, and filled with moulded carbon blocks, packed symmetrically, and insulated from one another by suitable packing. Through the centre of the mass, and in close proximity to the blocks, runs a resistance core with end electrodes. An alternating current is supplied to this core by means of the electrodes, and the heat adjusted to any desired temperature, by varying the current.

The actual temperature is necessarily slightly higher than that required for baking alone, in order to produce the necessary thermo-chemical action for the purification of the carbon.

Peat Coal.—Of late years the problem of adapting peat to the same fuel uses as coal has engaged considerable attention, and several processes for manufacturing what is known as " Peat Coal " have been evolved. In this connexion the possibilities of electric heating have not been overlooked.

The Jebsen process, invented by P. Jebsen, Norway, and commercially exploited by him at Stangfjorden, has been in successful practice for over three years. The peat is first kneaded and compressed into rectangular blocks by special machinery, after which it is subjected to a drying process, by exposure to blasts of the hot gases produced in the carbonizing retorts. These gases, which have an initial temperature of from 90° to 100°C. = 194° to 212°F., reduce the quantity of moisture present in the peat from 80 per cent. to 25 per cent. or thereabouts.

It is then ready to undergo the electrical carbonization process, which is carried out in what is virtually a resistance furnace with independent cores. Each furnace or retort, consists of an iron cylinder, about six feet long, by three feet in diameter, with removable end covers. These

retorts are mounted in a vertical position and lined interiorly with asbestos or fire-brick.

The heating resistances are in spiral form, supported from the walls of the retort, and so disposed that the peat under treatment, when packed into the cavity, comes into intimate contact with them. The disposition is such that practically all the heat evolved is utilized and absorbed by the peat, the loss, by radiation, being, to all practical intents and purposes, nil. Experience has determined the time and current necessary to effect the carbonization process, after which the current is switched off, and the retort, with its charge, allowed to cool. The lower cover is then removed, and the carbonized peat allowed to fall into a truck placed to receive it.

The temperature required to thoroughly effect the carbonization is from 400° to 500°C.=752° to 932°F. By lengthening the retorts, the process can be made continuous, the dried peat being continuously fed in above and the carbonized product removed, periodically, from below.

The Jebsen process of peat coal manufacture results in several marketable by-products, among which may be mentioned peat oil, paraffin, gas oil, coke, and gas, the latter being utilized, as already stated, in the preliminary drying of the peat. The peat coal produced by this process has a heating value of 7,500 calories, burns with intense heat, and produces very little ash, or soot. Samples, subjected to analysis at the Royal Norwegian High School, in Christiania, showed the following composition—

Carbon	.	.	.	.	.	.	76·91	per cent.
Hydrogen	.	.	.	.	.	.	4·64	,, ,,
Oxygen	.	.	.	.	.	.	8·15	,, ,,
Nitrogen	.	.	.	.	.	.	1·78	,, ,,
Sulphur	.	.	.	.	.	.	·70	,, ,,
Ashes	.	.	.	.	.	.	3·00	,, ,,
Humidity	.	.	.	.	.	.	4·82	,, ,,
							100·00	,, ,,

Peat carbon, produced by the Jebsen process, is said to be especially suited for calcium carbide manufacture. The product of the process is, roughly, 33 per cent. charcoal, 4 per cent. tar, 40 per cent. liquor, and 23 per cent. gas, the figures being based on the treatment of initially dried peat. The carbon is very hard, and of a deep black colour. The current necessary for the process is derived from five 80 k.w. generators driven by turbines of 128 h.p.

A process analogous to that of Jebsen, but not carried to such a high degree of carbonization, has been invented by Mr. Bessey, and was publicly demonstrated before a committee of press representatives and technical experts, at the works of Messrs. Johnson and Phillips, Charlton, Kent, in 1903.

The peat is first placed in a centrifugal drying apparatus, which drives out a considerable portion of the 80 per cent. moisture which it contains. Electrodes are then introduced, and the drying pushed to a higher degree by the resistance process of electrical heating, the necessary initial conductivity of the mass being secured by the addition of certain chemicals.

A company, known as the Electro-Peat-Coal Syndicate, has since been formed for the purpose of exploiting this process on a commercial scale, and it is estimated that peat coal can be produced at a cost of 5s. per ton inclusive.

Carbon Bisulphide.—The resistance furnace utilized in the manufacture of carbon bisulphide at Penn Yan, N.Y., U.S.A., is illustrated in Fig. 13. It is the invention of Mr. E. R. Taylor, and is the outcome of considerable forethought and experiment. In the original furnaces, independent carbon electrodes were utilized as terminals, being protected from a too rapid combustion by broken carbon, which was fed into the furnace through orifices immediately surrounding the electrodes. In the latest type of furnace the carbon block terminals have been entirely dispensed with, electrical connexion being made directly with the

carbon feed hoppers, through which the broken carbon is introduced into the furnace.

In brief, the action is as follows : the upper, cylindrical portion is filled with closely packed carbon C, through which the sulphur vapours, produced by the action of electric heat upon the fused mixture of carbon and sulphur, F at the hearth of the furnace, rise, and in passing are converted into carbon bisulphide, which is suitably collected and condensed.
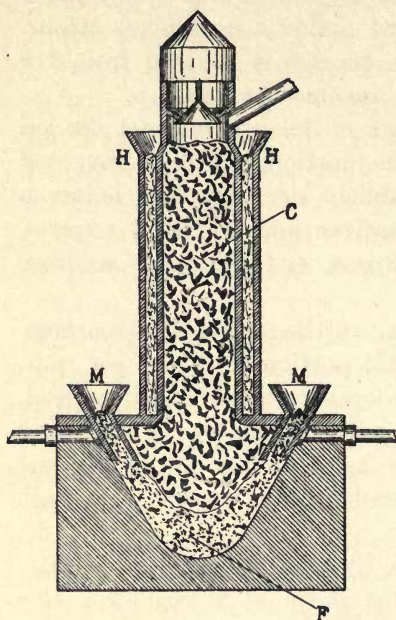
Terminal connexion with the furnace is secured through the carbon hoppers M M, which are four in number, situated at equal distances around the circumference of the hearth, and through which a constant supply of broken carbon is fed.

Fig. 13.

The raw sulphur is made to perform a primary duty before finally entering into combination with the carbon. It is fed in cold, through hoppers H H, which convey it into annular chambers, entirely surrounding the furnace body and hearth : in these, the sulphur, whilst still in a cold state, acts as a heat-conserving jacket, and only becomes molten when it approaches the bottom of the annular chambers, which communicate with the furnace hearth, and through which the sulphur feed is effected. It thus reaches the centre of activity in a heated condition, and no undue lowering of the general temperature results.

By varying the electrical connexions to the four terminal hoppers, a very thorough and complete fusion of the carbon and sulphur is effected in the region of the hearth.

The dimensions of these furnaces, as used at Penn Yan, are : height, 41 feet ; diameter, 16 feet ; and they require a current of 4,000 ampères, at from 40 to 60 volts, to operate them. The regulation is, to a certain extent, automatic ; as the temperature, and consequently the degree of fusion, increases, more molten sulphur flows in to the bottom of the hearth from the sulphur jackets, and the level of the molten mass rises until it encircles the electrode hoppers, and gives rise to an increase in the electrical resistance of the active column, with a consequent decrease in the current until the working conditions again become normal.

A later modification consists in locating the active heat zone nearer to the furnace base, a procedure which renders it possible to tap off accumulations of slag resulting from impurities in the charge.

Early experiments in 1903 showed an output of 5,000 kgs. of carbon bisulphide per furnace in 24 hours, but this figure has since been considerably increased. The output from the Penn Yan furnaces, to June 1902, was 1,500 tons.

The carbon bisulphide furnaces at Penn Yan are the largest electric furnaces at present in use.

SECTION IV

CALCIUM CARBIDE MANUFACTURE

General.—Calcium carbide, expressed in chemical formula, CaC_2, is produced by heating together a mixture of 65 per cent. lime, with 35 per cent. carbon, or coke.

A very high temperature, approximately $3,312°C. = 6,000°F.$, is required to effect the combination, the oxygen of the lime being driven off, and uniting with a certain percentage of carbon, to form monoxide (CO) and dioxide (CO_2) of carbon. Some heat is necessarily evolved as a result of the chemical combination pure and simple, but it is insufficient to render the mixture self-heating; consequently artificial means, in the shape of the electric furnace, have to be resorted to, in order that the mass may be raised to the requisite temperature.

As early as 1862, Wöhler prepared calcium carbide, by heating an alloy of zinc and calcium in the presence of an excess of carbon, but failed to isolate the compound. In 1893, Travers also succeeded in manufacturing calcium carbide, though in admixture with other substances, by heating a mixture of calcium chloride, carbon, and sodium. Moissan, however, must be credited with having been the first to manufacture and isolate calcium carbide with the aid of the electric furnace. He published his discovery on December 12, 1892, in the form of a paper communicated to the Académie des Sciences, which ran thus—

" If the temperature (in the electric furnace) reaches $3,000°C. = 5,432°F.$, the lime forming the furnace melts

and runs like water. At this temperature carbon quickly reduces calcium oxide, and the metal is separated in quantity; it unites easily with the carbon of the electrodes to form a carbide of calcium, liquid at a red heat, and easily collected."

At the end of 1892 Willson announced *his* discovery of calcium carbide, which had been made independently, and apparently without knowledge of Moissan's researches on the subject. Thos. L. Willson, the original discoverer of a commercial process of calcium carbide manufacture, was, in 1885, an employé of the Brush Company at Cleveland, where the Cowles Bros. were then operating their electric furnace. He subsequently experimented with the electric furnace at Spray, N.C., U.S.A., where the first successful production of calcium carbide was effected in 1888.

His attempts to patent its methods of production in the electric furnace proved futile, and the only patents now standing, which bear on carbide manufacture, either relate to certain details in the design of the furnaces themselves, or to such subsidiary processes as tend to promote the efficiency of manufacture, e.g. the preheating of the raw materials by suitable combustion of the reaction gases.

With reference to the early history of calcium carbide, Vivian B. Lewes, *Acetylene*, tells us that in 1886-1887 the lads employed at the Cowles' aluminium works were actually playing with the substance, and experimenting with the acetylene gas evolved on bringing it into contact with water. Yet it was not until 1892, five years later, when its commercial value and mode of preparation had been independently studied by Willson and Moissan, that it became an industrial product.

In France, M. Louis Michel Bullier claims to be the orignal discoverer of crystalline calcium carbide, and his claims have been upheld by the French Courts. The Bullier patents belong to the Société des Carbures Metalliques, a Parisian company founded by Bullier. In 1903, this concern, which controls the output of 17 carbide fac-

tories in the Alpine districts, compelled its dealers to sell at a uniform price of £14 per metric ton. The annual output is estimated at 18,000 tons.

Commercial calcium carbide, in which iron is usually present as an impurity, is a grey mass, with a metallic appearance and a crystalline fracture. Its specific gravity is 2·22, and its crystals, examined under the microscope, are seen to be transparent, and of a reddish tint, due to the impurities present.

When brought into contact with water, calcium carbide decomposes rapidly into lime, and acetylene gas, which latter is given off. The equation—

$$CaC_2 + 2H_2O = Ca(OH)_2 + C_2H_2,$$
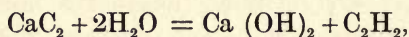
represents the reaction which takes place. Acetylene has also been produced directly in the arc furnace by Berthelot, who succeeded in bringing about the direct union of carbon and hydrogen in the requisite proportions.

M. Gin has made an extensive study of the reactions which take place in a carbide furnace during the formation of calcium carbide. Regarding the furnace contents as a series of layers, in which the temperature rapidly decreases from the interior to the exterior, he finds that, in these layers, different chemical equilibria are formed, the reaction being more endothermic the higher the temperature. The gases evolved in different parts of the furnace contain both free oxygen and free calcium. The former is liberated at the points of maximum temperature, or, in other words, its quantity increases with the current density. Calcium vapours, on the other hand, originate at points of lower temperature. The presence of free oxygen sets up combustion of the electrodes, immediately below the surface of the charge, whilst the calcium is deposited as the fine dust so familiar to carbide workers.

Gin explains the presence of these two elements in a free state, by referring to the researches of Berthelot, who proved

that carbon monoxide is dissociated at high temperatures ; in the majority of commercial formulae for carbide furnace charges there is an excess of lime. The formation of calcium carbide consists in simple substitution of carbon for the oxygen of the latter. The carbon monoxide formed as a secondary product of the reaction is, in the hottest parts of the furnace, entirely dissociated, whilst calcium vapours are evolved at the boundary surfaces of calcium oxide, and calcium carbide.

In a resistance furnace, calcium carbide commences to form at a current density of 1·2 ampères per square millimetre, through the core, whilst, if the density be increased to 2 ampères per square m.m., the product assumes a fluid condition. According to Vogel, at the latter density in the core of a resistance furnace, fluid calcium carbide commences to form rapidly in the immediate neighbourhood of the core. This rapid formation, however, only extends over a region of some three or four centimetres from the core, the remainder of the charge, though incandescent, remaining in a semi-solid condition, in which state it forms a gradually increasing mass, disposed in shunt to the resistance core proper, conducting a considerable portion of the main current through itself, and thereby decreasing the heating efficiency of the core.

The result is a mixture of true carbide, with a partially converted remainder, which offers difficulties in the way of economical separation. It is therefore necessary, in the operation of carbide furnaces of this description with a single core, that the furnace charge be periodically broken up, or agitated, and the crust formation thereby prevented.

To obviate this defect, it has been suggested, and, in fact, a German patent (No. 120,831, February 8, 1900) has been taken out on a resistance carbide furnace, of which the core, in multiple, is disposed in the form of a gridiron, which effectually prevents the formation of a superimposed

and uneconomical crust, whilst the carbide formed falls away, by virtue of its own weight, to the hearth of the furnace, the raw materials descending from above to take its place.

Of such a gridiron formation of five electrodes, 100 m.m. deep, 15 m.m. thick, and 1,200 m.m. long, the total weight is 13·5 kgs. ; the cross-sectional area, 7,500 square m.m. ; and the electrical resistance, 0·003 ohms. The current required, at a density of 2 ampères per square m.m., is 15,000 ampères, at a pressure of 45 volts, or 1,100 (German) H.P., of which 920 are utilized in the furnace. This disposition is secured by arranging three furnaces in series, the 1,200 m.m. of resistance core length, being equally divided between them. In the three furnaces, with gridiron cores, proportioned as above, there would be a total effective heating surface of 13,800 square c.m., as compared with 675 square c.m. in a three-electrode arc furnace with square carbons, each of 150 m.m. side.

Assuming a yield of 0·2 kg. of carbide per H.P. hour, the expenditure of 900 H.P. would produce 180 kgs. per hour in each furnace, or a total of 540 kgs.

MM. Vulitch and d'Orlowsky, of Paris, suggest the preparation of calcium carbide by first fusing the lime, *per se*, in an arc furnace, and then pouring it into an excess of some heavy hydrocarbon, such as the residue from petroleum distillation, in the body of which the actual carbide formation takes place. The product is loose and non-coherent, and saturated throughout with the hydrocarbon, which renders it practically non-hygroscopic and adapted for the intermittent generation of acetylene, evolution of the latter only taking place during actual immersion in water.

In the manufacture of calcium carbide, as in other electric furnace processes, the tendency has been to revert to the more moderate and easily regulable " resistance " principle of working. It is, however, questionable whether calcium carbide has ever been manufactured, commercially, without

the development of an arc or arcs, within the mass of material bridging the electrodes.

As M. Pradon points out, the presence of vapours of calcium and carbon in the neighbourhood of the electrodes reduces the E.M.F. necessary for the striking of an arc to from 8–10 volts, a pressure at which, owing to the impracticable increase in cross-sectional area of the furnace electrodes and connexions, it would be impossible to operate.

It is, of course, possible to smother the arc by judicious feeding of the raw materials, but the constantly changing nature and irregular movement of the charge permit it to strike again.

Bearing these facts in mind, it would seem probable that the whole commercial process of carbide manufacture depends upon a combination of the arc and resistance principles of furnace working, which operate irregularly, and irrespective of the design of the furnace itself, in so far as the latter may be intended to confine the reaction to one or the other of the two principles of operation.

The calcium carbide of commerce cannot be purified by any of the usual methods adopted with fusible and soluble products, in that it is, to all practical intents and purposes, infusible, and insoluble in any known solvent. It remains, therefore, to produce the carbide in as pure a state as possible, such that subsequent purification is rendered unnecessary.

There are, at present, two known methods of achieving this result, both of which consist in the addition of foreign materials to the charge of carbon and lime undergoing treatment in the furnace, which, either by combination with the impurities, or reacting upon them during the process, render them innocuous or convert them into such a form as permits of their ready removal from the finished product.

Hewes' method consists in employing, as a furnace charge, a mixture of 26 parts carbon, 64 lime, 8 calcium carbonate, and 2 peroxide of manganese. The function of the latter

is to form carbide of manganese (MnC_3), which reduces the temperature of the reaction, and tends to increased fluidity of the product. Methane (CH_4) is also produced, and serves as a diluent, lessening the tendency to a sooty deposit from the acetylene subsequently produced from the carbide.

The object of adding calcium carbonate to the mixture is to produce a generous yield of gas, which, bubbling up through the carbide, carries with it such impurities as the sulphides and phosphides of calcium to the surface, leaving them there in the form of a crust, which is readily separated from the charge when the furnace is opened.

Dr. W. Rathenau's process is specially adapted to the getting rid of silicious impurities in either the lime or carbon. He adds to the charge a metal, preferably iron, or its oxide, in sufficient quantity to take up and combine with all the silicon present as impurities. The result is the formation of iron silicide, which collects at the bottom of the furnace below the carbide, and may be drawn off, or subsequently separated from the charge, as circumstances may determine.

Silicide of iron, or ferro-silicon, thus produced, constitutes a useful by-product and may be marketed for various purposes.

Temperature of Formation.—There has been considerable discussion as to the temperature of formation of calcium carbide. Several experimenters have tackled the subject with a view to ascertaining the exact degree of heat necessary ; among others, Rothmund and Borchers (*Zeitschrift für Elektrochemie*, May 29, 1902). The former proved, by experiment, that the lowest temperature at which calcium carbide can be formed is 1,620°C. = 2,948°F. Below this temperature, again, at 1,560°C. = 2,840°F., and in the presence of carbon monoxide gas, the carbide already formed is disintegrated, or split up, into its constituent elements.

Borchers, who conducted his experiments with the aid of blow-pipe heating, found that a temperature of approxi-

mately 2,000°C. = 3,632°F., was necessary for the formation of crystalline calcium carbide, from which it will be seen that although, theoretically, only 1,620°C. is necessary, a temperature of at least 2,000°C. is required in practice.

Quality.—The commercial quality of calcium carbide is determined by its capacity for evolving acetylene gas. One kilogramme of pure calcium carbide evolves 348·4 litres of acetylene, the latter being determined at a pressure of 760 m.m., and a temperature of 0°C. = 32°F. This is equivalent to 5·587 cubic feet of gas per pound of carbide. The calcium carbide of commerce seldom yields more than 300 litres per kg., the average figure being between 280 and 290, or 86 per cent.

Current Used in Calcium Carbide Manufacture.—Either continuous or alternating current may be used in the production of calcium carbide, and an alternating plant is, in many cases, preferable, in that it lends itself more readily to long distance transmission, and is, withal, better capable of withstanding the strains incidental to large variations in the load, such as are invariably encountered in electric furnace working.

An interesting article by M. J. Pradon, in the *Zeitschrift für Calciumcarbid Fabrikation*, 1901, entitled "The Influence of the Nature of the Electric Current on the Manufacture of Calcium Carbide," throws some interesting light on many debatable points connected with this extensive application of electric furnace methods.

Discussing the probability of electrolytic action taking place in a carbide furnace when continuous currents are employed, M. Pradon discounts the greatly magnified drawbacks incidental to continuous current working. He states, however, that, under exactly similar conditions, and given identical charges of raw material, the carbide produced in a continuous current furnace is of a lower gas-producing quality than that resulting from the action of an alternating current ; the former product is of a compact

nature, which offers considerable resistance to fracture, whilst the latter is crystalline, and breaks readily.

Another interesting fact which has been noted in connexion with the operation of both types of furnace is, that in the case of direct current it is necessary that the preliminary mixing of the charge be thorough, in order to ensure homogeneity, whereas, with an alternating current furnace, a very casual mingling of the constituents suffices.

In connexion with the use of alternating currents for carbide furnace work, M. Pradon lays considerable stress on the lag due to self-induction, and, to obviate losses from this cause, he has designed a furnace operating on the " concentric " principle.

It consists of a movable hearth, in the form of a truck mounted on wheels, which receives and retains the carbide formed, and can be removed and replaced when full. When placed in position in the furnace, this truck is located below the centre of a metal chimney or flue, which serves to conduct away the gases of combustion. Down the centre of this chimney passes the vertical electrode. The side walls of the furnace are of metal, and one connexion from the alternating current generator is made to the upper portion of these walls, whilst the other is made to the lower extremity of the chimney.

The path taken by the current is thus downward through the metallic walls of the furnace, into the truck or hearth, and up through the unconverted mixture therein to the vertical electrode, through which it passes to the upper extremity of the chimney, and down again, being thus, through every portion of its circuit, subjected to the neutralizing effect of a return current.

An alternative method for the elimination of self-induction losses in an alternating current furnace is to do away with the arc and effect the conversion on the " resistance " principle. According to M. Pradon, this plan is impracticable, as, owing to the presence of vapours of calcium and

carbon, an arc is struck at a very low voltage, even 8 to 10 volts being sufficient. To operate below this voltage would entail an impracticable increase in the cross-sectional area of the furnace electrodes and connexions thereto.

Raw Materials.—As regards the raw materials used in calcium carbide manufacture, certain advantages, such as freedom from ash, and consequent contamination of the carbide with silicon, magnesium, iron, and similar impurities, are claimed for the carbon resulting from woody tissue, which is utilized, notably in the three-phase Memmo furnaces, to be described later.

In this connexion, a brief allusion to Prof. V. L. Emerson's invention for the conversion of saw-dust and saw-mill refuse into commercial products including a special form of carbon for carbide manufacture, may prove of interest.

The saw-dust, having first been subjected to a drying process, which is effected by the combustion gases derived from its subsequent treatment, is next charged into a retort consisting of a vertical iron cylinder, some 15 to 20 ft. high, by 3 ft. in diameter, surrounded by brickwork.

Within the cylinder are a series of perforated hoods, mounted on a central, hollow, revolving shaft, which is also provided with perforations between the hoods. The gaseous products from the distillation process which is carried on in this apparatus make their way out at the lower end of the cylinder, and, having passed through a purifying process, are partly used in carbonizing the charge by being forced through it as it passes down the retort, and, for the rest, serve to dry the sawdust, as already stated. The liquid products of the distillation are also collected and separated, being subsequently drawn off through two outlets ; of these, one is a wood creosote product which can be utilized for a variety of purposes, and the other, crude pyroligneous acid, from which wood alcohol, acetic acid, and various other products can be prepared. The carbon remainder passes out through a separate opening, and is

said to be a very pure form of carbon, especially adapted for carbide manufacture.

Experience has demonstrated that a carbide furnace works at its best when fed with a raw mixture of carbon and lime which has been reduced to granular form rather than powdered. Extreme comminution of the charge is inadvisable in that, setting aside the principal question of the expense involved in thus reducing the ingredients to a powder, there remains the additional disadvantage that, when thus finely divided, they agglomerate round the electrodes, forming an impermeable coating, which hinders the free escape of the gases formed in the reaction.

The action which takes place in a carbide furnace in the immediate neighbourhood of the electrodes, when fed with a charge which has been too finely divided, is thus described by Berger Carlson, in an article which appeared in *Zeitschrift für Elektrochemie*, about the end of 1899.

Carbon monoxide gas is formed as a natural result of the reaction, and by reason of the impermeability of the finely powdered charge, forms a cavity round the electrodes, the inner walls of which, from exposure to the radiant heat of the arc, become glazed by the fusion of the lime and its subsequent reaction upon the particles of carbon in its immediate neighbourhood. The internally glazed cavity thus formed still further encloses the reaction gases, with the result that the pressure gradually rises, until the walls of the cavity give way, and allow a portion of the carbon monoxide to escape, carrying with it a portion of the charge in the form of dust. Channels are thus formed within the general mass of the charge and, by virtue of the highly heated carbon monoxide from the region of the arc passing through them, also become glazed, and serve to conduct away from the furnace a considerable quantity of heat which would otherwise serve a useful purpose.

This constant honeycombing of the mass of raw material and subsequent caving in of the recesses formed gives rise

to serious fluctuations in the load, by setting up constant changes, having a considerable range, in the resistance of the fused mass which bridges the electrodes.

In order to eliminate these various drawbacks, the same authority advocates the use of a mixed charge, the particles of which have been reduced to the size of hazel nuts, and quotes statistics which go to prove that, whereas, with a finely powdered charge, 3,000 kgs. are necessary for the production of 1,000 kgs. of carbide, only 1,700 kgs. are required for the production of a similar quantity when the charge is of a coarse or granular nature.

It may be mentioned that the quantity of raw material theoretically required for the manufacture of 1,000 kgs. of calcium carbide, is 1,440 kgs.

Furnaces.—The improvement of electric furnaces for the production of calcium carbide, judging from the number of applications for patents, seems to have been a favourite theme for inventors. Thus, according to Kershaw (*Electrical Review*, July 7, 1899), the number of applications for patents on inventions for the production and utilization of calcium carbide numbered, in 1896, 159 ; in 1897, 172 ; and in 1898, 124.

Many of the furnace constructions dealt with are most ingenious, the principal aim on the part of the designers being, apparently, continuity of furnace action, whereby the plant may be worked continuously, day and night, with a consequent gain in efficiency ; and auxiliary heating devices, whereby the raw material is heated to a certain extent, prior to its introduction into the furnace, thereby involving a lesser expenditure of electrical energy than would otherwise be necessary for a given output of carbide.

Blount, in his paper before the Manchester Section of the Institution of Electrical Engineers, suggests a suitable design for a carbide furnace, based on the following requirements—

1. The furnace should make carbide sufficiently fluid to

be tapped and run away from the sphere of action; i.e. it must be continuous in operation.

2. It should not have an exposed arc, and the heat electrically generated should be conserved as much as possible.

3. It should be so constructed that the containing vessel is hardly affected by the high temperature necessary to form carbide.

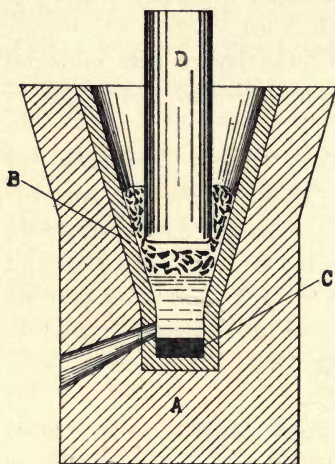Basing his design upon the three conditions set forth above, Blount suggests the furnace construction illustrated in Fig. 14. The following is his own description of the apparatus, which would certainly appear to possess several advantages over existing types.

FIG. 14.

" The furnace consists of a fire-brick casing A, with a magnesia lining B. The shape is conical, and at the bottom the furnace is contracted to form a hearth for the fused carbide. The tapping hole is at the bottom of this contracted part. The lower electrode is a carbon plate C, and the upper electrode, a massive carbon rod D, of circular section.

" The raw material is fed into the annular space between the upper electrode and the magnesia lining in sufficient quantity to enclose and smother the zone of highest temperature. This feeding may be done mechanically, and various devices suggest themselves, but it is probable that hand-feeding will be at least as effective, because the amount of labour required is not great, and the variation of conditions is so large, that the greater elasticity of hand-

feeding may be a positive advantage. For the safety of the workmen it may be necessary to draw off the carbon monoxide by a fan through a side flue, leaving the top of the furnace open and uninterrupted for manipulating the charge. In operating the furnace, a pool of carbide will be formed and maintained of such depth as to cover the hearth and to allow of tapping the pure and fairly fluid product, but the depth of this pool will be kept small, and special attention will be directed to maintaining its fluidity by the means indicated below. It will be observed that the cross-section of that part of the furnace immediately surrounding the lower end of the upper electrode is considerably greater than the cross-section of the hearth on which the carbide collects. Thus the smaller section of the column of carbide compensates for its conductivity being greater than that of the raw materials ; the desired temperature can be maintained, and the carbide will remain sufficiently fluid to be tapped."

Three-phase furnaces, as employed at St. Marcello d'Aosta, enable a more evenly distributed heating effect to be obtained, whilst, in practice, it has been found that the highest output of carbide is obtained from the intermittent type of furnace.

Ricardo Memmo, commenting on calcium carbide manufacture in Italy, sets down the following conditions as essential to the commercial success of the industry—

1. The price of the plant, per horse power installed, including machinery, furnaces, and all the necessary supplies, must not be higher than 500 francs = £20 approximately.

2. A certain ratio between the number of tons produced, and the number of effective H.P. produced, must exist. The price of calcium carbide, including general expenses, must not be more than 120 francs = £4 15s. per ton.

3. The capital expended must be liquidated in ten years. This corresponds to a sinking fund of 40 francs = £1 12s. per ton produced.

4. The selling price of the carbide must be 250 francs =£10 per ton, so that, including freight, loss, profits, etc., the price to consumer must not exceed 300 francs =£12 per ton. On the capital invested, at least 6 per cent. must be paid.

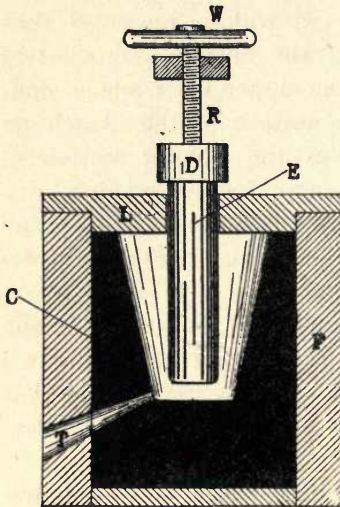The Willson carbide furnace, as originally constructed, is represented in Fig. 15, and consists of an outer structure F of fire-brick, with a lining of carbon C, which constitutes the crucible, or hearth of the furnace, and was covered in by a lid L, also of carbon, through the centre of which passed the upper carbon electrode E, adjustment being effected by means of a hand-wheel W and screwed rod R, attached to the clamp D supporting the carbon. T is a tapping hole, for drawing off the carbide formed, in a molten state. Incidentally, it may be recorded that this furnace was not originally designed for carbide manufacture, but was intended for the reduction of aluminium, and was found unsuitable for the purpose.

FIG. 15.

The charge was introduced in small quantities at a time, the electrode E being gradually raised, meanwhile, until a layer of molten carbide was produced at the bottom of the carbon crucible C, which then took the place of the second electrode.

This was followed by an improved form of the Willson furnace, in which a removable truck, mounted on wheels, took the place of the fixed carbon-lined crucible, and was

provided with a massive cast-iron base, which serves as the second electrode. This modified furnace was not hermetically sealed, the whole of one side being merely closed by iron doors whilst the furnace was in action. The free circulation of air possible with this design led to considerable loss and trouble, arising out of the waste of material and rapid consumption of the upper electrode ; it was, therefore, still further improved, prior to its adoption for carbide manufacture at Foyers. To this end two sides of the truck hearth were made removable, and consisted of massive cast-iron bars, each provided with a central opening for the escape of the carbon monoxide gas. This horizontal diffusion of the gases produced in the reaction was found to be an improvement upon the more usual vertical arrangement.

The writer understands that even this third stage in the development of the original Willson furnace has not proved altogether satisfactory to the British Aluminium Company who control the manufacture of calcium carbide at Foyers, and that a new continuous type of furnace, yielding 2,500 kgs. of 80 per cent. carbide per 1 E.H.P. year, has since been installed. No particulars concerning this later furnace are, however, available.

The Union Carbide Company, of Niagara, U.S.A., owns and works the Willson furnace patents in America. It is the only concern manufacturing calcium carbide in the United States, and its capacity is in process of extension to 100 tons per 24 hours. The cost of manufacture is stated to be in the neighbourhood of £5 per ton, and the product is graded into three sizes, varying from $3\frac{1}{2}$ in. to 2 in., 2 in. to $\frac{1}{2}$ in., and $\frac{1}{4}$ in. to $\frac{1}{12}$ in. respectively. Rotary continuous furnaces are employed, and the dust is worked up afresh with each charge.

The Gin and Leleux carbide furnaces, as used at Meran, in the Austrian Tyrol, are semi-intermittent in action, but disposed in pairs, and furnished with an ingenious

overhead arrangement, whereby a single upper electrode is made to serve for either furnace in turn. By thus working one furnace whilst the other is cooling and being charged afresh with raw material, a practically continuous operation is secured.

In general principle, the furnace resembles the modified Willson type, with removable truck hearth. There is, however, an additional feature in connexion with these furnaces which renders their mode of working distinct from that of the Willson type. It consists in a revolving fan, which extracts the gases produced in the reaction from the furnace chamber by suction, and passes them on to be utilized in a preliminary heating of the next charge ; a considerable saving in the upper carbon electrodes is thereby effected as the gases are withdrawn, or, at all events, diluted with the ingoing air, to such an extent that combustion is prevented.

At Meran these furnaces have each a capacity of 260 k.w., in three phases of 2,500 ampères at 33 volts. Each furnace operation lasts from 10 to 12 days without intermission, the only stoppages necessary being for the replacement of the upper electrode. The carbide is tapped from the furnaces in a molten condition, through two orifices, or nozzles, so designed as to prevent splashing. When these orifices become finally choked, as they do after several days, the remainder of the operation is performed, and the furnace filled, by raising the upper electrode until the chamber is charged to its utmost capacity. The furnace is then cooled and opened, and the block of carbide formed removed.

Five kgs. of carbide per k.w. day of 24 hours is the output claimed for these furnaces.

In 1900, according to M. Keller, this figure had been increased to 6·2 kgs. of carbide per k.w. day, representing a thermal efficiency of about 75 per cent.

The Gin and Leleux furnaces as employed at Milan,

Italy, and taking their energy from the Paderno three-phase sub-station, are each of 225 k.w. capacity, and work at a terminal E.M.F. of 28–33 volts. They are run in sets of three, star connected, one in each leg, or phase, of the supply system. The hearth of each furnace, which is in two layers, of high and low resistance respectively, constitutes one electrode, the other being arranged axially, and capable of vertical feed adjustment.

The high resistance layer of the hearth, heated by the passage of the current, serves to maintain the carbide in a state of fusion.

Graphite, or a mixture of graphite and anthracite, is the substance from which the electrodes are manufactured, and they are subjected to a baking heat of 1,200°C. = 2,192°F. for ten hours before use. They last about 150 hours.

Both the lime and coke used at Milan contain at least 85 per cent. lime and carbon respectively, and are mixed, prior to being fed into the furnaces, in the proportion of 64–68 parts coke to 100 lime. The resultant carbide is run off every two hours in quantities varying from 115–175 kgs. for each furnace. Each run lasts 80 hours, the final yield being from 1,100–1,350 kgs. of carbide.

The mean yield at this factory in 1900 was estimated at 5·6 kgs. per k.w. day.

The furnace construction devised by William P. Parks, of Chicago, was based upon the practicability of obtaining the carbide in a molten state, and drawing it off at the base of the furnace as formed, thereby rendering the process continuous.

A section of the furnace, as originally patented, is shown in Fig. 16. It comprises a cylindrical structure F, contracted half-way down as shown to form a hearth, which, in the shape of a circular block of carbon C, serves, at the same time, as the lower fixed electrode.

In the upper face of this block, which is flush with the contracted portion of F, an annular channel c is cut, and

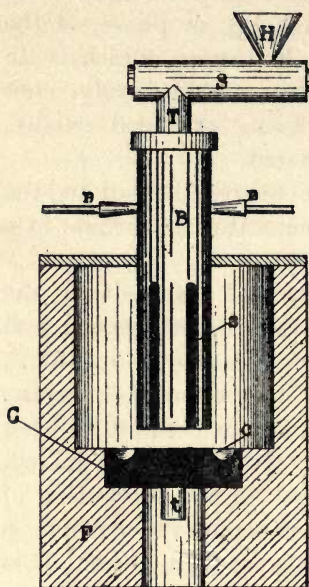led into a tapping opening *t*, its object being to collect the molten carbide formed, and convey it out of the furnace. The upper movable electrode is in the form of a hollow carbon cylinder B, its lower extremity, where it penetrates into the furnace, being subdivided by a series of radial slots as shown at *s*. The arc is thus split up into a number corresponding with the number of slots, and the heating effect thereby distributed throughout the charge instead of being confined to a single point, as would be the case were the extremity of the electrode left solid. T is a feeding tube, into which the raw material is fed by a screw conveyor S from a feed hopper H, and passes down the centre of the electrode B into the zone of greatest activity. In passing down the tubular electrode it receives a preliminary heating from the hydrocarbon burners *n n*, which are introduced through the side walls ; a considerable economy in the current, which would otherwise be required to bring the charge up from the normal temperature at which it enters the hopper, is thereby effected.

Fig. 16.

The resistance furnace for the manufacture of calcium carbide, invented by Mr. Hudson Maxim, is of an intermittent type, and produces the carbide in " block " or " ingot " form instead of the semi-molten state aimed at by many inventors.

It consists (Fig. 17) of a rectangular, refractory chamber, R, provided with means for the introduction and with-

drawal of the truck T, which constitutes the hearth of the furnace, and, running on rails, is easily removed, when full of carbide, and can be replaced by a similar empty truck, without any serious delay in the process of manufacture. It is provided with a refractory lining, B, and, through perforations in one of its side walls pass a series of horizontal pairs of electrodes, E, E2, E3, whilst the opposite side is slotted to permit the passage of the plates of carbide, p p, which serve as temporary short-circuiting pieces, to start the action of the furnace. The electrodes, E, E2, etc., take the form of hollow carbon cylinders, each mounted in a metal sleeve, or combination of sleeves, s, the intervening space between the metal of the sleeve and the carbon electrode, being filled in with ground carbon to ensure good electrical connexion.
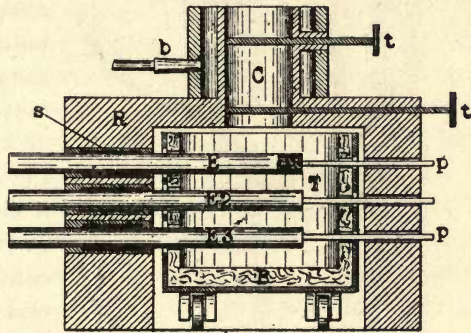

FIG. 17.

Through the tubular centre of the electrodes a supply of pulverized carbon is fed towards the interior of the furnace, and serves to protect their active extremities. The raw material is fed into the furnace through the central opening C, its rate of admission being regulated by the sliding shutters t t, whilst a preliminary heating of the charge is secured from an outer flue, kept hot by an oxy-hydrogen burner b. The action of the furnace is started by short-circuiting the various horizontal pairs of electrodes by means of the plates p p; once started, the action is maintained through the carbide of the charge itself, and, by gradually withdrawing the electrodes E, E2,

etc., whilst at the same time feeding in the raw material, a block of carbide is formed which extends practically the whole width of the truck. When this has been accomplished, the electrodes are entirely withdrawn, the truck and its contents removed, and another empty one inserted in its place, the same process being then repeated.
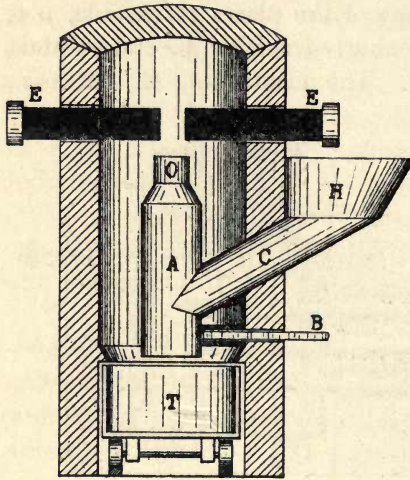

FIG. 18.

A carbide furnace, designed and patented by Messrs. J. Zimmerman and I. S. Prenner, possesses a novel distinction in the matter of feeding arrangements for the raw material, which, instead of being introduced into the heat zone of the arc from above, as usual, is carried up by a screw conveyor, from below and extruded just below the active extremities of the electrodes. The feed principle may be likened to that of a fountain.

The furnace is represented in Fig. 18; the mixture of carbon and lime is fed into the lateral hopper H, and passes thence, down the inclined conduit C, to the bottom of the screw conveyor A, the discharge orifice O of which is of smaller diameter than the conveyor itself, and, as shown, is situated at the top, just below the arcing space between the electrodes E E. In passing through the conveyor, which is driven from an external source by the belt or chain B, the charge undergoes a certain amount of compression, exuding finally into the intensely heated area of the arc, where it becomes converted into carbide, and passes, by gravitation, down the annular space between the conveyor

casing, and the inner wall of the furnace, into the receiving truck T, which can be removed or replaced when full, thus rendering the process continuous.

A patent, granted some time back to Dr. Hugo Koller, includes an arc carbide furnace of a special type, adapted for use with currents of higher voltage than it is customary to employ for the purpose of carbide production. The furnace itself takes the form of a long narrow conduit of refractory material, the length of which is governed, to a certain extent, by the voltage to be employed in the reaction. Massive carbon electrodes are introduced through the end walls, whilst a number of intermediate carbon blocks, spaced at regular intervals apart along the length of the furnace, and depending in number also upon the voltage, serve to form a chain of inter-connecting bi-polar electrodes, the space between each pair constituting a receptacle for the raw material and carbide formed therefrom.

The intermediate blocks are raised on suitable supports out of contact with the floor or hearth of the furnace, and the latter is lined, along the intervening spaces, with shallow carbon crucibles, or troughing, which assist in conducting the current, and at the same time serve as receptacles for the carbide. Only a small portion of the current is conducted along these carbon troughs, which are not in actual contact with the electrode blocks; the main reactions occur through the heat developed in the several arcs formed between each neighbouring pair of blocks.

This form of furnace construction is, from the very fact of its adaptability to circuits of comparatively high voltage, especially applicable to large units for the commercial manufacture of calcium carbide.

A carbide arc furnace, patented by J. H. Morley, has the usual interchangeable hearths and automatic feed arrangements, the distinctive novelty in its construction being the upper carbon electrode, which takes the form of a hollow rectangular conduit, descending vertically into

the furnace. The central aperture, or bore, of the carbon is open to the atmosphere, and furnishes a species of flue, or chimney, through which a downward current of air is induced. This meets the active charge, at the very point of greatest activity, and is instrumental in preventing overheating and explosions of gas produced in the reaction.

The process is rendered more thorough, and a more or less continuous furnace action secured, by a reciprocating motion communicated to the central carbon electrode. In addition to the up and down motion thus imparted, a certain turning movement is also given to the conduit, the motion of which thus resembles the turn of a screw, and tends to loosen the charge of carbon and lime immediately surrounding it, and bring it within the heat zone created by the arc.

We now come to a series of rotary furnaces, in which the hearth, or container, for the raw materials under treatment is constructed in circular form, and mounted in such a manner as to permit of its being revolved like a wheel. Continuity of action and a more homogeneous product are claimed for this class of furnace.

The Nikolai principle of carbide furnace construction provides for a continuous process, the furnace hearth being revoluble, and the raw material fed in at one point, whilst the carbide is withdrawn at another, the arc, or zone, of activity intervening.

The furnace itself consists of a circular, refractory trough, which constitutes in effect the tyre of a wheel, the latter being driven at a suitable speed, by gearing. This wheel and the attached revoluble hearth constitute one electrode of the furnace, the other being fixed at a given point above the trough, with sufficient clearance for the charge to pass beneath it, through the heated belt formed by the arc.

The mixture of coke and lime is fed into the trough at a regular rate from a point behind the fixed electrode, which latter is protected by a heat-conserving hood, and, having

been carried under it by the revolution of the wheel, is converted into calcium carbide by the arc. The carbide thus produced then passes on, and is removed at a point in advance of the fixed electrode by a scraper, leaving the trough free for the reception of a fresh charge when it again reaches the feeding point.

The Horry carbide furnace was designed by Mr. W. S. Horry with a view to overcoming many of the obvious defects of the earlier types of carbide furnace. Among the principal drawbacks which the inventor set himself to overcome are the intermittent nature of the furnace action, which, in many cases, necessitates shutting down the plant as soon as the furnace is full, in order to allow the contents to cool sufficiently for removal.

Another defect arising out of the mode of adjustment and general disposition of the electrodes is a constantly changing internal resistance, and consequently varying current, under which circumstances the mass of carbide already formed is again in part subjected to the further action of intense heat, tending to decompose it, whilst other portions of the charge, out of the immediate zone of heat, remain unconverted, thus leading to a somewhat mixed, and by no means homogeneous product.

The constructional principle of the Horry furnace is represented in diagram by Fig. 19, where H is an open fire-brick hopper, containing the mixture of lime and coke, and supporting at its lower or discharge extremity the two carbon electrodes E E, which are bevelled at their active edges, in order to present a vertical surface to the arc. The length of the latter is thus maintained constant, an important feature, which greatly facilitates regulation.

The hopper discharges its contents between the flanges of a rotatable metal drum D, which receives the carbide formed in the arc, and retains it by virtue of removable cover plates or battens B, which can be slid into place, or

removed, at will, As the formation of carbide goes on, the drum is slowly rotated by means of the hand-wheel and worm W, thus conveying the carbide, in a plastic condition, away from the region of the arc.

When it reaches a point diametrically opposite to the arc, the cover plates are removed, and the finished product scraped out, leaving that portion of the drum free for the reception of a fresh charge when it again comes under the mouth of the hopper. The cooling of the product is thus effected gradually as it gets farther and farther away from the arc, the heat not being entirely lost, but in part communicated to the unconverted portion behind.
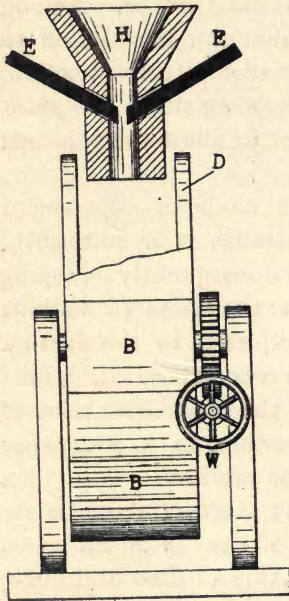
The action need never be stopped entirely, and the speed of rotation of the wheel is regulated in conformity with any variations in the current consumed by the furnace, which indicates sufficiently how the conversion is proceeding at the particular point of the drum which is then under the hopper. The carbide is removed in a plastic state.

FIG. 19.

At Sault Ste. Marie a Horry carbide plant of 20,000 H.P. has been installed.

The Bradley furnace, patented by C. S. Bradley in 1897, bears a striking resemblance to the Horry carbide furnace, in that it consists of a slowly revolving wheel, which, by bringing fresh materials into the region of the arc and removing the resulting carbide therefrom, renders the process continuous.

The arrangement consists of a wheel, with semi-circular rim, forming one-half of a circular channel for the reception of the raw materials and the carbide formed therefrom, the other half being constituted by semi-circular sections, or cover plates, which are latched, or otherwise fastened on the descending side of the wheel as it leaves the region of the arc, and removed again, on the ascending side, for the withdrawal of the product and unconverted portion of the charge. The wheel is revolved very slowly through the medium of worm gearing, driven by an electro-motor ; a structure, 15 ft. in diameter, may, according to the specification, be revolved once in five days.

The arc is either created between a single carbon electrode, 4 in. in diameter, adjustably mounted on a stand, and arranged to strike an arc with a temporary carbon core embedded in the raw material, or may be arranged between two oblique electrodes, operating at the mouth of the closed portion of the rim. In the former case, electrical connexion with the temporary core is secured through the medium of copper bolts, a commutator, and fixed brushes. The arc, once struck, is, of course, maintained between the fixed electrode and a portion of the core, rendered conducting by the heat of the reaction. At the discharge point, the cover plates, as before stated, are removed, and the unconverted portions of the charge fall into a conveyor, which returns them to the feed side of the wheel to again undergo the heating process.

By treating a mixture of powdered sand, and the oxides of calcium, strontium and barium respectively, silicides of these metals have been produced in the Bradley furnace, and it is suggested that they may prove of ultimate value in the various dye industries from the fact of their being powerful reducing agents.

Mr. C. S. Bradley has recently modified his rotary furnace construction, the modification being embodied in a patent taken out during 1903, which provides for lining the sides

and " belly " of the drum hearth with carbon or graphite plates, thus enabling the area of thermal activity to be extended throughout the entire mass of material under treatment, without fear of consequent injury to the structure itself, a contingency previously avoided by a layer of unconverted material.

A rotary carbide furnace construction has also been patented by Hudson Maxim. It consists of a drum of somewhat complicated construction, in which, according to the claims, the fused carbide is held against the inner surface, whilst any excess passes out through the open end of the drum.

A somewhat ingenious, but seemingly commercially impracticable form of construction for continuous carbide furnaces was that embodied in a patent, the specification of which, by Messrs. J. W. Kenevel, C. A. Spofford, and J. H. Mead, is dated August 24, 1897.

In general principle the furnace may be likened to a domestic mangle, or rolling mill, and consists of two cylindrical electrodes, which may be of carbon, between which the raw mixture of coke and lime is fed from a suitable hopper, the rate of feed being controlled by a slide.

Kerosene, fed on to the moving surfaces of the rollers by suitably disposed tubes, acts as a lubricant, and prevents the carbide from adhering thereto. The spindles of the rollers are insulated from them by glass sleeves, and are carried in sliding bearings, pressed together by springs, after the manner of a mangle, and driven by gear wheels carried on link pieces.

In passing between the electrode rollers, the mixture is converted into carbide by the current, which is conveyed to them through the medium of brushes and collector rings, a somewhat difficult problem to tackle effectually, when dealing with such large currents as are called for in electric furnace methods. The carbide, when formed, drops below on to baffles, placed to receive it.

Messrs. Lamoth and McRae, of Ottawa, are the inventors of a resistance furnace for the production of calcium carbide, the two electrodes being bridged by carbon pencils.

M. Raoul Pictet has devoted considerable time and attention to the study of carbide manufacture, and has designed more than one furnace for its production. His first practical experiment was conducted with a species of compound furnace, whereby the necessary heat was obtained in a series of three stages.

At the top was an ordinary blast furnace, consuming coke as fuel, and into which the cold charge of coke and lime was primarily fed. In this section, it attained a temperature of $1,980°C. = 3,600°F.$ It then passed on by gravitation to a second section, where, under the influence of an oxyhydrogen blow-pipe flame, its temperature was still further increased to $2,368°C. = 4,300°F.$ Finally, it passed into the region of the electric arc, where a temperature of from $2,757°$ to $3,312°C. = 5,000°$ to $6,000°F.$ was reached, and the combination of carbon and calcium effected.

In a subsequent design, the blast furnace and somewhat costly blowpipe sections were dispensed with, the gradual preliminary heating of the charge being effected instead by the waste gases from the furnace, assisted by the natural heat arising out of the chemical combination.

Two carbide furnaces of this description, constructed under M. Pictet's patents, were built some few years back at Ingleton, for the then Ingleton Carbide Company. Each furnace required 2,000 ampères to work it, and consisted of a hearth some 2 ft. square, by 3 ft. high, built of bauxite bricks, cased on the outside with a layer of firebrick, and mounted on foundations of ordinary brick, sufficient space being left below for the introduction and withdrawal of a truck for the reception of the carbide formed therein.

The carbon electrodes were square in section, with 6-in. sides, the negative being mounted at an angle of 30°

with the horizontal, whilst the positive was horizontal, and adjustable for feed purposes, the latter being effected by a hand wheel and screw motion.

Each electrode entered the furnace proper through a sheet iron, water-jacketed gland, whilst the terminal connexion itself, described separately in another portion of the book, was also water-jacketed.

Water circulation was secured by means of high level tanks, one to each electrode circuit. The electrical insulation of the circulatory system was further secured by mounting the water tanks on wooden bases, and by the introduction of 6-in. lengths of rubber tubing, in all pipe connexions, both supply and waste.

An opening was provided in the bottom of the furnace proper for the discharge of carbide into the truck placed to receive it, whilst a flue, also in connexion with the discharge orifice, conducted such heated gaseous products as escaped with the carbide through a space between the furnace linings to the top, whence an iron tube, enclosed in a fire-brick flue, and inclined at an angle of 25°, led up from the furnace to a suitable point above, where the iron tube penetrated the fire-brick wall of the flue, the latter being bent at right angles, for the purpose, and continued upwards to form a feed hopper or chute, down which the mixture of coke and lime was fed in the form of compressed briquettes.

The hot gases of combustion passed up between the inner flue wall and the iron tube to the outer end, which effected a junction with the chimney shaft. In their passage they served to impart a preliminary degree of heat to the descending charge in the iron tube.

The furnace action was started, and a primary draught created by an ordinary fire, which was lit within a space provided for the purpose between the two furnaces.

The original Pictet furnaces at Ingleton have since been replaced by Parker furnaces, described on page 94.

Pictet estimates that by the economies consequent on efficient preheating of the raw materials in calcium carbide manufacture, the cost can be reduced to £3 8s. per ton.

Dr. Borchers' improved method of carbide production involves several distinctly novel points, chief among which may be mentioned the utilization of the excess heat evolved for producing steam in an encircling boiler, or large water jacket, which surrounds the furnace ; any excess of heat over and above that required in the process of carbide formation is thus utilized in the generation of steam, which may serve in turn for driving an engine, thus effecting a considerable saving.

This suggestion, of totally enclosing the furnace and its contents in a water jacket, possesses also the attendant advantage that any unconverted charge remaining at the end of the operation can be withdrawn cool, and its admixture of carbon thereby preserved from the combustion which usually ensues when the unconverted remainder of an ordinary carbide furnace charge is exposed to the air.

The drawbacks incidental to existing types of carbide furnace, which Dr. Borchers' improved construction is intended to overcome, are—

(1) Partial combustion of unconverted carbon when the charge is withdrawn, and consequent contamination of the remainder by ash, together with the necessary addition of fresh carbon.

(2) Particles of dust are carried over by the resultant gases and inconvenience the attendants, besides adding, by their combustible nature, to the danger of fire.

(3) The amount of power consumed in carbide manufacture is abnormal.

In addition to the above novel feature of water-jacketing the entire furnace, which is accordingly constructed with very thin walls, Dr. Borchers proposes to work his carbide furnaces on the following plan—

In the resistance type, a heating core of carbon is packed

between two carbon electrodes, situated at opposite ends of the furnace, and surrounded by a filling of lime. Current is then switched on and heats the carbon column, with the result that the layer of lime in immediate contact with it is fused, and enters into combination with the carbon to form carbide, which flows away to the bottom of the furnace. A fresh layer of lime takes its place, and the reaction is repeated, or rather continued, until the whole of the carbon forming the resistance is used up, when the current is switched off, and the resulting carbide, after having been allowed to cool, removed.

In Dr. Borchers' arc furnace the electrodes are disposed vertically, the upper descending axially through a hopper, which also serves to feed the charge into the furnace, and the lower one passing up to meet it, through a hinged trap-door in the hearth or base of the furnace, which can be opened at the end of the operation, for withdrawal of the carbide formed.

To commence with, a mixed charge of coke and lime is well rammed into the furnace around the electrodes and the hopper, whilst the latter is also filled with a coarsely ground charge of raw material, to such a depth as to prevent the escape of the gases evolved in the reaction. In the upper portion of the furnace, remote from the actual heat zone, is located an inclined metal plate, perforated to allow the passage of the furnace gases, and packed, above, with a layer of wood shavings, or other suitable material, to act as a filter on the gases passing through, and free them from the dust and solid particles which they would otherwise carry with them out of the furnace.

The dimensions of the furnace are such that when the operation is completed, a block of carbide is formed in the centre, surrounded on all sides by a layer of unconverted charge, which remains non-conducting by virtue of the water-cooled walls. This block is left to cool for a few hours before withdrawal, the excess heat stored up in it being, as before

mentioned, absorbed by the surrounding water and thereby utilized in the generation of steam for power purposes.

A patent taken out by Ricardo Memmo in 1897 relates more especially to two improvements, continuity of furnace action, and pre-heating of the charge, in the efficiency of the process of carbide manufacture, and covers a form of construction in which the furnace proper is tubular, with a movable graphite hearth. This latter is supported on an iron foundation, which can be raised or lowered as required by either a screw, or rack and pinion motion. To commence with, the hearth is adjusted at a point, just below the upper electrode, the raw mixture to be converted being fed in by a screw conveyor, from a hopper, provided with a refractory lining.

In order to effect the pre-heating of the charge, water is included in the mixture supplied to the hopper, and forms water gas, which is burnt, to heat the air supplied to a circulatory system, which includes both the jacketed walls of the furnace, and the hopper itself.

La Societa Italiana del Forni Electricci, Italy, about this time, took out a patent for a carbide furnace, in which the gases of combustion were similarly employed, after purification and storage, to pre-heat the raw material, which was delivered through an elliptical tube by a screw feed motion. The electrodes consisted of carbon blocks, one of which was adjustable by means of a lever to which it was attached by a metal clamp, or plate. The furnace was lined with carbon, and the combustion gases passed out through orifices in the walls of the chamber to a suitable collecting point, where they were duly collected, purified, and stored, as described above, to be ultimately consumed in pre-heating the charge before its entry into the furnace proper.

The three-phase carbide furnaces designed and patented by Ricardo Memmo have been in use at St. Marcello d'Aosta, Italy, since 1897. Charcoal is employed in place of the

more usual coke to provide the carbon necessary to the combination. Wood, from the abundant supply provided by the vast forests of the Alps, is converted into charcoal in gas retorts, the resultant gas being again utilized in heating other furnaces for baking both the lime and mixture of the latter with charcoal. Charcoal and lime, having been individually subjected to the baking process, are next pulverized, and subsequently mixed in the correct proportion for the production of calcium carbide. Small quantities of water and tar are added, to secure agglomera-
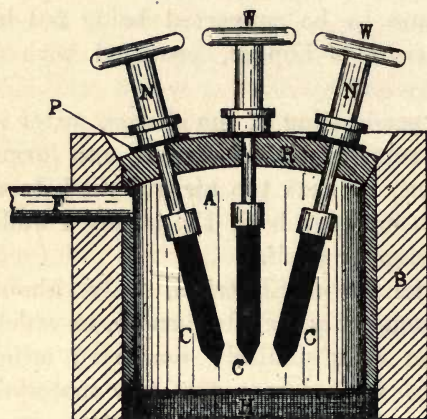
FIG. 20.

tion, and the mass is formed, by a machine, into bricks, which are subsequently baked in a furnace heated by the gaseous products of the electric furnaces. These bricks constitute the raw material with which the furnaces are fed, and it is worthy of note that, treated in this manner, little or no dust, which gives rise to considerable trouble in carbide furnaces fed in

the ordinary manner with a pulverized charge, is formed.

The types of carbide furnace in use at St. Marcello, are both intermittent and continuous in action. The former, Fig. 20, is extremely simple in construction, and consists of a cubical chamber A, built of refractory brick, cased externally with ordinary brick B. The floor or hearth H is compressed magnesium oxide, or lime, and an iron door, lined internally with refractory brick, serves for the removal of the carbide formed.

Above the door is a feed orifice, through which pro-

jects a cast-iron chute, down which the bricks are fed into the furnace, whilst in the opposite wall is a flue F for conveying away the gases formed in the conversion, to be ultimately used in baking the bricks, as already described. The three carbon electrodes C C C enter through the arched roof R, which is also of refractory brick ; they are each five inches in diameter, and are supported by holders, on the extremities of large iron rods, threaded for the greater portion of their length, and passing through bronze nuts N, supported on cast-iron plates P, which cover the openings in the furnace, any remaining space being cemented up with a mixture of graphite and glue. Hand wheels W are attached to these nuts, and serve to adjust the relative positions of the three carbons inside the furnace.

The capacity of the latter is seventy cubic feet.

To commence with, the carbons are lowered until they make contact with a short-circuiting plate of graphite, and the interior of the furnace is filled with bricks, duly prepared as described above ; a lining, about half an inch thick, of unconverted mixture is usually left adhering to the walls from the previous operation ; it protects the structure from excessive heat, and, incidentally, prevents the newly formed carbide from adhering to the walls. The furnace door is closed, and all spaces luted with clay or lime.

The generating plant is then started up, and the load soon attains its normal value, viz., 1,200 ampères on each circuit, at 145 volts. After about half an hour, the furnace is fed through the main door, and subsequent regulation is effected according to the readings on the ammeters, which are included, one in each circuit.

The furnaces are charged once every quarter of an hour, to make up for the decrease in volume of the charge arising out of the conversion. A complete operation lasts about five hours, after which the current is switched on to the next furnace. Another interval of five hours is then necessary in order to permit the contents of the furnace to solidify,

when they are removed, red hot, by means of iron bars, Each block of carbide thus formed weighs from 150 to 250 kilogrammes, and is left for some considerable time to cool before it is broken up.

The output of carbide manufactured at St. Marcello works out at 4·37 kgs. per k.w. day of twenty-four hours, but, according to *L'Electricien*, July 8, 1899, this figure has been increased to 4·88 kgs. per k.w. day.

The consumption of electrodes during one operation of the furnace is 4·5 to 5 kgs., or 24*s*. per ton of carbide produced. The figure is a high one, and is attributed mainly to the frequent stoppages for discharging and recharging, during which a wasteful combustion of the electrode carbon goes on.

In the continuous carbide furnace operated at St. Marcello, the three electrodes E E (Fig. 21) are grouped "star" fashion, and the arcs are struck between them and a common carbon electrode C, which constitutes the hearth of the furnace.

FIG. 21.

The latter is a cylindrical structure R of refractory brick, the three carbon electrodes entering at an angle through the upper walls, and being supported and fed downwards in a similar manner to the foregoing.

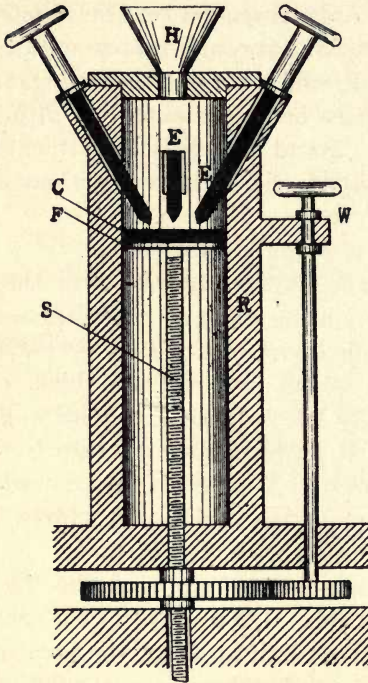The feed hopper H is situated over the centre of the

furnace, above the carbons, whilst the hearth, which consists of a cast-iron plate F covered with several layers of graphite C, is supported on a central screwed stem S, and can be raised or lowered throughout the entire height of the furnace by means of a hand wheel and gearing W. To commence with, it is raised until the graphite plate makes contact with the three carbon electrodes, and is gradually lowered by means of its hand wheel, as the operation proceeds, and fresh material is fed in.

As the process of carbide formation goes on, the hearth, as already stated, is gradually lowered, making room for more carbide, and a further supply of raw material. At a certain point, the remaining, partially converted and unconverted charge is gripped and held by three clamping jaws, operated by screws, whilst the carbide already formed is removed at the base of the furnace, and the hearth re-adjusted for the reception of a fresh charge.

Six or seven hours' continuous working suffice to bring the hearth to its lowest point, with a column of finished carbide above it, surmounted by a layer around the arcs, in which the process of conversion is still going on. A door at the base of the structure permits of the removal of the carbide first formed, and the process is thereby rendered continuous.

Regulation is effected by moving the hearth only, the adjustment of the carbons themselves being only of a nature to compensate for their consumption.

The Parker carbide furnace, designed and patented by Mr. A. Parker, of Chorley, has, for its main object, the securing of a more wide-spread action throughout the mass of unconverted material, with a consequent lessening of the crust or unconverted residue, which is always present in carbide furnaces, and has to be either mingled with the carbide formed, thereby decreasing its efficiency as a gas producer, or again subjected to the action of the furnace in conjunction with the next charge to be introduced.

The Parker furnace, the principle of which is represented in sectional plan by Fig. 22, consists of a slowly rotating cylindrical crucible A, lined with carbon C, which constitutes the negative electrode, and a rectangular vertical block, B, which forms the positive electrode, and is placed axially within the crucible, A. The slow rotation of the latter, coupled with a simultaneous upward motion, com-
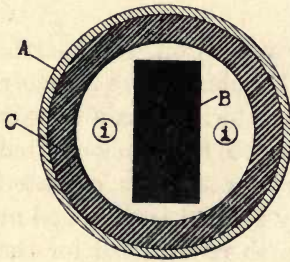
municated to the electrode B, serves to build up a solid and homogeneous block of carbide, surrounded by a very thin crust of unconverted material. The corners of the electrode B, coming, as they do, into close proximity with the inner wall of A, effectually agitate the contents during the process of conversion, whilst the arc is constantly moved from one point to another, thereby tending to homogeneity of action. The feed hopper inlets i i are arranged, one on either side of the positive electrode B at the upper portion of the furnace, and a regular feed is automatically secured.

The process of removing a full crucible, substituting an empty one, and readjusting the electrode B preparatory to again switching on the current, is said to occupy only three minutes.

In a modified form of this furnace, a flattened or ovoid electrode is substituted for the rectangular formation shown in the figure.

The Parker carbide furnace is now in use by the Acetylene Gas and Electric Smelting Company, Ltd., who have purchased the patent rights, having superseded the original Pictet furnaces which were installed by the Ingleton Water Power Company.

The type of furnace employed by the United Alkali Company, at Widnes, resembles that devised by Parker. It

operates on the resistance principle, the upper electrode being continuously embedded in the charge, whilst the remaining electrode is integral with the crucible containing it.

In operation, the latter is slowly rotated, and the upper electrode gradually raised, raw material being fed in meanwhile, until a block of carbide, practically equal to the capacity of the crucible, has been built up. By this continuous relative movement of the charge and electrodes, equivalent, in point of fact, to a slow stirring motion, very complete action is secured, and but little of the contents of the crucible remain unconverted.

In 1901, Dr. Oscar Fröhlich, of Steglitz, Germany, patented and assigned to the Siemens and Halske Company, of Berlin, a somewhat ingenious carbide 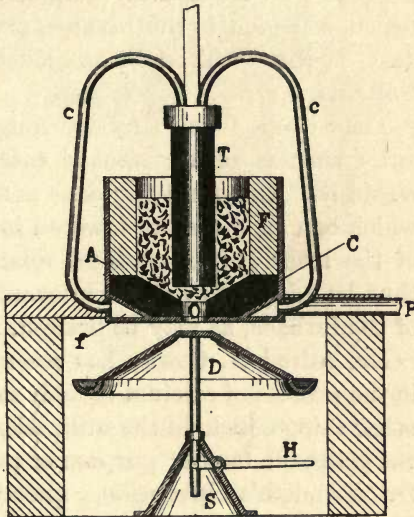furnace, the principal novelty in which consists in the collection and utilization of the otherwise waste gases, mainly carbon monoxide, resulting from the reaction itself.

Fig. 23.

The furnace in which Dr. Fröhlich effects this, is represented in Fig. 23, and consists of a cylindrical iron crucible A, lined interiorly with fire-clay F, and a sloping funnel-shaped carbon hearth C, which forms one electrode of the device, and centres in a discharge orifice or outlet O for the carbide. The other electrode T, also of carbon, takes the form of a vertical tube, or flue, the upper end of which is capped and fitted with the tubular conduits $c\ c$,

95

which curve over as shown, and descend to an annular flue *f*, disposed around the lower portion of the crucible.

The carbon monoxide and other reaction gases pass up through the central tubular carbon electrode T, and by way of the conduits *c c* to the flue *f*, where they are burnt in admixture with air, which enters through holes in the flue walls. The products of combustion pass off by way of the pipe P. The heat of combustion of the reaction gases, which, collected in this manner, are almost entirely free from dust, is thus utilized in auxiliary heating of the crucible contents.

The carbide formed falls through the orifice O on to the outer surface of the conical table D, which is lipped to retain it. This receiving cone is carried by a vertical stem, which can be raised or lowered in its standard S by means of the lever H; its position, relatively to the crucible, can thus be adapted to either intermittent or continuous action of the furnace, as may be desired.

Mr. Alfred H. Cowles has recently patented some details in the process of calcium carbide manufacture, which, among other things, include the utilization of the carbon monoxide gas given off for the purpose of pre-heating the charge. In Dr. Fröhlich's invention, already described, the gas is used rather as an auxiliary to the electric heating in the furnace itself.

A form of carbide furnace construction, based upon Cowles' latest patent, is depicted in Fig. 24. It consists of an inverted cone-shaped crucible A, of iron, lined interiorly with refractory non-conducting material R. The hearth of the furnace consists of a solid carbon block B, also protected by an iron casing, and electrically separated from the main body of the furnace by a layer of insulating material L. This carbon block also constitutes one fixed electrode, the others E E consisting of carbon rods, disposed radially, like the spokes of a wheel, through the upper part of the furnace walls.

A cursory study of this form of construction will show that the heating, being effected on the resistance principle, is most concentrated at, or near, the hearth itself, where the various current paths converge. The object of this concentration is to secure a molten product which can be run off at the tap hole T provided in the hearth.

Mounted axially in the centre of the lid D, which effects a gas-tight junction with the furnace proper, is a pre-heating chamber or tower H, having a feed aperture at the top. It consists, like the furnace, of an iron shell, lined with refractory material, and through its walls, a short distance up from the furnace lid, pass pipes, P P, which communicate with the main furnace chamber as shown, and serve to convey the carbon monoxide and other gases to burners in the pre-heating tower, where they are burnt in conjunction with a blast of air introduced through the smaller pipes p p after the manner of a blow-pipe.

The descending charge thus receives a preliminary heating before entering the furnace, an initial elevation of its general temperature, which should effect considerable economy in the current necessary to complete the process of carbide formation.

A form of arc furnace, invented by R. C. Contardo, which is applicable, with some slight modifications, to either calcium carbide manufacture, or the smelting of metallic ores, consists of a refractory chamber, with curved, or
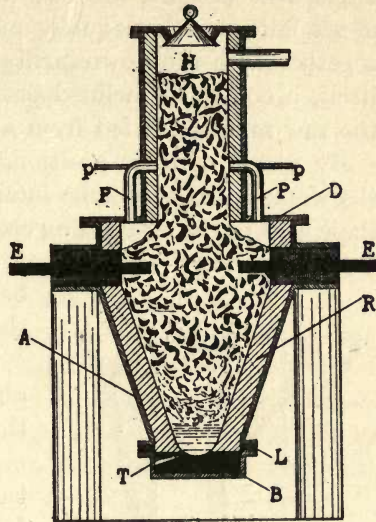

Fig. 24.

97   H

contracted hearth, immediately above which are disposed the two electrodes. Above these again, and meeting at an angle over the arc, are two inclined plates which may be of graphite, or other equally suitable material. These form, together with the downwardly sloping walls of the furnace itself, a couple of inclined passages or chutes, down which the raw material is fed from a central orifice above.

By virtue of their position, immediately above the arc, the sloping plates become intensely hot, and communicate their heat to the descending charge, which is thus pre-heated before entering the active centre of the furnace, immediately below the electrodes, where the operation is concluded.

FIG. 25.

In general construction, the above furnace is very similar to that illustrated in Fig. 32.

The King carbide furnace turns out its product in "block" form. The hearth consists of a truck T (Fig. 25), at the bottom of which is a slab of carbon C, forming one electrode of the furnace, the other, E, being vertically adjustable. The truck is mounted on rails, and provided with a mechanica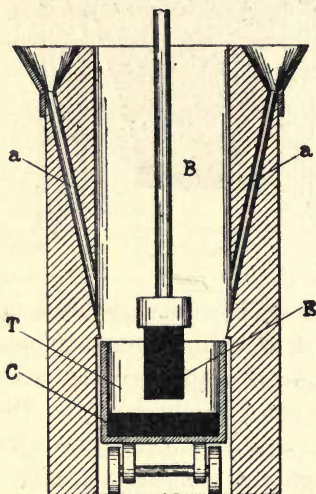l attachment, not shown in the figure, whereby a small reciprocating movement is communicated to it, during the action of the furnace, tending to shake down and level the charge. It is enclosed in a brickwork chamber B, down inclined channels a a, in the walls of which the raw material is fed. As the operation proceeds, the upper electrode E is gradually raised, whilst fresh material is fed in, until the truck is full of carbide together with partially converted raw material. It is then allowed to cool, run out

of the chamber B, and emptied, the carbide being separated from the unconverted material, and the latter worked up into the next charge.

Air ducts, not shown in the figure, are provided within the walls of the structure, which, by circulation of the air within them, serve to keep the inactive portions of the furnace fairly cool, and confine the centre of thermal activity to the truck hearth.

The furnace employed at the works of the Deutsche Gold und Silberscheide Anstalt consists of a removable hearth, or coke-lined truck, which also constitutes one electrode, and a fixed upper structure of refractory brickwork, which surrounds the truck when in its working position, and assists in conserving the furnace heat.

The upper carbon electrode is adjustable, and passes through an aperture in the roof, as do also the feed inlet, and a pipe for conveying away the carbon monoxide gas formed in the reaction.

To commence with, the truck hearth, previously filled with a granular mixture of coke and lime, is run, on rails, to a point immediately beneath the hood, into which it is then raised, vertically, by chains and pulleys, until its lower projecting flange effects a gas-tight junction with the lower rim of the fixed structure above.

The upper adjustable electrode is then lowered into position through the opening provided for it in the hood, and the current switched on. A current of from 2,000 to 3,000 ampères at 60 to 65 volts is required to operate the furnace, and an output of five kilogrammes of carbide per kilowatt day is said to be secured, the resultant product being 85 per cent. pure carbide. The upper carbon electrode is consumed at the rate of about 50 kgs. per ton of carbide produced.

In carbide furnaces designed for continuous action, some difficulty is experienced in securing the requisite regularity of action, owing to the time expended in raising each batch

of raw material which arrives at the heat zone to the temperature necessary for effecting combination.

The action is thus jerky and intermittent, rather than continuous.

A German patent, the principle of which is illustrated in Fig. 26, has in view the elimination of this defect. It relates to a continuous carbide furnace, in which one electrode, A, is vertical, whilst the other, B, is inclined to it, meeting it at the lower extremity, with the exception of the ne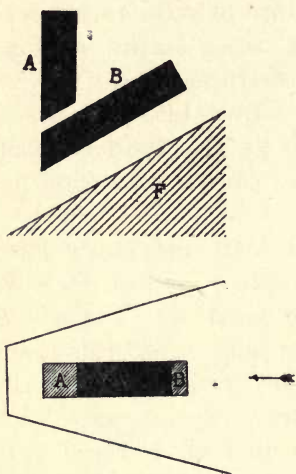cessary arcing space. The furnace hearth F is also inclined at an angle, which coincides with that of the electrode B, and its walls, moreover, converge, to form a species of funnel, or tapering conduit, with its smallest extremity situate at the meeting point of the electrodes, where also the discharge orifice for the finished carbide is located.


Fig. 26.

The raw charge, fed in at the widest dimension of the furnace, thus forms a bridge between the electrodes for the greater part of their length, the resistance of which varies inversely with the cross-section. The heating effect is thus gradually increased, as the mixture of coke and lime travels towards the arcing zone, and is finally concentrated in the region of the arc, where the operation is completed and the carbide withdrawn.

Energy Required in Calcium Carbide Manufacture.— Blount's theoretical estimate of the energy necessary to produce calcium carbide is thus arrived at—

" Moissan has shown that the heat of formation of calcium oxide is 145 Calories, and that the reaction,

$$CaO + 3C = CaC_2 + CO,$$
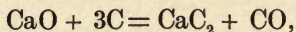
takes place at $3,300°C = 5,972°F$. The specific heat of CaO may be taken as approximately 0.12; that of carbon as 0.47. The energy necessary to raise 56 grammes of CaO and 36 grammes of C to this temperature is 79.5 Calories. The formation of calcium carbide from Ca and C is esteemed an endothermic reaction, requiring 48 Calories. The total energy needed is, therefore,

$$79.5 + 145 + 48 \text{ Calories} = 272.5 \text{ Calories}.$$

From this must be deducted the energy evolved by the oxidation of carbon to CO, i.e., 29 Calories. Therefore, the energy to be supplied to form 64 grammes of CaC_2 is 243.5 Calories.

" In this calculation, the energy evolved or absorbed by the formation of CaC_2 from Ca and C_2 is a doubtful quantity. No reliable data have been arrived at. The estimate given is likely to err on the right side, the more so as no credit has been taken for possible regeneration by utilizing the sensible heat of one charge for warming up the next.

" Thus it may be taken, for practical purposes, that the formation of one ton of calcium carbide requires 5,889 H.P. hours, or conversely, for each H.P. day of 24 hours, 4.1 kgs. of calcium carbide may be formed."

The *Progressive Age*, in 1896, deputed Messrs. Houston, Kennelley, and Kinnicutt to carry out some experiments in carbide manufacture on a commercial scale at Spray, N. Carolina, with a view to determining the actual cost of production.

The plant was of 300 H.P. and the current was delivered at the furnace terminals at an E.M.F. of 100 volts. There were two furnaces, each with a hearth area 3 ft. by 2 ft. 6 in., the hearth, and fixed electrode, consisting of a carbon plate, 8 in. thick, supported on an iron base plate. The

upper electrode was vertically adjustable, and consisted of a composite carbon block, 12 in. by 8 by 3 : it was consumed at the rate of $\frac{1}{16}$ in. per hour. The charge consisted of the usual coke and lime, containing 37 per cent. carbon, and 52 per cent. lime, respectively. The furnaces were started by striking an arc between the upper electrode, and a small quantity of the raw charge placed upon the hearth. The upper electrode was gradually raised, and fresh material added, until a pyramidal mass of carbide was built up, equal, or nearly so, to the cubic capacity of the furnace.

Two runs were made, the weight of raw material treated in each case being 900 kgs., whilst an output of about 90 kgs. of calcium carbide resulted from each. The consumption of energy was, in the first instance, 193·1 H.P. for three hours, or 579·3 h.p. hours = 432 k.w. hours ; and, in the second, 195·3 H.P. for 2 hours 40 minutes, or 520·8 h.p. hours = 388·5 k.w. hours.

The respective yields were thus 3·75 kgs. of 80 to 85 per cent. carbide per h.p. per 24 hours, and 4·15 kgs. for the same expenditure of power respectively.

Many and varied are the figures relating to the energy required for the production of calcium carbide, not only on a commercial scale, but also from a theoretical standpoint based on calculations involving thermal data regarding the component materials themselves. In this connexion, Mr. J. B. C. Kershaw, F.I.C., contributed a very interesting series of articles which first appeared in the *Electrician*, November 23, 1900.

Dealing, primarily, with the theoretical side of the question, the following table, excerpted from the *Electrician* of that date, gives his figures, in tabular form, as gleaned from various authorities on the subject of calcium carbide manufacture, the actual references being quoted in the original article—
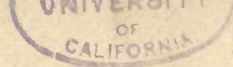
AUTHORITY.						KILOWATT HOURS.
Sieber	.	.	.	.	.	1,523
Addicks	.	.	.	.	.	1,941
Bredel	.	.	.	.	.	1,960
Wolff	.	.	.	.	.	2,043
Pictet .	.	.	.	.	.	2,640
Haber .	.	.	.	.	.	2,670
Gin	.	.	.	.	.	3,069
Lewes .	.	.	.	.	.	3,290
Allen .	.	.	.	.	.	3,293

In the above table, the figures represent the kilowatt hours theoretically necessary to produce one metric ton (2,204 lbs.) of calcium carbide containing 80 per cent. carbide.

As Mr. Kershaw observes, there is a wide disparity between the figures quoted above, which is in the main due to the fact that no allowance has been made for waste of material in the furnace, nor for the heat required to raise the temperature of the charge, in the first instance, to that at which the actual carbide formation takes place.

In the course of his article, the Author discusses the various possible sources of error, and, in summing up, decides in favour of the calculation made by M. Gin, and published in *L'Éclairage Électrique*, May 6, 1899.

The following is the reasoning referred to—

" The temperature of the reaction is taken as 3,300°C. = 5,972°F., and the following formulae are used for calculating the specific heats of the carbon and lime at that temperature—

Carbon (atomic heat)	.	.	.	$4.26 + 0.00072t$.
Lime (gramme molecule)	.	.	.	$11.4 + 0.001t$.

Using these data, the following figures are obtained for the production of the gramme molecule of calcium carbide—

Heat necessary to raise 56 grammes of lime to 3,300°C.	43,060 Calories.
Heat necessary to raise 36 grammes of carbon to 3,300°C. . . .	53,940 ,,
Heat necessary to split up 56 grammes lime into Ca and O . . .	145,000 ,,
Total	242,000 ,,

Less—

Heat produced by formation of 28 grammes of CO	26,100 Calories
Heat produced by formation of 64 grammes of CaC$_2$ . . .	3,900 ,,
Net Heat required . .	212,000 ,,

212,000 Calories = 245·5 watt hours electrical energy
=3,837 k.w. hours per ton of carbide.

Mr. Kershaw next proceeds to deal with the various experimental and estimated yields of carbide, the results of which are embodied in the following table—

AUTHORITY.	KILOWATT HOURS.
Lewes	4,105
Korda	4,380
Houston and Kennelly	4,393
Bullier	4,470
Liebetanz	4,800
Wolff	5,111
——	6,514

The figures in the above table represent the kilowatt hours necessary to produce one metric ton (2,204 lbs.) of calcium, containing 80 per cent. carbide, as determined by actual experiment, and estimates based on the results of the same.

Finally, in Table No. 3, below, Mr. Kershaw gives us the results obtained in actual practice—

AUTHORITY.	KILOWATT HOURS.
——	3,576
*Lewes	3,788
*Keller	3,871
*Carlson	4,104
Patten	4,105
Borchers	4,157
Keller	4,291
Lewes	4,351
Haber	4,470
Pierard	4,920
Nikolai	5,066
Carlson	5,616
Haber	5,960

The above figures represent the kilowatt hours necessary to produce one metric ton (2,204 lbs.) of calcium carbide, containing 80 per cent. carbide, in actual commercial practice.

Summing up these various data, Mr. Kershaw finally decides in favour of those marked with an asterisk as being the most reliable. They represent results obtained with the Deutsche Gold und Silberscheide Anstalt form of furnace; the Willson furnace, as used at Foyers; and the Gin and Leleux production, in use at Meran, in Austria. These three types are described elsewhere, and may be taken as representing three of the most efficient carbide furnaces then in practical use.

Cost of Calcium Carbide Manufacture.—The cost of calcium carbide manufacture must necessarily be largely governed by local conditions, source of power, cost of raw materials, etc., so that it is impossible to formulate any hard and fast rule on the subject.

Some interesting figures, from various sources, are assembled in the form of a statistical article on the progress of the industry by Kershaw, in the *Electrical Review*, September 22, 1899.

At Lourdes, in the Hte. Pyrenees, the cost is estimated at about £12 per ton. In Switzerland, at that time, carbide was selling at £14 per ton, and, in Paris, at £19.

At Meran, in the Austrian Tyrol, it was estimated to cost £7 5s. per ton, f.o.r., and that after allowing for interest on capital and depreciation of plant.

At Niagara, in 1899, it was estimated that carbide could be produced at from £7 5s. to £8 per ton.

Liebetanz, in his paper before the Buda Pesth Congress, estimates the cost of production with steam power at £11 14s. per ton, and with water power at £8 18s.

According to Carl Hering (*L'Éclairage Électrique*) it requires, theoretically, 1,900 lbs. of lime, and 1,230 lbs. of carbon to produce one ton of calcium carbide; in actual

practice, 2,050 lbs. of lime, and 1,420 lbs. of carbon are necessary. These figures apply particularly to the carbide factory at Meran, in Austria, where the cost of lime, per ton, was then about 16s., and of carbon, 32s.

One electrode suffices for ten tons of carbide, and costs £6 12s. or approximately 13s. per ton.

The electrical energy required per ton of carbide produced was 6,400 h.p. hours, which, at £2 per E.H.P. year, works out at a little above £1 16s. per ton.

Accessory machinery, losses, etc., account for about 200 H.P., or 4s. per ton, the output being 6·5 tons per diem.

Labour, at 3s. to 3s. 4d. per day, amounts to 15s. per ton. Amortisation £1 per ton, and general expenses £1 per ton ; maintainance of plant, 6s. per ton. Total cost, at Meran, £7 5s. per ton.

SECTION V

Iron and Steel Production in the Electric Furnace

Introductory.—M. Keller, of the electro-metallurgical firm, Keller, Leleux and Co., France, in a paper before the Iron and Steel Institute, 1903, states the conditions under which electrical reduction processes may be economically adopted ; they are as follows—

" Although the reduction of iron ores by electricity has formed the subject of a practical study by the Author, the results of which will be described further on, it may be stated at once that the employment of electricity as a reducing agent is only practicable from an economic point of view : first, when it is a question of manufacturing special qualities of iron, from pure ore, delivered at the works on favourable terms. Secondly, when it is desired to foster an iron and steel industry in a country hitherto undeveloped in this respect, into which all the coal must be imported, where iron ore of good quality abounds, and where natural sources of power are available in the immediate neighbourhood of the ore deposits.

" The Author has determined, experimentally, that one k.w. year, utilized in an electric reducing furnace, is capable of yielding about four tons of steel-making pig-iron. In a general way, therefore, the reduction of iron ore by electricity in a country possessing metallurgical works and equally good conditions of transport throughout, is only theoretically practicable if the ore can be obtained on equal terms, and if the cost of the kilowatt year does not

exceed £1 5s. 6d. It must be borne in mind, however, that the scale of production of an electric furnace is less than that of blast furnaces, and that, on this account, establishments equipped for electric working would be of less capacity ; the working expenses being also proportionately higher, it does not appear as if the reduction of iron ores, so far as the smelting of ordinary pig is concerned, will ever enter the sphere of practice in any European hydro-electric works."

The advantages of the electric reduction process are thus detailed by the same authority—

" A high degree of purity can be reached by the electric method of production, owing to the method of generating the heat, which enables the action of the fuel to be limited strictly to that of a reducing agent. By this means the action of the sulphurous gases is, to a great extent, avoided ; and, since the quantity of coke required per ton of iron is so small, the very best qualities can be utilized for the purpose. It is therefore possible, with good ore, to obtain a pig-iron which will compare in purity with Swedish iron. A further advantage consists in the higher temperature of working, which the use of electricity permits, without, however, causing an excess of carbon in the material. It is also possible, in consequence of the hot working, to form slags of ultra-basic character."

In steel production, on the other hand, the cost of the electrical energy is a secondary consideration. In melting and fining one ton of steel produced from scrap iron and steel, M. Keller estimates that about 1·10 k.w. year is necessary, and, even using steam as the primary source of power, the cost of energy will only amount to about £1 12s. per ton of steel.

According to Heroult, 2,500 tons of steel have been already produced in the electric furnace, whilst plant, with an aggregate capacity of 400 tons of steel per day, is in operation.

In both the Heroult and Keller electric furnace steel processes, the heating arcs are struck between the metallic charge and the electrodes. The Heroult furnace is in operation at La Praz, and the Keller at Livet, on the Romanche.

As will be seen from the above, the cost of smelting iron ores by electrical means is somewhat large, and, in the present stage of its development, can only hope to compete with ordinary blast furnace processes, in special cases, as for example, where power can be had at a comparatively low figure, whilst pure ore is plentiful.

Dr. H. Goldschmidt, who has acted in the capacity of inspector, appointed by the German Patent Office to report on the various electric smelting processes, has furnished some interesting information and data on the subject (*Zeitschrift für Elektrochemie*, 1903).

With reference to the earliest industrial application of the electric furnace to smelting processes, it may be mentioned that to Heroult belongs the honour of having made the pioneer move, for, according to Goldschmidt, he delivered his first car-load of steel, consisting of bars weighing 400 kgs. each, and amounting, in all, to 8,890 kgs., to Messrs. Schneider & Co., Creusot, on December 28, 1900. This consignment was the product of his electric furnace at Froges.

The electric furnace has not been commercially applied in America to iron and steel manufacture, but Europe has been the scene of many experimental and commercial trials, with some of which very successful results have been obtained. This latter fact, combined with the existence of rich iron deposits in Canada, a country in which water power is abundant, has prompted the Canadian Government to appoint a Commission to visit Europe, and study the possibilities of electric smelting, ore reduction, and steel manufacture, with a view to its industrial development in Canada.

Sweden, France, and Italy are the principal countries

to be visited by this Commission, which, at the time of writing, is actually engaged upon its work of investigation. Some valuable information should be the outcome of this enterprise, and the advent of the official report will doubtless be awaited with interest by metallurgists in general.

The resistance furnace, with carbon core, has, until comparatively recently, been commercially inapplicable to the smelting or reduction of non-volatile metals, for the simple reason that the mere presence of carbon in the core has led to the formation of a carbide by reaction with the metal liberated from the ore.

Acheson has, however, surmounted this obstacle by protecting the carbon core from contact with the charge of metallic ore by an impervious sheath, e.g., carborundum. The arrangement is very simple ; around the carbon or granular coke core of an ordinary resistance furnace of the well-known Acheson type is packed either a quantity of carborundum crystals, already formed, or sufficient silica and carbon, mixed in the correct proportions, to form carborundum. Outside this, again, is placed the mass of ore to be reduced. In action, the carborundum forms a coherent impermeable sheath, which is self-supporting, and maintains its position around the core, even after the encircling charge has fallen away from it by virtue of the reduction taking place. With the aid of this protecting sheath, Acheson has succeeded in effecting the direct reduction of silicon and aluminium in the electric furnace.

Processes.—In connexion with the various thermo-electric processes, experimental and otherwise, for the manufacture of steel, the following table, containing results and data furnished by Goldschmidt, of Essen, at the Fifth International Congress of Applied Chemistry, may prove of interest.

Name.	Year.	Type of Furnace.	Charge consists of	Energy Required per ton of Steel (H.P. Hours).	Cost of Production per ton of Steel.
Gin-Lelux	1897	Furnace with carbon electrodes	Cast iron and scrap iron	—	—
Stassano	1898	Furnace with carbon electrodes, 500 h.p.	High percentage Italian ores	3,800–4,000	£3 15 0
Gysinge	1900	Furnace without carbon electrodes, 225 h.p.	Cast iron and wrought iron	1,320	£8 12 0
Froges-Heroult	1901	Furnace with carbon electrodes, 400 h.p.	Cast iron and scrap iron	1,200	—
Keller	1901	Furnace with carbon electrodes, 1,200 h.p.	Iron ores and cast iron	3,800	£3 12 0 to £4 0
Harmet	1901	Furnace with carbon electrodes	Iron ores	3,600	£1 4 0 (not total)
Schneider	1901	Furnace without carbon electrodes	Iron ores	—	—
Ruthenberg	1901	Furnace with carbon electrodes	Iron ores	1,000	£2 8 0
Conley	1902	Furnace with carbon electrodes	Cast and scrap iron	1,042	£5 14 0

I I I

According to Ruthenberg, the production of one ton of metallic iron requires, by the

Stassano process	.	.	.	.	3,000 h.p. hours.
De Laval ,,	.	.	.	.	3,500 ,, ,,
Rossi ,,	.	.	.	.	4,800 ,, ,,
Ruthenberg ,,	.	.	.	.	500 k.w. ,,

Comparing the economy of the blast furnace process with that of the electric furnace, Ruthenberg points out that a ton of coke is required for the production of one ton of pig-iron, of which only a little more than 150 kgs. are actually required for the reduction of the ore, the remainder being necessary to melt the reduced iron, and, incidentally, to form cinder, whilst no inconsiderable portion is lost or wasted in the form of combustible gas.

One of the earliest attempts to apply the electric furnace to smelting operations, was that made in 1892 by De Laval, of Stockholm, his furnace being of the resistance type, but differing from most others of a like kind, in that the core consisted of fused magnetite. The mass of this latter, which constituted a molten bath, was disposed between, but separated from, two pockets of molten iron, which served the double purpose of terminal electrodes and receptacles for the reduced metal which found its way into them during the process, and was constantly tapped from them in order to ensure a constant level.

An alternating current was used with this device, the ores to be smelted, mixed with the necessary proportion of carbon, being fed into the bath of molten magnetite, where they underwent reduction by the heat generated electrically in the molten mass.

The Gin furnace for steel manufacture is based on the same resistance principle, and is probably one of the simplest in point of application.

It comprises a long trough, shown at T, in transverse section, Fig. 27, lined with refractory material R. This

trough is filled with fused cast iron F, which, in addition to being the material under treatment, also constitutes the heating resistance column. The terminal connexions
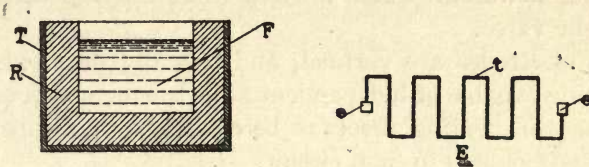

FIG. 27.

through which current is conveyed to the molten column are large blocks of steel, kept cool by internal water circulation, and also by virtue of their greater cross-section.

The inconvenience attendant on so unwieldy a construction as would be entailed by arranging the resistance channel or furnace hearth, in one straight length, is eliminated by doubling it back upon itself several times in zig-zag fashion, as shown at E, Fig. 27, where *t* is the trough, and *e e* the terminal electrode blocks. Thus constituted, the furnace may be likened to a huge incandescent electric lamp filament ; it is mounted, for portability, on a trolley, which can be run in and out of an arched furnace, for the reception of the charge of molten pig-iron, which has been primarily fused in the latter.

There are two distinct methods of manufacturing steel by the Gin process known respectively as the " dilution " method, and the " ore process." They are employed either independently, or in combination. The former is very simple, and consists in adding a calculated percentage of scrap iron to the molten mass, in which it dissolves, followed by the speedy diffusion of the carbon throughout the mass, and its consequent conversion into steel.

The " ore process " entails the addition of iron oxide to the mass, the oxygen of which assists in the elimination of undesirable impurities.

M. Keller's electric blast furnace for the reduction of

iron ores resembles an ordinary blast furnace in general appearance, its hearth being surmounted by a shaft of refractory brick for the reception of the ores, flux, and reducing materials, which are fed in at the top through a gas-tight valve.

The electrodes are vertical, and laterally disposed, each one being capable of independent adjustment, which enables their several heating effects to be equalized by means of an ammeter included in each circuit.

There are at least four of these electrodes to a furnace, and any one of them can be removed and replaced without stopping the run. At the commencement of a run the current is switched on, and the furnace chamber filled with raw materials. Fusion commences at the bottom, in the neighbourhood of the hearth, but soon extends upwards throughout the entire mass, the resultant gases being led off and burnt, to dry and preheat the ores.

The steel fining furnace is placed at a lower level, its inlet being just below the tap-hole of the blast furnace, so that the reduced iron can flow into it. Two vertical electrodes are used, which just establish contact with the surface of the slag, but do not penetrate to any appreciable depth.

The E.M.F. at the terminals of the reducing furnace is 25–30 volts, and of the steel furnace, 50–75 volts.

M. Keller estimates that an electro-metallurgical works, with 10,000 H.P. available, could produce, by his process, 60 tons of steel per diem, of which 50 tons would accrue from 55 per cent. ore, and the remaining ten tons from the fusion of scrap.

The cost of the process, assuming a k.w. year of 8,400 hours to run into £2, would be from £3 12s. to £4 per ton of steel, exclusive of royalties, payable on the patent rights ; the electrical energy would be responsible for only 13s. 3d. of the above total cost.

The electrical manufacture of steel by the Keller process,

as carried on at Kerrouse, France, has proved highly successful. All varieties of iron ore have been electrically fused and treated. Practical trials have demonstrated that for the manufacture of one ton of steel from ordinary ores, electrical energy to the extent of 2,800 k.w. hours, or 3,800 e.h.p. hours is required.

The total cost of manufacture, including electrodes, coke, ore, refining materials, etc., and general expenses, was found to be from £3 15s. to £4.

The ultimate disposition at Kerrouse will consist of a battery of electric furnaces, served by one portable refining furnace, which, in the form of a large ladle, is placed before each furnace in turn, and the electrodes lowered into its contents, tapped from the reducing furnaces.

The Simon electric furnace, for smelting iron and other ores, consists of a movable truck hearth, which carries the negative electrode, consisting of horizontal carbon blocks embedded in a layer of powdered ferro-manganese. Small priming blocks of carbon rest on the upper surfaces of these, and serve as a temporary bridge between the cathode and the vertical anodes, which are similar carbon blocks embedded in a compressed mass of slag, tar, and resin. The upper electrodes slide vertically in a frame, and the active hearth of the furnace is enclosed.

The electrical process of iron smelting and steel production, originally devised by M. Henri Harmet, consisted of three distinct operations, viz., the reduction of the ore ; the fusion of the ore ; and, finally, the refining of the resultant metal. In a later patent, the order of the first two processes has been reversed, the ores being first fused and then reduced.

Electrical heat is largely employed in the process, but is supplemented by the heat of combustion of the gases produced in the intermediate, or reduction chamber, which are mixed with air, and forced, under pressure, into the lower portion of the first, or fusion chamber.

The three furnaces are arranged with their hearths sloping in cascade, so that the fused matter may run from the fusion chamber into the reduction furnace, and the resultant metal from the latter into the refining oven.

In the fusion chamber, the electrodes are placed at the bottom, or hearth, whilst in the intermediate, or reduction furnace, they are vertically arranged, with their lower extremities touching, but not penetrating, the upper layer of slag.

The coke is fed into the reducing furnace down a vertical tower, or cylindrical structure, resembling an ordinary blast furnace, emerging finally, upon the sloping hearth, at a point just in advance of the tapping holes leading to the refining oven ; it thus interposes an incandescent screen, through which the molten metal and slag have perforce to filter, before passing into the latter.

The initially smelted metal forms a thin layer on the hearth of the reducing chamber, upon which floats the slag, and also a coating of coke, detached from the main column. The molten ores from the fusion chamber, flow on to this mixture of coke and slag, and in the intense heat generated by the electric current are reduced, as in an ordinary blast furnace, passing through the descending screen of heated coke, before finally reaching the refining oven, which operates on a similar principle to that of the Martin type.

A later patent taken out by M. Harmet covers an electric blast furnace with a lower '' fusion zone,'' and an upper '' reduction zone.'' The electrodes pass through the walls, and the excess heat, generated in process of fusion, is utilized for purposes of reduction. To this end, the gases from the top of the furnace are collected, and led off by pipes, to a fan or blower, which re-introduces them, under pressure, into the furnace, in the neighbourhood of the fusion centre. They again pass upward, carrying with them the excess heat energy into the reduction zone.

The gases, on coming into contact with the incandescent coke, are converted into carbon monoxide, which effects the necessary reduction of the descending charge as it diffuses upwards. It will be seen from this that the operation is continuous.

A patent granted to Prof. W. S. Franklin, of Lehigh University, towards the latter end of 1903, covers a somewhat ingenious form of electric furnace construction, primarily intended for the reduction of iron ore, but also applicable to the manufacture of glass. The furnace, illustrated in Fig. 28, consists of a pear-shaped depression, or hearth, in a refractory base B, extending upwards into a funnel-shaped opening or feed hopper.

The novelty of the design lies in the construction of the upper electrode E, which may be of carbon, or metal, according to circumstances. Its outer surface is furnished with downwardly inclined teeth, *t t* like those of a saw, whilst it is clamped, at its upper extremity, to the moving member of an eccentric or reciprocating motion R.

FIG. 28.

The raw charge is fed into the funnel-shaped mouth H, around this central electrode, which latter, by its vertical movement, carries it down into the furnace proper, the return stroke, owing to the slope of the teeth *t t*, moving the charge in the hopper but little, if at all. In this manner, a constant feed is secured.

When applied to the reduction of iron ores, a layer of
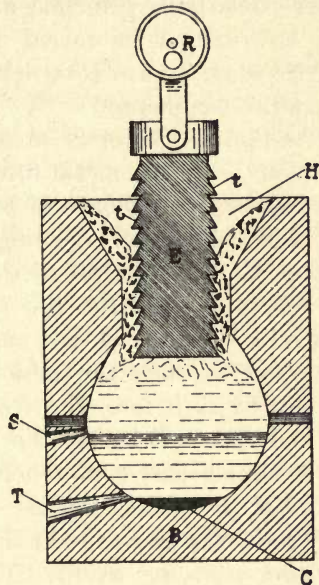
carbon C is placed at the lower portion of the hearth, electrical connexion with it being secured by an iron rod, passing through the refractory wall. Over this is packed a filling of slag, and the current turned on. The resultant heat is regulated by the height of the upper electrode ; if the latter dips into the molten slag, the furnace operates on the resistance principle, and the heating effect is moderate ; if, however, it be raised out of contact with the surface of the slag, an arc is struck between the two, and the temperature augmented.

As the ore descends on to the surface of the molten slag, it melts, and the metal filters through to the lower portion of the hearth, whence it is drawn off by way of the tap-hole T. A similar opening S, at a higher elevation, provides for the removal of the superfluous slag.

When utilized for the electrical manufacture of glass, an initial charge of that substance is given to the furnace, in order to start the action, after which the raw mixture is fed in as before, the resultant glass being drawn off in a molten condition at the lower tap-hole T.

A simple and comprehensive patent, taken out in 1899 by Dr. Borchers, relates to resistance furnace methods of smelting and ore reduction, in which carbon is employed as the reducing agent. The process consists in packing the whole of the carbon employed in the reaction between two electrodes, to act as a heating resistance core, and surrounding the mass with an encircling filling of the ore or substance to be acted upon. No preliminary mixing of the two ingredients is necessary in this method, which is closely allied to that of Dr. Borchers, described under the section dealing with carbide furnaces.

In 1901 a French patent was taken out by the Société Electrométallurgique Française on an arc furnace for the manufacture of all varieties of iron and steel in one operation, by the direct treatment of specific mixtures of iron ore, carbon, and such other ingredients as are determined by the nature of the product required.

The furnace construction is very simple, consisting of a refractory crucible, provided with a domed cover of loose fire-bricks, which can be removed for charging purposes, and through which pass two similar vertical electrodes. These latter do not extend to the bottom of the crucible, but only to a level with the upper tapping-hole, provided for the removal of the slag formed in the smelting process.

The molten metal collects at the bottom of the crucible below the level of, and consequently out of contact with, the electrodes, and is drawn off at a separate tapping-hole, situated at the lowest point of the hearth.

The principle of the arc smelting furnace, devised by Dr. F. C. Weber, consists in allowing the raw material, or ore, to fall vertically through the intense heat zone produced by a number of arcs, into a suitable receptacle placed below.

The furnace comprises a tower-like structure, with the usual feed hopper at its upper extremity, around the point of entry of which, into the furnace, is arranged an outer perforated jacket, to permit the escape of the combustion gases.

Below, the structure broadens out into a species of tunnel for the reception of a removable truck to contain the molten metal smelted by the arcs. The electrodes for these latter pass through the side walls of the furnace at varying heights, just above the receiving chamber, being arranged in equal horizontal rows of opposing carbons. Several of these rows are arranged, one above the other, constituting, when active, a perfect sheet, or bank of arcs, through which the raw material has to pass in falling to the base of the furnace.

Each arc is given independent control, so that its intensity and consequent heating effect may be regulated at the will of the operator, the usual procedure being to graduate them in such manner that the most intense heat is at the top, where the charge first comes into contact with them.

To prevent current leakage between the electrodes other than through the legitimate path of the arc, they are passed through the furnace walls in such directions as to take the longest possible path, viz. at an angle to both horizontal and vertical planes.

A convenient arc furnace for the reduction of metallic ores, manufacture of steel, etc., has been devised by M. Paul Heroult. It involves the production of two arcs in series, or may, if the electrodes are submerged in the raw material to be treated, be regarded as a resistance furnace, in which the conducting path is constituted by an upper layer of the unconverted charge.

In general principle it is extremely simple, comprising an open crucible with a refractory lining, provided with the necessary tapping holes, and two similar vertical electrodes, between the respective extremities of which, and the surface of the conducting charge, the two arcs are struck.

The electrodes are mounted in massive holders attached to screwed stems permitting vertical adjustment, means for which are provided in the shape of bevel gear, and hand-wheels, mounted on swinging brackets, attached to suitable supports on either side of the crucible. Two separate voltmeters, connected between the two electrodes and the molten mass under treatment, respectively, serve as gauges of the condition of the two arcs, whereby an equal adjustment can be secured.

One form of the Heroult apparatus for the direct production of steel resembles, in general construction, its prototype, the Bessemer converter.

It consists of a steel structure, shaped somewhat like a converter, and furnished with the usual pouring lip and chimney, or gas outlet. It is lined throughout with refractory material, such as fire-clay, and, rounded at its base, to permit the necessary tilting, is mounted for convenience on toothed rockers, gearing with fixed rails, similarly cogged.

Rigidly attached to the back of the crucible, and thus moving with it, are vertical supports, carrying horizontal arms for the reception of the carbon electrodes, which are two in number, placed side by side, the arcs being struck in series, thus obviating the necessity for any electrical connexion to the crucible itself.

A rack and pinion motion, worked by a hand-wheel, in combination with a clamping device, serves to adjust the arcs, and fix them in position. The mode of terminal attachment to the carbon electrodes, which are square in section, is somewhat novel, and deserves special mention.

The electrodes themselves abut, through the medium of one face only, against the plane surface of the clamp attached to the horizontal supporting arm. Around them pass, loosely, two flexible metal bands, also attached at their free extremities to the supporting arms. The contact between electrode and support is made mechanically and electrically secure by driving in copper wedges between these bands and the electrode surfaces, a proceeding which not only renders the whole construction rigid, but provides a path of very low electrical resistance between metal and carbon.

In larger models of the above converter the offices of oscillating the crucible and adjusting the carbon electrodes may be performed by hydraulic power instead of manually, whilst the pouring lip may be extended into a ladle, permitting the resultant metal to be cast direct from the furnace.

According to Goldschmidt, Heroult produces in his furnace a tool steel of the finest quality from a raw mixture of cast iron and steel scrap.

Each charge weighs approximately three tons, the electrodes being placed above, and an alternating current of 4,000 ampères at 60 volts, employed in producing the arcs.

The percentage of impurities in the product is estimated to be—

Sulphur	.	.	.	.	.	0·007	per cent.
Silicon	.	.	.	.	.	0·003	,, ,,
Manganese		.	.	.	.	0·150	,, ,,
Phosphorus		.	.	.	.	0·003	,, ,,
Carbon	.	.	.	.	.	0·60 to 1·80	,,

At the time of writing a plant is in contemplation, having a capacity of 600 H.P., and capable of dealing with 15 tons of metal every twenty-four hours, in three operations of the furnace.

Fifteen hundred tons of steel have already been made by the Heroult method in France and Sweden, the process being exploited, in the latter country, by the Aktiebolaget Heroults Electriska Stal.

Heroult's procedure in making steel by the electric furnace method consists in first melting a charge of scrap iron, either *per se*, or mixed with pig-iron. The molten mass is then covered with an artificial slag, and subjected to the action of the arc, the sole object of which is to raise it to the necessary temperature. The first slag is then poured off, and new fluxes introduced, whereby all impurities are removed, and, on adding carbon and other ingredients incidental to the quality of steel required, perfect deoxidation is obtained.

The works of the Société Electrométallurgique Française, at La Praz, Savoy, who manufacture aluminium, and also ferro-chrome and steel, by the Heroult process, utilize a maximum of 14,000 H.P. The machines recently installed for electrical steel manufacture are 500 H.P. single-phase alternators, with an output of 2,750 ampères at 110 volts, and 33 periods per second.

A later design of electric furnace, recently patented by Heroult, for the production of ferro-silicon, ferro-manganese, cast iron, etc., presents several novel points. It is, however, not an independent piece of apparatus, but is intended to be used in conjunction with a preparatory furnace of

the ordinary type, in which the ores to be reduced are primarily heated and softened before being subjected to the action of the electric furnace described below.

A sectional elevation is represented in Fig. 29. It works on the resistance principle, the heating resistance taking the form of a column of coke C, which is fed into the furnace conjointly with the ores, and at the same time serves as a reducing agent. A B are the two inlet or feed passages ; the former sloped as shown to facilitate the entry of the already softened ore, *r*, and the latter, a vertical funnel, or chimney, for the coke feed.

The hearth, where the principal fusion takes place, is provided by the carbon crucible D, which also constitutes the negative electrode, being provided with suitable means for connexion to the external circuit.

FIG. 29.

The positive electrode E also consists of a carbon block, situated in the upper portion of the structure, just above the mouth of the ore inlet A. In the upper wall of this latter is arranged a flue F, through which the hot gases evolved during the process make their escape, and pass over into the preparatory furnace, where they are utilized in maintaining the necessary heat. H is an intermediate, or, as the inventor terms it, " false " electrode, also of carbon.

The course of the current is from the upper electrode E, across the ore feed inlet to H, and thence through the column of mixed coke and ore to D.
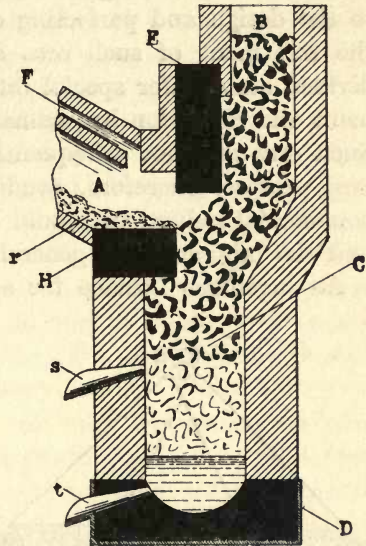
A primary heat zone is thus created at the point of entry of the ore, where it is most needed, and the process is continued through the mixed column as it passes down to the crucible D, where the molten metal is collected, and drawn off at the tap-hole t; s is a similar tap-hole, at a higher elevation, for the removal of the slag.

Marcus Ruthenberg has confined his attention mainly to the design and perfecting of furnaces and processes for the treatment of such ores as, by virtue of their finely divided state, offer special difficulties in the way of treatment and reduction by ordinary smelting furnace methods. Such ores are, not infrequently, exceedingly rich in metal; any process, therefore, tending towards their successful commercial reduction, should be welcomed by metallurgists and the mining world generally.

An ingenious furnace for agglomerating magnetic sand, an ore extremely rich in pure iron, is represented in Fig. 30. It takes the form of twin cast-iron hoppers, H H, hinged together at the top, as shown, by an insulating joint, and provided with a ring R for suspension from a suitable support. These hoppers converge at the bottom to opposing discharge orifices, d d, which are water-jacketed as shown, for the purpose of keeping them cool, and thereby preserving them from destruction by the great heat evolved.
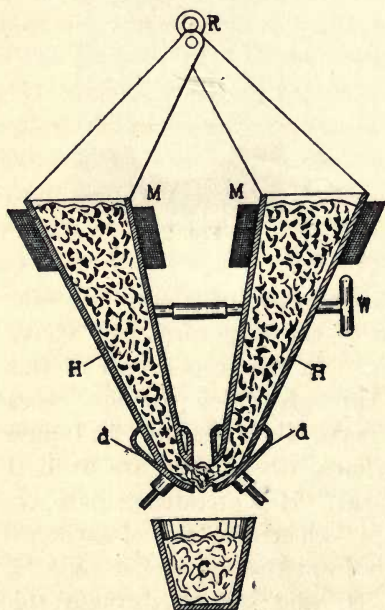
Terminal connexion with

FIG. 30.

the hoppers is made at points near these discharge openings, and a screwed rod, and handwheel adjustment W, about half-way up, serves to regulate the distance between them at the will of the operator.

M M are electro-magnet windings encircling the upper portion of the hoppers, and energized by a current when the furnace is working. Both hoppers are thus rendered magnetically active, and communicate their magnetism to the particles of magnetic ore, or sand, which they contain. Under the magnetic influence, these particles adhere together, and, as they emerge from the discharge orifices below, agglomerate into masses, which are then subjected to the heating effect of the main current passing through them from hopper to hopper, the latter acting as terminal electrodes.

The agglomeration is thus rendered permanent, and the ore falls away, in plastic masses, into the crucible C placed below to receive it. In this form it is more readily treated by ordinary smelting processes.

Another patent, granted to the same inventor, for agglomerating magnetite, is equally ingenious in its design and construction. It consists of a cast-iron hopper situated above, and discharging immediately on to the periphery of a cast-iron cylinder below. The cylinder and hopper form the electrodes of the main furnace circuit, and the former, driven by a motor, through a worm gear, automatically draws the issuing magnetite away from the discharge orifice of the hopper, whilst at the same time it is agglomerated, as in the previous process, by the heating effect of the current. The discharge orifice of the hopper is, of course, protected, as in the previous furnace, by a cooling water-jacket.

If so desired carbon and the necessary flux ingredients may be introduced to form a mixture with the crude magnetite before subjecting it to the action of the furnace, and the ore thus reduced to metal in a single operation.

The Ruthenberg process, which was demonstrated before a committee of experts in January, 1903, at the works of the Cowles Electric Smelting Co., West Lockport, N.Y., consists, briefly, in first purifying the raw ore to the highest possible degree, incorporating it with powdered reducing material in the shape of charcoal, or coke dust, and then subjecting it to the action of one of the furnaces described above, from which it emerges as a reduced, fritted mass, suitable for direct use in steel manufacture without any further treatment.

Some 33 per cent. of fuel, and all the limestone incidental to the ordinary blast furnace process is thus saved, whilst the resultant steel is stated to be of a better and purer quality than that produced by ordinary combustion methods pure and simple.

The process entails the combustion of 500 kgs. of soft coal per ton of product, of which 150 kgs. are necessary to effect the reduction. The expenditure of energy necessary in other processes to maintain the fusion of the entire mass is, in the Ruthenberg process, dispensed with, only a small portion of the ore, that bridging the actual terminals, and constituting the resistance core, being treated at a time.

The terminals of the electro-magnetic arrangement are identical with those of the furnace proper, there being no electrodes, in the ordinary acceptation of the term, though the water-cooled discharge openings of the hoppers really act in this capacity.

Prior to its introduction into the furnace hoppers the ore is purified as far as possible, all earthy and cinder-forming matter being eliminated. It is then crushed, the degree of granulation, or comminution, being largely determined by the quality of the ore ; low grade ores require to be finer than those rich in metal. The crushed ore is then mixed with the necessary ingredients, and in the proportion indicated by the desired analysis of the product, and introduced into the hoppers. The high temperature

attained at the discharge orifices fuses it into a homogeneous mass, denuded of a portion of its oxygen. The remaining complement of oxygen is eliminated in course of cementation, which is secured by keeping the mass heated after its discharge from the electric furnace. The final treatment or fusion is effected in an ordinary open hearth furnace.

Ruthenberg states that the energy required in smelting one ton of iron ore by his process is 500 k.w. hours. He further claims that his process of electrical steel manufacture reduces the cost 20 per cent., and that the product is superior to that manufactured by the Bessemer process.

He has, in addition to the apparatus already described, also patented another resistance furnace process for the smelting and reduction of iron ores ; the process consists essentially in thoroughly incorporating a carbonaceous reducing material with the broken fragments of ore, coking it in place, and reducing the resultant mass to spongy iron, which is finally fused.

The resistance furnace in which these several phases of the complete process are effected has horizontal electrodes, which pass through the walls in the neighbourhood of the hearth, the heating resistance circuit being completed by a mass of the molten metal. Immediately above this is the fusion zone, in which is effected the fusion of the spongy metal, which has already been reduced, at a still higher level, in the reduction zone. The coking zone is above this latter again, and the process is effected by the heat from the waste gases, which play over the mass immediately after it has been charged into the furnace.

It is rumoured that a number of Canadian capitalists have purchased the patent rights of the Ruthenberg process of electric smelting and steel production, which lends itself readily to the treatment of iron, sand, and magnetic iron ores. They will construct a plant on the Welland River, at Chippewa, utilizing Niagara power from the

Canadian side. Their object is to work the extensive deposits of magnetic ore in Ontario and Quebec, in the vicinity of which fuel is scarce, but water-power plentiful, a double recommendation for the installation of an electric furnace plant. The outcome of this industrial venture will be awaited with interest.

The development of the process by its inventor has been of an encouraging nature. In a paper before the American Electro-Chemical Society in 1902, he quoted the work performed upon one ton of ore by the electric furnace as in the neighbourhood of 500 k.w. hours. In a subsequent paper (1903) the inventor was able to announce that he had brought the consumption of electrical energy, for a similar quantity of ore, down to one-half the original figure, or 250 k.w. hours.

The Conley furnace, so named after its inventor, Michael R. Conley, and exploited by the Conley Electric Furnace Company, is of a simple design, which lends itself to a variety of operations.

The furnace, Fig. 31, is cylindrical, being constructed, as usual, of fire-brick F. The upper portion is funnel-shaped, as shown, and constitutes a feed hopper, the walls of which converge to a contracted portion or neck, n, about two-thirds down, where the primary heat zone is situated. Below this contraction the furnace expands into a hearth H provided with a tapping hole t, where the molten furnace products collect, and are drawn off. Midway between the contraction and the floor of the hearth is placed a second heat zone, $n2$, which either *per se*, or in combination with the primary zone, n, permits a variety of combinations in the way of electrical connexion of the mains carrying the current.

The furnace is of the resistance type, the incandescent portion consisting partly of the electrodes e e and, within the furnace, of the charge itself. The electrodes e e are segmental in form, and consist of a graphite clay mixture ;

they are mounted between segmental pillars of the fire-brick structure, in such manner as to permit of consider-able adjustment to compensate for combustion and wear. They meet at the point of entry into the fur-nace chamber, and form a contin-uous band, which, in conjunction with the conducting charge, be-comes incandescent when the re-quired current is passed through. Each segmental electrode is pro-vided with a terminal, and it will be seen that, by varying the elec-trical connexions to the furnace, as stated above, the direction of maximum heat can be varied at will, in either a horizontal or ver-tical direction.

As already mentioned, the furnace is designed for a number of uses, chief among which are the reduc-tion of iron ores and the manu-facture of steel.

In Conley's latest form of resist-ance furnace for the smelting of iron ores, and the manufacture of steel,

FIG. 31.

with facilities for direct casting from the furnace itself, certain modifications have been made in the original design, de-scribed above. It consists, as before, of a fire-brick struc-ture, the upper portion of which is funnel-shaped, and has a central rib, or partition, also of fire-brick. The walls of the funnel converge to a neck, where the principal heat zone is located. Three resistance plates, consisting of one part graphite to three of fire-clay, are introduced at this point, and provided with terminals for connexion to the external circuit. The section of the central portion
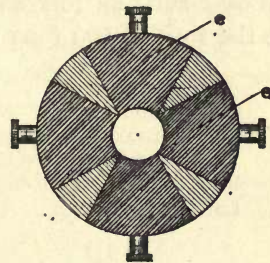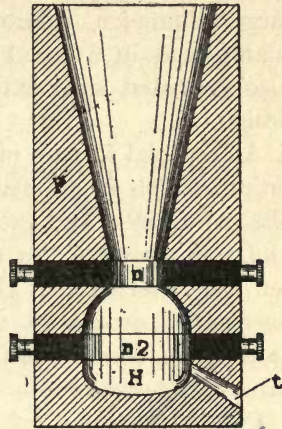
of these plates is reduced, in order to increase the resistance, and, consequently, the heating effect. Below this heat zone the furnace expands, as before, into a hearth of larger diameter, where the molten metal collects and is maintained in a fused state by a carbon resistance belt, also provided with external terminals, as in the previous design.

An especial feature of the furnace consists in a magnesite lining, which is applied to all exposed carbon surfaces of the resistances, and prevents direct contact between them and the charge of ore to be reduced; the carbon required for the reaction can thus be exactly computed, and the necessary percentage added to the ore without fear of subsequent contamination by carbon particles which might otherwise become detached from the electrodes themselves.

Conley's estimate of the cost of steel production by his process runs as follows : Working on ores, and producing at the rate of 100 tons per day :—

	£
Electrical energy	50
Thirty tons of coke at 8s.	12
Two hundred tons of ore (65 per cent. metal) at 14s. .	140
Repairs and maintenance	10
Labour	25
Total £237

or an average cost of £2 7s. 5d. per ton.

Working on pig iron and scrap, and producing at the rate of 24 tons per day—

	£	s.	d.
Electrical energy	12	10	0
Twelve tons of wrought iron at 112s. .	67	4	0
„ „ cast iron scrap at 64s.	38	8	0
Repairs and maintenance . . .	5	0	0
Labour	13	0	0
Total	£136	2	0

or an average cost of £5 13s. 6d. per ton.

Contardo's furnace for the reduction of metals such as

iron from their ores and the manufacture of steel, consists (Fig. 32) of three distinct parts, or chambers : (A) a funnel, or feed hopper, with suitable regulating device, and gas outlet, for the introduction and control of the charge of raw material or ore to be reduced. (B) an intermediate portion, or hearth, which is the seat of the necessary heat, provided by an arc or arcs, struck between diametrically opposed electrodes E, and shielded from direct contact with the charge by an inverted V-shaped roof R of refractory material, thus protecting the charge from the introduction of impurities, such as might become detached from the electrodes themselves; and (C), a receiving chamber, or crucible, for the reception of the molten metal, provided with the usual tapping hole at its lowest point, and within the walls of which, communicating with suitable inlets, are passages, or flues F for the introduction of reducing and carburetting gases, respectively, into the presence of the heated mass. The nature of the gases introduced through these flues is determined by the required composition of the finished product, and may, if the process be one of smelting pure and simple, be either omitted altogether, or regulated as desired.
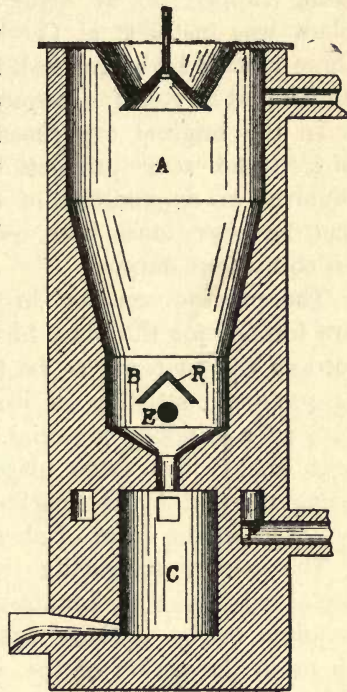
Fig. 32.

The Stassano process for the electrical production of iron and steel, consists, briefly, in first subjecting the ore to a process from which it emerges in a state of fine sub-

division. Lime and coke, also ground to a fine powder, are then mixed with it in the necessary proportions, and the mixture, aided by a suitable binding material, is moulded into briquettes, in which form it is subjected to heat in specially designed arc furnaces.

The process is continuous, the resultant metal and slag being tapped off at regular intervals. An experimental plant was installed at Cerchi, in Italy, the furnace being three metres high, and calling for an expenditure of 1,800 ampères at 50 volts for an output of 30 kgs. of metal per hour.

In the original experiments with the Stassano process of iron and steel production, 1 kg. of manganiferous steel involved an expenditure of 4·08 E.H.P. hours ; this figure, has, however, since been reduced to 2·7 E.H.P. hours for an equivalent output.

The process consists, in the main, in substituting an arc furnace for the blast furnace at present employed, and feeding the material to be treated, into it, in the form of briquettes, consisting of iron ore and carbon, lime, and tar, as a binding material. The process is synonymous with that which takes place in a blast furnace, the ores being reduced by the carbon and the siliceous remainder removed in the form of slag.

The ores most usually treated are those in which the metal exists as a carbonate or oxide ; if the former, the ore requires to be initially roasted. Previous to subjecting them to the action of the arc, all ores are powdered and mixed with the proportions of carbon, lime, and silica, which a prior analysis of the ore may show to be necessary. From 5 to 10 per cent. of pitch is then added as a binding material, and the mass moulded into briquettes by hydraulic pressure.

About half an hour is the time required in producing sufficient metal to form a small ingot, the power consumption being in the neighbourhood of 3,000 H.P. for each ton of metal produced.

The Stassano electric smelting works are in operation at Darfo, near the Lago d'Isco. According to Goldschmidt, Stassano has succeeded in producing soft iron, with a carbon content less than 0·2 per cent., directly from iron ore on a commercial scale in the electric furnace. It is necessary to add that very pure ores are available, as the following table of chemical compositions will show—

CHEMICAL COMPOSITION OF ITALIAN ORES.

SUBSTANCE.	MAGNETITE.	RED HAEMATITE.	LIMONITE.	LIMONITE.
Fe_3O_4 . .	78·400%	—	—	—
Fe_2O_3 . .	—	88·850%	80·930%	73·840%
MnO . .	0·700%	0·470%	0·567%	0·567%
SiO_2 . .	8·650%	2·960%	1·970%	1·970%
Al_2O_3 . .	7·330%	3·420%	2·152%	2·152%
CaO . .	2·100%	0·870%	0·590%	0·590%
MgO . .	1·030%	—	—	—
S . . .	0·055%	0·078%	0·070%	0·070%
P . . .	0·008%	0·093%	0·124%	0·124%

A consideration of the energy required, and cost, of the electrical process devised by Stassano, yields the following figures. Working at an efficiency of 80 per cent., 1 H.P. hour is equivalent to 508·2 Calories, or the heat derived from 1 kilogramme of coal is equal to 3 H.P. hours. Cost of instalation, per E.H.P., £12; annual cost (10 per cent. for interest and depreciation, £1 4s., maintenance, 8s.) £1 12s. The cost of 1 H.P. hour, on the basis of 7,000 working hours per annum, is therefore 0·055d.

In the Stassano furnace, the charge is heated solely by radiation, the heat of the arc, which is maintained by 2,000 ampères at 170 volts, alternating current, being reflected on to the charge by a domed roof.

The electrodes pass through water-cooled sleeves, and are supported by conducting rods, sliding in gas-tight glands, and adjustable therein, by means of small hydraulic cylinders, which afford a simple and convenient means of feeding or withdrawing the carbons. Once the action is started, the arc is drawn out to as great a length as one metre, the oper-

ation of the furnace being accompanied by considerable noise.

A great measure of the success attained by Captain Stassano in his electric smelting process is attributed by Goldschmidt to the care bestowed upon the composition of the furnace charge, with a view to securing complete reduction and a maximum yield. The following table represents the percentage composition of a typical Stassano furnace charge, which, thoroughly incorporated, and mixed with tar as a binding material, is moulded into briquettes prior to its introduction into the furnace.

	ORES.		FLUXES.		COAL.		TAR.
Fe_2O_3	93·02%	CaO .	51·21%	C .	90·42%	C. .	59·2%
MnO .	0·610%	MgO.	3·11%	Ash .	3·88%	Hydrocarbons	40·5%
SiO_2 .	3·79%	Al_2O_3 Fe_2O_3	0·5%	H_2O .	5·70%	Ash .	0·27%
S . .	0·058%			—		—	
P . .	0·056%	SiO_2 .	0·9%	—		—	
CaO MgO	0·5%	CO_2 .	43·43%	—		—	
H_2O .	1·72%	—		—		—	

A charge consists of ores, 100 kgs. ; coal, 23 kgs. ; and fluxes, 12·5 kgs., the various constituents being apportioned as follows—

	ORES.		COAL.		FLUXES.
Fe_2O_3 .	93·02 kgs.	C .	20·9 kgs.	CaO .	6·401 kgs.
MnO. .	0·619 ,,	Ash .	0·892 ,,	MgO .	0·389 ,,
SiO_2 . .	3·79 ,,	H_2O .	1·21 ,,	Al_2O_3 Fe_2O_3	0·062 ,,
S . .	0·058 ,,			SiO_2 .	1·125 ,,
P . .	0·056 ,,			CO_2 .	5·429 ,,
CaO MgO	0·5 ,,			—	
H_2O .	1·72 ,,	—		—	

The resultant metal has the following composition—

Iron	.	.	.	.	.	99·764 per cent.
Manganese	.	.	.	.	.	0·092 ,, ,,
Silicon	.	.	.	.	.	Trace.
Sulphur	.	.	.	.	.	0·059 ,, ,,
Phosphorus	.	.	.	.	.	0·009 ,, ,,
Carbon	.	.	.	.	.	0·090 ,, ,,

The following thermal data regarding the heat required for bringing about the various stages of the process are quoted—

	CALORIES.
For the reduction of 1 gramme-molecule of Fe_2O_3	192·000
For the conversion of 1 kg. of water at 100°C. =212°F. into steam, at the same temperature	637·000
For raising the temperature of 1 kg. of steam at 100°C., by 1°C.	0·480
For calcining 1 kg. of flux	425·000
For raising the temperature of 1 gramme-molecule of CO_2, 1°C.	0·016
For raising the temperature of 1 gramme-molecule of CO, 1°C.	0·0068
For fusing 1 kg. of iron	350·000
For fusing 1 kg. of slag	600·000
The combustion of 1 kg. of C to CO, generates	2,175·000
Required, for the decomposition of ferric oxide $\dfrac{92·02 \times 192}{0·16} =$	111,552·000
For the evaporation of the water contained in the ore and coal $(1·72 + 1·21)\,637$.	1,866·41
Required, to superheat the steam to 500°C. =932°F., $2·93 \times 0·048 \times 400$	562·56
Required, for calcining the flux $12·5 \times 425$	5,312·5
Required, for raising the temperature of the CO_2 to 500°C. $\dfrac{5·429 \times 0·016 \times 500}{0·044} =$	987·09
Required, for heating the CO generated, $\dfrac{20·9}{0·012} \times 0·0068 \times 500 =$	5,921·667
Required, for fusing the iron produced, 65×350	22,775·2
Required, for fusing the slag, $13·89 \times 600$	8,334·0
Total	157,311·427
The oxidation of C, to CO, produces $20·9 \times 2,175 =$	45,457·500
Balance	111,853·927

Assuming, therefore, an efficiency of 80 per cent., this total of

$$111{,}853{\cdot}927 \text{ Calories,} = \frac{111{,}853{\cdot}927}{635{\cdot}3 \times 0{\cdot}80} = 219{\cdot}08 \text{ H.P. hours,}$$

or, the yield being 65·114 kilogrammes of iron, the energy required for the production of 1 kg. is

$$\frac{219{\cdot}080}{65{\cdot}114} = 3{\cdot}364 \text{ H.P. hours,}$$

and the cost, based on the foregoing estimate of 0·055d. per H.P. hour, works out at 15s. 5d. per ton.

A smaller model of the Stassano furnace, which is used for experimental purposes at Darfo, requires 1,000 ampères at 80 volts.

Turin is at present the scene of Stassano's electric smelting operations, where he is conducting experiments with his process, on behalf of the Italian Government.

Assuming a plant of 5,000 H.P., producing steel at the rate of 30 tons per day, with a thermal efficiency of about 66 per cent., Stassano estimates the cost of manufacturing 1,000 kgs. to be as follows—

	£	s.	d.
1,600 kgs. of ore at 12s. per ton . . .	0	19	2½
For pulverization of same at 2s. 5d. per ton.	0	3	10
200 kgs. of flux at 4s. per ton . . .	0	0	10
250 kgs. of coke at 36s. per ton . . .	0	9	0
Crushing same at 1s. 7d. per ton. . .	0	0	5
190 kgs. of other materials (tar, etc.) at 56s. per ton	0	10	8
Mixing at 2s. 5d. per ton	0	5	5
Wear of electrodes, 12 kgs.	0	2	10½
Labour	0	4	9½
Maintenance of furnace	0	9	7
Accessories	0	2	5
Electrical energy, 4,000 H.P. hours at 0·055d..	0	18	3
Other costs	0	2	4½
Total	4	9	8
Less the value of inflammable gases, 900 cubic metres at 0·192d.	0	14	5
Nett Cost	£3	15	3

Dr. Goldschmidt, in a paper before the Electro-Chemical

Society of Cologne (1903), gave some interesting particulars regarding the Stassano process. The following are a few of the salient points mentioned.

The current used in the experiments which have been carried out at Darfo, in Italy, is alternating, and is derived from two large dynamos, each of 500 H.P., and a smaller one of 100 H.P. The process, like other reduction methods, consists essentially in reducing the iron ores with charcoal or coke, by virtue of the heat derived from an electric arc, working above the charge, suitable fluxes being introduced, to eliminate undesirable impurities.

The latest form of Stassano furnace consists of a closed cylindrical structure, with domed roof, constructed of masonry, and having a cavity one metre in diameter and one metre high. A sloping feed channel serves for the introduction of the ore, whilst two tapping holes, at different elevations, provide for the withdrawal of the molten metal and slag respectively. The entire furnace can be revolved around a vertical axis.

The electrodes are introduced through the walls at opposite extremities of a diameter, and at or about the centre of the furnace cavity; at the commencement of the process their inner extremities are close together, but, as the operation proceeds and the temperature increases, they are withdrawn until the arc extends across the entire width of the furnace cavity.

With the arc at its maximum, the current is so regulated that in—

20 minutes, the E.M.F. is	80 volts, and the current	800 ampères.
40 ,, ,, ,,	100 ,, ,, ,,	1,000 ,,
70 ,, ,, ,,	70 ,, ,, ,,	600 ,,
100 ,, ,, ,,	50 ,, ,, ,,	500 ,

The entire reduction process occupies two hours, from first switching on, until the reduced metal is ready for casting, during the first half of which period the charge is being introduced.

The following is the composition of a typical charge, which was reduced by a current of 1,000 ampères at 80 volts—

Iron ore	.	.	.	.	.	.	.	1,000 parts.
Limestone	.	.	.	.	.	.	125	,,
Carbon	.	.	.	.	.	.	160	,,
Miscellaneous (hydrocarbons, etc.)		.	.	120	,,

The total weight of the above charge was 70·25 kgs., and the following table represents the original weight of reducible substances, together with the weights actually obtained in the process—

SUBSTANCE.	ORIGINAL WEIGHT (GRAMMES).	PRODUCT (GRAMMES).
Iron	32,557	30,727
Manganese	239·7	28·3
Silicon	910	Traces
Sulphur	29	15
Phosphorus	28	2·7

The actual yield was thus 30·8 kgs. of wrought iron.

Below will be found a tabular analysis of the impurities in four different samples of steel manufactured by the Stassano process.

	I.	II.	III.	IV. (CHROME STEEL).
Carbon . .	0·04%	0·09%	0·17%	1·51%
Manganese .	0·05%	0·18%	0·17%	0·26%
Silicon	—	Trace	Trace	—
Sulphur	—	—	0·05%	—
Phosphorus	—	—	0·029%	—
Chromium .	—	—	—	1·22%

An iron and steel plant, at Gysinge, Sweden, employing electric furnaces designed by M. F. A. Kjellin, is now producing steel of excellent quality, which is unusually dense and homogeneous. It is very tough, and, when annealed, can be readily worked in a cold state, without any tendency to distortion consequent on hardening, as is frequently the case with ordinary grades of steel.

The inventor attributes the improved quality of the steel, manufactured by his process, to the almost complete absence of gaseous matter, especially hydrogen.

The capacity of the latest Kjellin furnace, installed at Gysinge, is 1,880 kgs., and, charged with raw materials in a cold state, it is capable of producing 1,500 tons of steel per annum. It is supplied with current from a single-phase alternating current generator, driven by a vertical turbine, capable of developing 300 H.P.

The principal considerations which led to the design of the Kjellin furnace are as follows. M. Kjellin early recognized the fact that in operating steel furnaces on the ordinary resistance principle, with independent electrodes, the molten metal absorbs impurities from the latter, which, especially if of carbon, are also consumed, and thus add to the expense of the operation, whilst the carbon monoxide gas formed as a result of the combustion, hinders the elimination of this gas from the mass of the steel itself. On the other hand, if carbon be dispensed with, and the current led direct to the mass of metal under treatment, the enormous currents required necessitate the use of copper leading-in cables at least equal, in cross-sectional area, to the resistance column of metal.

Water-cooled iron terminals have been suggested, but fresh difficulties arise out of the magnetization effects ; moreover, the use of alternating currents, one of the desirable incidentals to such a large power conversion, leads to fresh complications, owing to skin effect, hysteresis, and consequent loss of power.

With a view to surmounting these various difficulties, Kjellin, in 1899, suggested to M. Benedicks, general manager of the works at Gysinge, the form of construction now known as the Kjellin furnace. It consists of an annular groove, or hearth, built of refractory bricks, and closed in at the top by refractory covers, which are removable for charging purposes.

Centrally, within this ring is placed one limb of a rectangular iron core, built up of thin sheet-iron laminations, upon which is wound a copper wire coil, which constitutes the

primary winding of a closed-circuit, step-down transformer, the secondary, in the shape of the contents of the annular hearth, having only one turn. Current is supplied to this primary winding at a pressure of 3,000 volts, and the ratio of transformation is such that the current through the furnace charge is approximately equal to the primary current multiplied by the number of turns in the primary winding, or about 30,000 ampères.

The first Kjellin furnace was installed at Gysinge in February, 1900, and the first ingot of steel successfully cast on the 18th of the following month, the expenditure of energy being 78 kilowatts for 24 hours, and the yield 270 kgs. An improved efficiency was secured in November, 1900, when a second furnace was completed, capable of producing from 600 to 700 kgs. of steel in 24 hours, with an energy expenditure of 58 k.w. With this construction, however, the available cooling surface, and consequent radiation losses were out of all proportion to the furnace capacity, and, in 1902, a neighbouring sulphite pulp mill having been destroyed by fire a year previously, its available water power was adapted to steel manufacture on the Kjellin principle, with the result that a third furnace was constructed, and has been working satisfactorily since May, 1902.

It has a capacity of 1,800 kgs. of charge, 1,000 kgs. of steel being tapped off at a time, leaving the remaining 800 kgs. to complete the secondary circuit and avoid shutting down the power plant. The output is 4,100 kgs. of steel in 24 hours, with an energy expenditure of 165 k.w., or 225 E.H.P., the charge being introduced into the furnace in a cold state.

The raw materials employed are Dannemore pig iron and wrought iron, which are fed into the furnace along with scrap steel, and in the proportions indicated by experience, as yielding the best percentage of carbon.

M. Kjellin is reported to have spoken as follows regarding his invention—

" By the electric furnace described, the steel has no op-

portunity of taking up such gases, or other impurities, and the quality is also better than that of crucible steel with the same analysis. To make special steels with nickel, tungsten or chromium, offers no difficulties, and the alloys are quite homogeneous. The cost of production depends, principally on the efficiency of the furnace and the price of power.

" At the furnace now in use at Gysinge, the losses have been experimentally proved to be 87·5 k.w., so that the effective power absorbed by the steel is $165-87·5 = 77·5$ k.w., and, as these produced 4,100 kgs. of steel in 24 hours, one effective kilowatt produces about 53 kgs. of steel ingots in the same time. Every kilowatt more in the furnace, when the size is not altered, increases, then, the output with 53 kg. steel ingots, and we calculate, when, within a few months, we get a stronger water wheel, to produce about 6,000 kgs. of steel ingots with 200 k.w. in 24 hours.

" As the absolute cost of labour and repair will be the same, these costs for one ton of steel ingots will be about two-thirds of the cost now, and the price of power, per ton, will also be sensibly diminished.

" Thus, a furnace of 736 k.w., or 1,000 E.H.P. will produce 30,000 kgs. of steel ingots in 24 hours when charged with cold materials. With hot materials the output is much greater. For instance, if 250 kgs. of molten pig iron are charged for each ton of steel ingots produced, the output is increased from 30,000 to 36,000 kgs. in 24 hours with the same expenditure of energy.

" The cost of labour and repair for such a furnace will, in my opinion, be less that those of an open-hearth furnace of the same size, so that, where power is cheap, there is a possibility of producing a steel at a smelting cost not exceeding that of the open-hearth furnace."

The following is a detailed estimate of the cost of the Kjellin process, based on data obtained in actual practice at Gysinge—

4,100 kgs. of steel are produced in 24 hours, with an

energy expenditure of 225×24 H.P. hours ; 1,000 kgs. require, therefore, 1,320 H.P. hours.

		£	s.	d.
Cost of electrical energy, assuming 1 H.P. hour to cost 0·18d.		1	0	0
Charge (pure charcoal, cast iron and wrought iron)		6	10	0
Repairs and lining		0	9	3½
Depreciation and interest		0	2	3
Labour		0	10	0
Total cost, excepting royalties, business charges, etc.		£8	11	6½

In the Kjellin process the furnace gases do not come into contact with the steel. The cost of the furnace is given as 15,000 kronen (£832).

The following table gives the analyses of three samples of steel manufactured by the Kjellin process at Gysinge—

	I.	II.	III.
Carbon .	1·45%	1·20%	0·95%
Silicon .	0·47%	0·74%	0·35%
Manganese	0·49%	0·46%	0·33%
Phosphorus	0·011%	0·013%	0·014%
Sulphur	0·010%	0·010%	0·015%

Other Metals.—One of the difficulties incidental to reduction processes, as carried out in the electric furnace, is that the molten metal formed, readily absorbs the carbon of which the electrodes are composed, and thereby becomes contaminated.

Several inventors, realizing the importance of this drawback to electric smelting, have set themselves the task of providing a remedy. E. G. Acheson has patented a method of protecting the carbon core in resistance furnaces by coating it with a refractory sheath of a carbide, which, whilst preventing actual contact between core and charge, nevertheless conducts the heat generated by the former to the mass of the latter.

M. Simon, whilst investigating the possibilities of preparing metallic manganese in the electric furnace, also experienced this difficulty, but succeeded in overcoming it by

enveloping the anode in a sheath of manganese slag, in which the metal existed as the lower oxide, and was therefore inactive in the presence of carbon.

George Egly protects the lower electrode or cathode, in his furnace for the reduction of protoxide of nickel, by covering it with a layer of magnesia, about 2 c.m. in thickness.

In 1895, Moissan succeeded in producing silicon in the electric arc furnace by reducing silica, in the form of quartz, with carbon, in a coke crucible. Acheson has since, 1902, applied the resistance furnace principle to this process, utilizing graphite as a reducing agent. To this end, he mixes silica and graphite in the proportions necessary to the reaction, and forms the resultant mixture into a column or pyramid, which he utilizes as a conducting core in a resistance furnace. This admixture of graphite with the silica, imparts sufficient conductivity to the mass ; thus, it was found by experiment that a core two by two, by three inches, had an initial resistance of 33 ohms, which fell to 5 ohms as the reduction proceeded.

The success of the above and similar experiments has led Acheson to take out a patent covering the applications of graphite as a reducing agent for use in electric furnaces of the resistance type. The essential properties which fit it for use as such are—

(1) Its high purity, and consequent inability to contaminate any ores heated in its presence.

(2) High electrical and thermal conductivity, whereby the necessary current is transmitted and the resultant heat evenly distributed.

(3) Extreme divisibility, permitting an advanced degree of comminution, thereby lending itself to the production of an intimate mixture with the ore to be reduced.

The Tone furnace, invented by Mr. F. J. Tone, engineer to the Carborundum Company, Niagara Falls, has been devised with a view to overcoming one of the drawbacks

incidental to electric smelting, where carbon is used as a reducing agent, viz., the tendency on the part of the liberated metal to recombine with the excess of carbon present in the furnace charge, to form a carbide. As already stated, this has been a common experience with metallurgists in treating the ore of a metal whose temperatures of reduction and volatilization are approximately the same.

In the Tone furnace, illustrated in Fig. 33, this tendency is overcome by a more general distribution of the heat generated in the furnace, combined with a judicious distribution of the charge about the central source of that heat. The charge C is thoroughly mixed, and so arranged about the resistance core R as to permit globules of the reduced metal to form, and descend by gravitation to the lower portion of the structure, whence they drip, finally, into the receptacles A A. E E are the terminal electrodes, arranged at the upper and lower extremities of the core R, which consists of a pyramidal pile of carbon blocks, with intervening spaces.
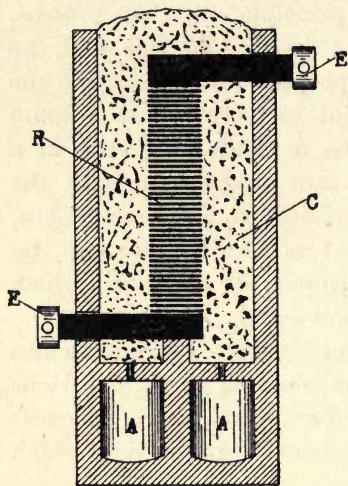
Fig. 33.

The temperature of the furnace needs to be very carefully regulated, such that the reduced metal is not volatilized, whilst the heating effect is evenly distributed and general throughout the mass.

Copper.—The Heroult process has been applied to the extraction of metallic copper from its ores. In 1903, experiments conducted at La Praz, France, under the personal supervision of the inventor, yielded satisfactory results.

In connexion with these experiments, the following

details have been made public. Two carbon electrodes, of square cross-section, were used, each side being 25 c.m. The mineral, which contained 7 per cent. metallic copper, was placed in a rectangular crucible, the electrodes descending vertically into it. Eighteen tons of ore were treated in 24 hours, the resultant matte containing from 43 to 45 per cent. copper, whilst the slag only retained from 0·1 to 0·2 per cent. of the metal. The current required to effect this result was from 3,500 to 4,000 ampères at 110 volts.

M.M. Keller, Leleux, & Co. have also conducted experiments on the electrical extraction of metallic copper from its ores, utilizing a Keller furnace with two centres of activity, each provided with an independent pair of electrodes. The actual reduction is effected in the first heat zone, the second serving to maintain the high temperature of the mass, pending the thorough separation of matte and slag.

Twenty-five tons of ore were treated in 24 hours, the power consumed being 500 k.w. The consumption of electrodes amounted to from 5 to 7 kgs. per ton of ore.

The composition of the resultant matte was as follows—

Silica	.	.	.	.	.	0·8	per cent.
Aluminium	.	.	.	.	.	0·5	,, ,,
Iron	.	.	.	.	.	24·3	,, ,,
Manganese	.	.	.	.	.	1·4	,, ,,
Sulphur	.	.	.	.	.	22·96	,, ,,
Phosphorus	.	.	.	.	.	0·005	,, ,,
Copper	.	.	.	.	.	47·9	,, ,,

And of the slag—

Silica	.	.	.	.	.	27·2	per cent.
Alumina	.	.	.	.	.	5·2	,, ,,
Lime	.	.	.	.	.	9·9	,, ,,
Magnesia	.	.	.	.	.	0·39	,, ,,
Iron	.	.	.	.	.	32·5	,, ,,
Manganese	.	.	.	.	.	8·23	,, ,,
Sulphur	.	.	.	.	.	5·7	,, ,,
Phosphorus	.	.	.	.	.	0·062	,, ,,
Copper	.	.	.	.	.	0·1	,, ,,

The above trials were carried out in the presence of M. Ch.

Vattier, who, acting under a commission from the Chilian Government, has lately visited France for the purpose of carrying out experiments in the electrical smelting of copper ores.

M. Vattier's report contains some interesting comparative figures relating to costs, etc. In the coke furnaces at present in vogue in Chili, 3,200 kgs. of coke, costing £13, are required for each ton of copper produced. On the other hand, a consumption of 1·25 k.w. year, is estimated as sufficient to smelt 16 tons of ore, corresponding to one ton of copper, in the electric furnace. Assuming the cost of 1 k.w. year to be 24s., a figure based on the abundance of water power in Chili, the cost of energy per ton of copper produced would amount to 30s., and, allowing 36s. for electrodes, etc., the total cost of production per ton of metal works out at £3 6s.

Arsenic.—The importance of arsenic as a marketable commodity may be gauged from the facts, published by the *Mineral Industry*, that the total output for 1900 was 7,300 metric tons, produced by Great Britain, Germany, Italy, Spain, and Canada, the two first named being the principal manufacturers. The demand is said to be quite equal to the supply, so that there is little doubt as to the need for this useful metal.

Unfortunately, the ordinary metallurgical processes for its extraction from the various arsenic - bearing ores possess many attendant disadvantages, not the least of which arise out of the poisonous nature of the fumes given off during the process, and their deleterious effect on the surrounding animal and vegetable kingdom.

This is all the more unfortunate in that many of the well-known arsenic bearing ores are also rich in gold and other noble metals. An improved process, therefore, calculated to increase the output and efficiency of extraction, would doubtless be welcomed by metallurgists in general.

Such a process, applicable to at least one rich grade of arsenic ore, has been invented by Mr. G. M. Westman, of New York. It comprises, in effect, a resistance furnace process, and the ores capable of treatment by it are known as " mispickel," or arseno-pyrite ores, which also contain ores of gold, silver, and other metals of value. They are very rich in arsenic, averaging 46 per cent. by weight of that metal, which exists in the form of sulph-arsenide of iron ($FeS_2 + FeAs_2$).

In brief, the process of reduction consists in heating the ore electrically, in a closed furnace, from which atmospheric oxygen is hermetically excluded. The iron combines with the sulphur, forming ferric and ferrous sulphides, which are thrown down in the form of a fused matte, and include the precious metals; the arsenic itself is liberated as a heavy metallic vapour, and collected in suitable condensers as a fine, metallic powder.

The process is carried on in a circulating atmosphere of nitrogen gas, formed, in the first place, from the atmosphere by extracting the oxygen, by combination with a small quantity of arsenic vapour, to form the oxide. Once produced in this manner, the same volume of nitrogen is, by circulation, used repeatedly in the furnace.

The general construction of the latter is delineated in Fig. 34, where F is the furnace proper, with a refractory hearth or lining R of fire-brick, in which are embedded the two cast-iron electrodes E E.

A central hopper H serves for the introduction of the ore, but, at the same time, prevents ingress of air. M is the mass of fused ore, which constitutes the resistance path between the electrodes; C C C C are condensers, with bottom traps t t, in which the powdered arsenic collects and is removed. The tube T completes the circulatory system for the nitrogen gas, which is kept in motion by a mechanically driven blower B. This latter is reversible, such that when one set of condensers becomes heated, the

current of gas may be reversed, and the heat energy, thus stored up, utilized for maintaining the general temperature of the furnace, which would otherwise tend to fall.
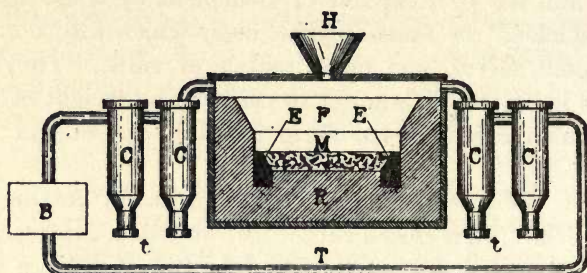
Fig. 34.

An exhaustive test was conducted on an experimental furnace of this type by Mr. Carl Hering, the results of which were detailed in the *Electrical World*, April 27, 1901. The following essential facts are extracted therefrom.

The process, owing to the small size of furnace employed, was naturally wasteful of energy, but, by measurement of some losses, and computation of others, a fair estimate of the probable cost of reduction in a larger furnace was arrived at.

An alternating current of 8,000 to 10,000 ampères at a periodicity of 120, was used, the electrodes, which, as already stated, were of cast iron, being about six square inches in cross-sectional area, and rather long.

The losses, which totalled more than half the energy supplied to the furnace, were due to several contributory causes, viz., skin effect, hysteresis, resistance, Foucault, or "eddy" currents, and conduction. The losses in leads alone, from the secondary of the transformer to the furnace terminals, amounted to 44 kilowatts, whilst 9 to 10 kilowatts were lost by radiation and conduction.

In one trial 90 kgs. of ore were supplied to the furnace in the hour, the power consumed in the conversion being about

105 k.w. ; the current varied from 4,000 to 8,400 ampères, and the voltage from 22 to 12, representing a rate of approximately 1,140 k.w. hours per metric ton of ore.

According to Mr. Hering, it is quite safe to assume that in a large, well-designed furnace, the engine power required in the reduction process would not be more than 1,000 k.w. hours per metric ton of ore.

The theoretical heat energy required has been variously estimated at from 200 to 400 k.w. hours per ton, which points a margin for improvement.

The patent rights in the Westman process are the property of the Arsenical Ore Reduction Company of Newark, New Jersey, who are applying it to the large deposits of ore in what is known as the Big Dan claim in Ontario, recently acquired by them.

The following extract from Mr. Hering's original article contains some general information acquired during the tests, which should prove useful in the design of electric furnaces generally.

" Most of the losses point to the importance of using continuous currents, if possible, as it is very difficult to lead such very large alternating currents through conductors. When, however, alternating currents must be used to avoid electrolysis, as is often the case, then many difficulties are reduced by proportioning the furnace so that the current is as small as possible and the voltage as great as possible ; i.e., the resistance column of the material should be made as long, and as small in cross-section, as the circumstances permit. The loop formed by the alternating current circuit should have as small an area as possible, so as to diminish the induction. The leads should, of course, be made as short as possible, every inch saved in length being important. The transformer should be placed within as few inches of the furnace, as possible. Those parts of the conductors which are unavoidable, as, for instance, where they pass through the walls of the furnace, should be made of insulated lamina-

tions alternately of opposite polarity, otherwise the skin and inductive effects will become important. For these parts, the best electrically conducting material should be used, so as to reduce the cross-section as much as possible, as such large pieces of metal conduct considerable heat away from the interior of the furnace. The frequency should also be made as low as possible when such very large conductors have to be used.

" Metallic casings of the furnace should be avoided, particularly if of iron. If bands are necessary, they should be made of a non-conducting material, or have insulated joints in them to prevent closed circuits in the neighbour-hood of the large alternating field necessarily produced in the part of the circuit in the furnace itself. These are some of the considerations underlying the design of large alternating current resistance furnaces.

" The heat led off through the walls of the furnace, which was about one metre cube, amounted to about 5 k.w., the inner temperature being from 1,000° to 1,200°C. $=1,832°$ to 2,192°F., that necessary for the vaporization of arsenic being only 450°C. $= 842°$F. The channel for the liquid matte was about 50 c.m. long, and 10 c.m. wide. This loss, which is not large for a furnace of about 150 H.P., could be diminished only by having thicker walls, but it becomes relatively less the larger the furnace.

" Theoretically, the following relations can be shown to exist for different sizes of furnace, the assumption for enabling a general law to be stated being, that the furnace is a hollow sphere with relatively thick walls, and that the temperature of the outside surface remains the same. The capacity, or interior volume increases as the cube of the inner diameter. The thickness of the walls will increase with the square root of this diameter, and the radiation losses, per unit volume of the capacity, or interior space, will diminish in inverse proportion to the square of the diameter. That is, for twice the inside diameter, the capa-

city becomes eight times as great, the walls 1·4 times as thick, and the radiation loss per unit volume of the inside becomes only one quarter as great, showing the great advantage of larger furnaces in diminishing this loss. For rectangular furnaces, especially if quite long, these relations will not be quite as favourable, and these general laws then apply only approximately.

" Heating the material quickly, i.e., making each particle pass through the process as quickly as is consistent with the proper operation, will, of course, reduce the size of the furnace for the same output, but, assuming that a certain definite number of heat units are required per ton of material, as is generally the case, the larger furnace would require the smaller current. Both should therefore be considered in designing a furnace.

" In all electric furnaces, the fire-brick lining, when very hot, becomes a conductor, a quality which is made use of in the Nernst lamp. In resistance furnaces, this should be taken into consideration, as it lowers the resistance between the electrodes, and necessitates a greater current, at a lower voltage, to produce the same heating effect. This means that greater flexibility in the regulating apparatus is required. The heat generated in this lining is not lost, except in so far as it diminishes the thickness of the heat insulating walls of the furnace. The conducting of the lining can be prevented only by keeping it cool, which is wasteful."

Zinc.—The electrical distillation of metallic zinc from its ores was a problem attacked by Messrs. Cowles Bros. in the early eighties, the original type of resistance furnace, invented by them for this purpose, being depicted in Fig. 35, where F is the furnace proper, constructed of fire-clay, in cylindrical form, and embedded for heat conserving purposes in a refractory non-conducting bed B of considerable thickness. The back of the furnace consisted of a carbon plate or disc C, which also constituted a terminal elec-

trode, the other taking the form of a graphite crucible G, which served the treble purpose of electrode, removable cover, or plug, and condensing chamber for the metallic zinc, which distilled over into it through the orifice o. It was closed by a lid L, and fitted with an outlet pipe P for the escape of the gases generated. The resistance heating column was constituted by the mass of ore R itself.
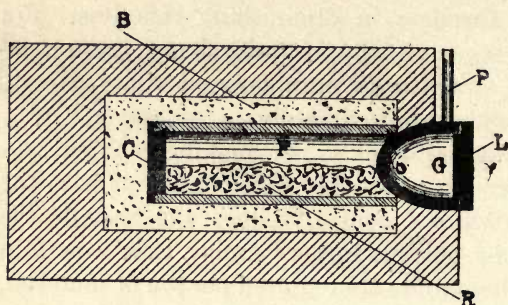
Fig. 35.

It is probable that the practical difficulties mentioned in connexion with resistance furnaces in the introductory chapter of this book militated against the adoption of this furnace on anything like a commercial scale.

De Laval's furnace for the distillation and reduction of the ores of volatile metals, such as zinc, is adapted for use on either the arc or resistance principles, as circumstances may determine.

It is represented, in sectional elevation by Fig. 36, and is so constructed that the charge does not come into direct contact with the arc or heated resistance, but passes gradually beneath it, under the action of a reciprocating feed arrangement, and receives, by radiation, a gradually augmented supply of heat.

The apparatus consists of a refractory structure F having the form shown in the figure, a feed hopper H combined with a reciprocating piston P, and an outlet O. A is the arc, or heated resistance as the case may be, the gradations of heat from which are secured by the contour of the charge ; this latter, under the influence of the reci-

procating feed, assumes the slope shown ; it thus receives a preliminary moderate heating at the apex A of the mass, which gradually increases in intensity as it moves forward under the source of heat, the process being finally concluded immediately below the latter.
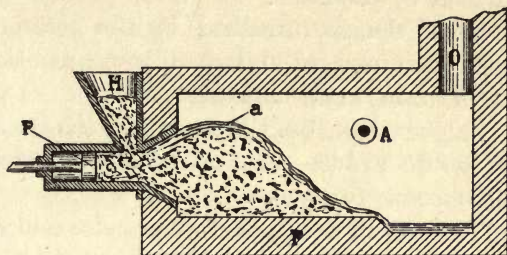
Fig. 36.

A steady reaction is thus secured without a too violent liberation of gas.

The process, as applied to the distillation of metallic zinc from zinc lead ores, consists in introducing the pulverized ore, in stack form, as illustrated above. The radiant heat of the arc, struck between two lateral electrodes, causes the non-volatile constituents of the charge to melt and flow down into the well of the hearth, whence they are tapped off in the usual manner ; fresh surfaces of the sloping stack are thus continually exposed to the arc as the fusion proceeds. The volatilized zinc, together with certain gases, passes off through the outlet shown, and is suitably collected and condensed.

To eliminate the sulphur in an untreated zinc sulphide the inventor suggests mixing iron ore with the charge, prior to its introduction into the furnace.

Messrs. O. W. Brown and W. F. Oesterle have taken out a patent for the electrical smelting of blended zinc sulphides, one of the claims being that valuable by-products (calcium carbide and carbon bisulphide) are formed in the process. Coke, or carbon, is mixed with the ore, and the mixture heated in an electric furnace to a temperature " sufficiently high to produce the desired products." Metallic zinc separates out, is volatilized and collected by condensation

in the usual manner, whilst the carbon, calcium, and sulphur, also present in the ore, combine to form the above-named by-products.

These details furnished by the patent specifications are somewhat meagre, and there is no mention of its practical application on an industrial scale.

Salgués describes (Paper before the Société des Ingénieurs Civils de France, 1903) a process of treating zinc ores in the electric furnace.

The ore, in the form of the oxides and sulphides, is mixed with a suitable flux, and subjected to the action of the furnace in which it is fused, and a reaction started, either in itself, or with suitable reducing agents, carbon, iron, etc. The resulting slag contains practically no zinc, whilst the latter is either tapped off, or distils over according to the conditions of operation.

Treating ores containing 40 per cent. metallic zinc, in furnaces of 100 k.w. capacity, nearly 5 kgs. of metal per k.w. day have been obtained.

The operation is conducted in a closed furnace, and has been on practical trial at a carbide factory at Campagna, in the French Pyrenees.

Dorsemagen has devised a process for the electric furnace reduction of siliceous zinc ore, the products being metallic zinc and carborundum (silicon carbide). A mixture of the ore with carbon is heated in an ordinary electric furnace, with carbon electrodes, the result being that silicon carbide is formed, whilst the metallic zinc distils over.

An analogous process is due to Borchers and Dorsemagen, and is employed in the treatment of compound ores containing both iron and zinc, the products being ferro-silicon and zinc. The process is practically identical with the foregoing.

An Italian process of zinc smelting in the electric furnace, invented by Casaretti and Bertani, is worked by an electro-metallurgical company. One kilogramme of zinc is pro-

duced per 2 H.P. hours, and the consumption of coal in the furnace is 15 kgs. per 100 kgs. of ore.

Chromium.—Herr Aschermann has succeeded in preparing chromium in the electric furnace. He uses a gas-tight steel structure, containing a graphite crucible, which forms the hearth of the furnace, and into which passes from the outside, a movable electrode. The raw material consists of a mixture of oxide of chromium and sulphide of antimony, in the proportion of ten parts to twenty-three. This is placed in the crucible, and the furnace closed, whereupon a current of about twenty ampères is passed through, and suffices to fuse the charge.

Alloys of chromium and antimony result from the fusion, whilst an amorphous mass of the suphides and oxides of antimony remains on the upper walls of the crucible. The antimony may be driven off in its entirety by reheating, whilst the carbon, an appreciable quantity of which is absorbed and dissolved by the chromium, separates out as graphite on cooling.

The process was exploited at Cassel, Germany, in 1897-98.

Molybdenum.—Can be prepared in a similar manner from its dioxide (MoO_2) by heating the latter in conjunction with a small percentage of carbon.

Tungsten.—Is prepared by reducing tungstic acid (H_2WO_4), with a small percentage of carbon, in the electric furnace. If the carbon be in excess or the mass too thoroughly fused, a cast metal or carbide is the result. Care must therefore be exercised, in preparing pure metallic tungsten, to regulate the temperature, and allot the proportion of carbon required for the reduction most carefully.

Nickel.—An electric furnace process for the direct production of nickel from its ores has been exploited at Sault Ste. Marie, Ontario, U.S.A.

A revolving electric furnace, designed by F. H. Clergue, was employed, in which the ores were smelted by the heat of the arc. A ferro-nickel alloy was said to be obtained in

one operation, a sample of which, submitted to Messrs. Krupp, of Essen, gave great satisfaction, and is rumoured to have led to the placing of a large order for the alloy.

Sodium.—A. H. Cowles has taken out a patent on an electric furnace process for smelting or reducing sodium aluminate. To this end, the latter is broken up and intimately mixed with granular carbon, and the mixture subjected to heat in a closed electric furnace. Metallic sodium is liberated in the form of vapour, and passes over to be collected and condensed in a suitable receiver, whilst the aluminium of the compound combines with the carbon to form aluminium carbide, which can be tapped off from the furnace hearth.

Alloys of Iron and Steel.—In his presidential address to the Society of Chemical Industry, in July, 1901, Mr. J. W. Swan touched upon the growing importance of this industry, not only from the steel manufacturer's point of view, but also as an alternative industry to which many idle carbide plants might, for the nonce, be applied.

Chromium and chrome iron are being made at Essen by the Goldschmidt process, by the Willson Company in America, and by several of the French metallurgical companies. Ferro-silicon is being produced at Meran, in the Austrian Tyrol, and also at a few of the carbide works in France.

According to Mr. Swan, the raw ingredients consist of scrap iron, quartz and coke. The daily yield of each furnace is 1,200 kgs., and the product contains 77·5 per cent. iron, and 21·5 per cent. silicon, and costs, at Meran, £8 per ton. The yield, in the electric furnace is one ton per 5,000 k.w. hours.

Ferro-titanium is produced by heating together scrap iron, titaniferous ore, and aluminium, in an electric furnace. Over 30,000 H.P. were available in 1901 for the manufacture of these alloys in the electric furnace.

In this connexion, it may be mentioned that the Willson Aluminium Company recently installed a 3,000 H.P. plant

for the manufacture of ferro-chrome, at Great Kanawha Falls, thirty-six miles above Charleston, W.Va., U.S.A. The chrome ore used in the manufacture is imported from Australia and Asia Minor, and the resultant alloy contains as much as 70 per cent. chromium.

In 1901, the entire output of the plant was being taken by the Carnegie and Bethlehem Steel Companies, who employed it for hardening armour plates for the U.S. Navy.

Gin (*L'Industrie Électrique*, April 25, 1901), gives some interesting statistics relating to the thermo-electric manufacture of ferro-silicon at Meran. The materials and proportions used were—

Iron scale (forge)	1,000 parts.
Quartz	410 ,,
Coke	398 ,,

The respective percentages of useful material were : iron, 71·9 per cent. ; silica, 91·3 per cent. ; and carbon, 63·9 per cent. of the raw material. The normal consumption of energy was at the rate of seventy watts per square centimetre of section. The material was cast in lots of 776 kgs., an interval of 15 hours separating two consecutive casts. The efficiency of the process was 80 per cent., and the yield, 200 grammes per k.w. hour. The fusion temperature varies from 1,130° to 1,400° C. = 2,066° to 2,552°F.

The resultant product had the following percentage composition—

Silicon	21·45 per cent.
Iron	77·50 ,, ,,

The working costs at that period were in the neighbourhood of 200 francs per metric ton, or, in English currency, £7 18s.

In the same article, M. Gin describes a method of manufacturing ferro-silicon from steel furnace slags. The latter, which, in this particular instance, was obtained from a Martin furnace, had the following composition—

Silica	.	.	.	.	.	.	50·42	per cent.
Alumina	.	.	.	.	.	.	2·26	,,	,,
Ferrous oxide	.	.	.	.	.	34·1	,,	,,
Manganese monoxide	.	.	.	.	9·42	,,	,,
Lime, magnesia, etc.	.	.	.	.	3·30	,,	,,

The above, mixed with coke, in the proportion of 1,680 kgs. of slag to 600 kgs. of coke, containing 80 per cent. carbon, yielded a product which analyzed as follows—

Silicon	.	.	.	.	.	.	29·64	per cent.
Iron	.	.	.	.	.	.	53·7	,,	,,
Manganese	.	.	.	.	.	13·18	,,	,,
Carbon	.	.	.	.	.	.	·52	,,	,,
Miscellaneous	.	.	.	.	.	2·96	,,	,,

The yield consisted of 4,090 kgs. in 110 hours, the current required being 6,950 ampères at 29·1 volts, or an energy consumption of 5,380 k.w. hours per metric ton.

Ferro-silicon is a far more active agent than carbon in the process of steel manufacture. The combustion of 1 per cent. evolves heat to the extent of 7,830 calories, as compared with 2,473 calories for the combustion of a similar quantity of carbon.

According to Keller (Paper before Iron and Steel Institute, 1903) the degree of purity attainable with ferro-silicon manufactured in the electric furnace is governed by the percentage of silicon present ; in other words, the larger the silicon content, the greater the purity of the alloy.

He explains this by the fact that it is the iron itself which is responsible for the introduction of impurities, and that, owing to the higher temperatures necessary for the production of alloys with a large silicon content, the impurities are either volatilized, or eliminated by secondary reactions.

He has obtained the following analysis for a 50 per cent. ferro-silicon—

Phosphorus	.	.	.	.	.	.	0·02	per cent.
Sulphur	.	.	.	.	.	.	Trace
Carbon	.	.	.	.	.	.	,,

Actual working results have demonstrated that the energy

required for the production of one ton of 30 per cent. ferro-silicon in the electric furnace is 3,500 k.w. hours. Messrs. Keller, Leleux, & Co., in their works at Livet, Isere, France, have an available total of 15,000 H.P. It has been found practicable, with an expenditure of 4,000 H.P., to turn out twenty tons of 30 per cent. ferro-silicon per day, whilst alloys with as high a silicon content as 70 to 80 per cent. have been manufactured. The furnaces employed at the Livet works are of the resistance type, and are of 650 H.P. capacity.

Ferro-Chrome.—The Willson Company, in 1898, were stated to be manufacturing ferro-chrome at the rate of 60 tons per month.

Aluminium Alloys.—The Cowles furnace, for the manufacture of aluminium alloys, consisted of a fire-brick structure, with massive fire-clay lid, in which latter, orifices were left for the escape of the gases. The electrodes entered through two opposite walls at an angle, and consisted of bundles of carbon rods mounted in massive metal caps, the material of which was a constituent of the alloy under preparation, in order to guard against contamination of the product in the event of fusion, which sometimes occurred towards the end of a run. The electrodes entered through tubular conduits, and were provided with screwed rod adjustment.

The furnace was lined interiorly with broken charcoal, which latter was protected from any tendency to agglomerate under the intense heat of the furnace, by a previous immersion in lime paste, which coated each particle and separated it from its neighbour.

In this connexion it is interesting to note that here were the elements necessary for the production of calcium carbide, then a comparatively unknown compound ; and, indeed, it is probable that calcium carbide, in minute quantities, was frequently formed, incidentally, during the action of this early Cowles furnace.

Alumina, in the form of corundum (crystallized) was

employed in this process, the initial charge consisting of 15 kgs. corundum, 30 kgs. of granulated copper, and sufficient carbon to impart the necessary conductivity to the mixture. The current required for the operation was 3,000 ampères at 50 volts, which was maintained throughout the run, the electrodes being adjusted according to the variation in electrical resistance of the mass under treatment. Each run lasted from two to three hours, the reaction which took place being represented by the equation—

$$Al_2O_3 + 3C = 3CO + Al_2.$$
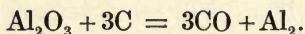
The carbon monoxide gas formed was burnt under a chimney, and the resultant products of combustion carried through a special flue, in which they deposited any metallic particles carried over by them from the furnace.

The product contained from 15 to 20 per cent. of aluminium, and the output of the later trials at Milton were 33 grammes per k.w. hour, as against a theoretical yield of 152 grammes, or an efficiency of only 22 per cent.

This aluminium bronze, or aluminium gold, as it is sometimes termed, consists of one part aluminium and nine parts copper.

The introduction of the Heroult and Hall processes for the manufacture of pure aluminium have entirely superseded the Cowles process for the production of aluminium alloys, the pure metal being first obtained, and then alloyed in the desired proportion, thus yielding a much purer and more homogeneous product.

A later process, patented in 1901 by A. H. Cowles, for the manufacture of aluminium bronze in the electric furnace, though far from efficient, presents several novel points. The furnace consists of a porous carbon crucible, hermetically sealed by a close-fitting lid, through which passes a carbon rod. This latter, and the crucible itself, constitute the two electrodes. Volatile products, e.g. sodium, resulting from the reduction of sodium aluminate in the

crucible by carbon, pass through the porous walls of the latter, under pressure of the gases produced in the reaction and are condensed on the inner walls of a cooling tank, or water jacket, which surrounds the crucible, and with it forms an annular space, in which the volatile product is collected. The aluminium carbide remains behind in the crucible, or, if copper, or other metal be employed, an aluminium alloy is the result.

In order to prevent clogging of the pores in the walls of the crucible a very high temperature is necessary, a fact which would presumably detract from the efficiency of the process.

The Comminution, or Pulverization of Metals, with or without the subsequent production of their oxides by combustion in oxygen, is a branch of metallurgy to which the electric furnace, duly modified, is admirably adapted.

The general method of procedure consists in heating the metal, either by means of an arc or resistance furnace, to the temperature of volatilization ; the resulting vapour burns in air or oxygen, and the oxide of the metal is produced. In the event of comminution of the metal, pure and simple, being required, the operation is carried out in a neutral atmosphere.

One of the earliest applications of the electric furnace to these requirements was made in 1896 by the Société Civile d'Études du Syndicat de l'Acier Gerard, of Paris, who took out a patent on a process for the production of steel from pig iron. In the main, the process consisted in pulverizing the metal, and afterwards subjecting it to an air blast, which resulted in the oxidation of silicon, sulphur, phosphorus, and carbon, and in due course the conversion of the iron into steel.

To effect the necessary pulverization, an arc was suggested, the primarily fused metal being poured, in a falling stream, between the two carbons and consequently through the heat zone of the arc, after which it passed through an air blast,

and was subsequently collected in the hearth of the furnace.

In a modified method, the metal was heated in a resistance furnace, having water-cooled terminals, and oxidation of the vapour effected by a blast of air projected against the surface of the molten mass at the point of maximum temperature.

The process, patented in 1902 by C. S. Lomax, for the manufacture of the oxides of lead and tin, is almost identical with the above, the general principle of furnace and operation being illustrated in Fig. 37, where H is a shallow hearth with enlarged or expanded end cavities, the metal in which remains cooler by virtue of their greater cross-section and consequent carrying capacity, and in which terminal electrodes are inserted for connexion to the source of current. P is a supply pipe, for the delivery of air under pressure through a series of branch nozzles n at or near the surface of the molten metal in H. The oxides, thus formed, pass over, under direction of the controlling air blast and cover C, into a receiving chamber R, where they are collected.
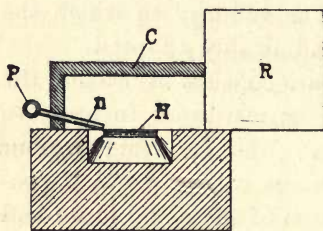
FIG. 37.

It is claimed for this furnace that pure dioxide of tin may be produced by the action of an air blast, the temperature of which has been primarily raised to 400°C.=752°F., the molten mass being at 1,200°C.=2,192°F., whilst, under similar conditions, but with a cold air-blast, putty powder, a mixture of the dioxide and monoxide of tin, is formed. In the manufacture of lead oxides a cold air blast is employed.

M. Paul Bary has devoted considerable attention to this subject, and his more recent apparatus is based, in principle, upon the volatilization of a stream of molten metal carrying

a current by the intermittent arc which follows a rapid and continuous series of interruptions.

It is a well known fact that if a current of certain density be passed through a metallic film, the continuity of the latter is momentarily destroyed, and immediately restored again at a rate amounting to some hundreds of interruptions per second ; it is upon this phenomenon that M. Bary has based the construction of his latest apparatus, which presents several points of interest.

A sectional elevation of the furnace is represented in Fig. 38 ; it comprises an upper chamber A divided from a lower receiving chamber B by a horizontal partition p. The construction is circular, and, through equidistant points around the circle formed by the partition p, pass, vertically, a series of small tubes n n, extending upwards
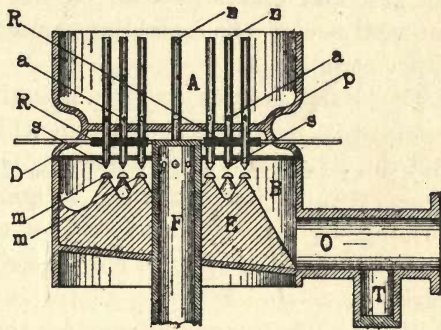
FIG. 38.

above the surface of the molten metal in A, but provided with side perforations at a a to permit the passage of the metal into the lower chamber B. At their lower extremities s s, which extend into B, the tubes n converge into fine nozzles, which serve to concentrate the falling streams upon a series of metal buttons m m placed immediately beneath them. An insulating partition D is introduced just above the line of nozzles, which electrically isolates the upper portion A from the lower B, the only connexion between the two, being through the tubes n, nozzles s, buttons m, and the passing streams of molten metal, which, as already indicated, automatically break up and reform

themselves several hundred times per second under the action of the current which they carry. R R are resistances located between the upper and lower chambers, and included in the main circuit. These, heated by the current, serve to maintain the contents of both chambers in a molten state. The metallic buttons m, and the conductors leading to them, are embedded in a refractory base E, which slopes towards the outlet O. The oxidized products pass over through this outlet into a suitable receiving chamber, any excess of unconverted metal being caught, in passage, by a trap T.

F is an inlet for the introduction of the necessary oxidizing gas, and serves also as an electrode connexion to the external circuit, the remaining connexion being made to the upper chamber A.

The Bary process for the manufacture of stannic acid comprises a resistance furnace in which the tin is vaporized, and the resultant vapour, passing through an orifice in the upper part of the structure, is ignited by a blast of air, forming, by combustion, dioxide of tin. The patent is controlled and applied by the Tin Electro-Smelting Co., Ltd., of Paris.

The electric furnace process for the manufacture of white lead, patented by Messrs. Bailey, Cox, & Hey, consists in striking an arc between a tubular electrode, and the surface of the molten lead to be converted. The tubular electrode serves also as a conduit, through which is introduced a mixture of steam, carbon dioxide gas, and acetic acid vapour, the reaction between which, and the vaporized lead at the central heat zone, results in the formation of commerical white lead.

By a new method, pigments of metallic oxides are produced by burning, in special flues, the waste vapours from electric reduction furnaces. The varying mixtures, from different ores, give a great variety of colours, waste is avoided, and the products are in extremely fine powder without grinding.

SECTION VI

PHOSPHORUS MANUFACTURE IN THE ELECTRIC FURNACE

Speaking generally, the main difficulty experienced in the manufacture of phosphorus, *per se*, in the electric furnace, is the necessarily high temperature at which the vapour leaves the furnace chamber. This vapour was originally condensed immediately after leaving the furnace by means of a water circulatory system, but improvements have since been effected by the Compagnie Electrique du Phosphor, Billaudot & Cie.

In the method adopted by this firm, the vapour is led through a system of cooling towers, whereby the condensation is carried on, by air cooling, at a slower rate, and it is said to yield not only a better quality of phosphorus, but also a larger quantity, and at a reduced cost.

In 1899, it was stated (Tatlock) that one-half the world's production of phosphorus, approximately 1,000 tons, was manufactured by electric furnace methods.

A process for the manufacture of phosphorus in the electric furnace was invented independently by Dr. Readman and Mr. Thos. Parker, in 1888.

The two inventors subsequently combined interests, and the Parker furnace, illustrated in Fig. 39, was the outcome.

It consists of a fire-brick structure F, with a domed roof, through an aperture in the centre of which the raw material is fed from the hopper H by the mechanically driven screw conveyor S. The disposition of all parts is such that air is

hermetically excluded from the interior of the furnace. The lower portion of the structure is contracted to form a hearth A, as shown, and, through the side walls at this point, are introduced the terminal carbon electrodes E E in parallel sets, which serve to convey the current to the charge, the furnace operating on the resistance principle. This linear distribution of electrodes results in distributing the heat area, and rendering the effect more uniform.
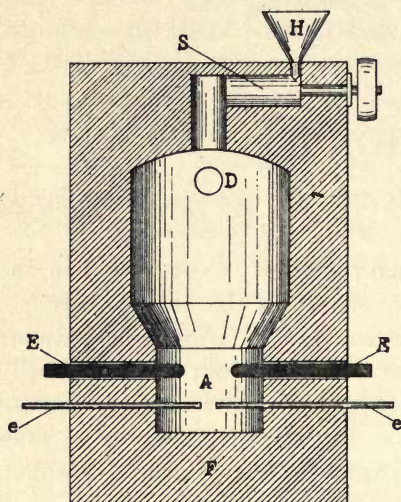
FIG. 39.

The two rows of smaller electrodes *e e*, placed below the main electrodes, suffice to start the heating of the charge, and bring it up to a certain point, after which it is maintained by the current passing between E E. D is a flue for conducting away the gases and vapours formed during the process.

The Readman and Parker process was perfected commercially in 1888. It was exploited on a large scale at the works of the Electric Construction Company, Wolverhampton, and has since been adopted by Messrs. Albright and Wilson, at Oldbury. The mineral phosphate is first pulverized, then mixed with carbon and sand, and finally heated in the closed electric furnace described above, whereupon the phosphorus distils over and is collected under water.

The capacity of the furnace is 80 kgs. of phosphorus per furnace per day. The process is fairly economical, in that from 80 to 90 per cent. of the phosphorus contained in the charge is recovered. In 1898, the Oldbury works utilized

some 700 H.P., and the Niagara works 300 H.P., in the manufacture of this element, but the plant and output have since been considerably extended. Phosphorus, to the amount of fifteen tons per month, is said to be produced at Niagara Falls by the Oldbury Chemical Company.

Similar plants are in existence at Geneva (Switzerland), and Greisheim (Germany), in which latter country the refusal of patent rights has left the electric furnace method open to all comers.

The resistance furnace, invented by H. A. Irvine for the electrical manufacture of phosphorus, is closely allied to the original De Laval furnace, described in the section on smelting, in that the resistance column is in a state of fusion. The furnace consists of a refractory chamber, with a domed roof, in the centre of which is fitted a feed hopper, and through which, on either side of the hopper, descend vertical carbon electrodes, their lower extremities reaching to within a short distance of the floor or hearth of the furnace, which latter, together with the side walls, is composed of packed carbon.

Tap holes are provided, whereby the level of the molten mass on the furnace hearth, and consequently the cross-section of the conducting column between the electrodes, is maintained constant. Two lower horizontal carbon electrodes, projecting through the furnace walls, on a level with the hearth, also provide a ready means of changing the direction of the current path, if such be necessary.

The action is first started through a layer of granular coke, so placed as to bridge the lower extremities of the electrodes, and is subsequently maintained through a mass of conducting slag, formed from the fusion of the raw materials. The charge consists of a mixture of phosphate rock, carbon, and the necessary proportion of a suitable flux, and, in its molten state, covers the furnace hearth to a constant level, determined by the aforementioned tap holes. The unfused charge rests on the top of this molten

mass, and, as it melts, flows down to take the place of that already fused and drawn off.

The principal difficulty experienced in the application of furnaces of this type to industrial operations on a commercial scale is that of finding a sufficiently refractory and non-conducting lining, which shall, at the same time, be proof against oxidation by the furnace contents.

The Machalske electric furnace process for the manufacture of phosphorus, invented by Dr. F. J. Machalske, of Long Island City, New York, and exploited by the Anglo-American Chemical Company, is illustrated in Fig. 40. The furnace consists of a central chamber, or crucible C, 36 by 12 by 18 in., built up of carbon blocks, and lined interiorly with calcined magnesia and a special mixture, whilst outside it is jacketed with fire-clay, red brick, and a mixture of borax and asbestos flour. The upper electrode E is mounted in a special holder or clamp A, and provided with a hand wheel and worm W for feed adjustment. It is 4 in. in diameter, and 8 ft. long. The lower electrode E2 passes vertically up through the floor of the furnace, and is also provided with a screw and hand wheel adjustment, W2, as shown.

The raw material, or phosphate, is placed in the hopper H, and fed into the furnace chamber by the screw conveyor S. Once the action is started the arc can be drawn out to as great a length as 15 in.

An alternating current is employed, with a voltage ranging from 30 to 120. Each furnace takes from 1,000 to 4,000 ampères, and a temperature of $3,867°C. = 7,000°F.$ is available within five minutes of switching on.

A molten slag, consisting mainly of calcium silicate, is produced, and run off at the tap hole T, whilst the phosphorus is driven off as vapour, and passes, by way of the outlet O, into suitable condensers, where it is solidified in the form of dark yellow shavings. These are subsequently treated with sodium hypobromide, whereby the red phos-

phorus is converted into yellow, and impurities eliminated.

The chemical equation representing the reaction which takes place, is as follows :—

$$Ca_3(PO_4)_2 + 3SiO_2 + 5C = 3CaSiO_3 + 5CO + 2P.$$
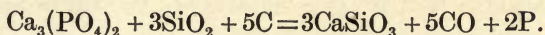
The calcium monosilicate, as already stated, accumulates on the furnace hearth, whence it is run off in a syrupy condition.

In the Machalske furnace, as described above, 68 kgs. of the raw phosphate can be treated in a quarter of an hour, yielding yellow phosphorus at $3\frac{1}{2}d$. per pound, reckoned on a basis of $2d$. per B.O.T. Unit.

Two of these furnaces, each consuming 2,000 ampères, are in use by the Anglo - American Chemical Company in the manufacture of yellow and red phosphorus.

Fig. 40.

Dr. Machalske states, that in the course of his experiments with the above process of phosphorus manufacture, he discovered that, by means of an electric furnace, connected to special condensing apparatus, chlorides of carbon, more especially carbon tetrachloride, could be produced by treating a mixture of common salt, carbon, and sand.
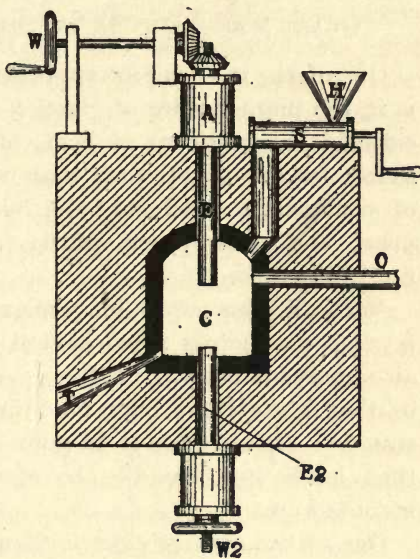
SECTION VII

Glass Manufacture in the Electric Furnace

One of the more recent applications of the electric furnace is in the manufacture of glass, a process which entails considerable expenditure of heat, and a comparatively clean source for the latter, such that no impurities, in the shape of combustion products, etc., shall enter into the fused mass, and destroy the purity and transparency of the finished article.

Nernst's discoveries in connexion with such earths as become conductors when heated to a certain degree, have an important bearing on the development of this industry, in that glass itself may be numbered among those substances ; molten glass is, in point of fact, an electrolyte, and thus lends itself readily to electric furnace methods of manufacture.

One of the earliest electric furnaces for glass production was patented in Germany, in 1882, by Messrs. S. Reich & Co. It was of the resistance type, and consisted essentially of a carbon crucible, open at the base, and lined internally with a net or bag of platinum wire.

The raw material was fed into this, and, having been fused, by the heat developed in the carbon walls, dripped through into refining vessels placed underneath.

The arc furnace, invented by Albert A. Shade, is specially adapted to the fusion of silica or its compounds, as in glass manufacture, but is also applicable to other electric furnace processes. The hearth is a long inclined trough, of circular

section, lined with refractory material, and provided, at its upper extremity, with a screw conveyor or other device, for securing a continuous feed, and at its lower end with a discharge orifice and pouring lip.

The diameter of the lower half of the trough-shaped hearth is less than that of the upper, being proportional to the desired rate of passage of the material under treatment, and the arc electrodes, arranged in diametrically opposed pairs, enter through the side walls at a point just above the reduced diameter. They are disposed in the lower half of the inclined hearth or chute, the last pair of electrodes being very near the discharge opening. In line with the electrodes, but at a higher elevation, are a series of pipes, opening into the furnace chamber, and suitably protected from the heat. These convey exhaust furnace gases into the interior, where they are burnt, and serve to dry and pre-heat the charge during its descent, thus preparing it for the more advanced heating effect of the arcs.

Vertically disposed within, and entirely surrounded and protected by the masonry of the furnace structure, are a series of electro-magnets, one to each pair of electrodes, with its active poles immediately below the arcing space. Sandwiched between each neighbouring pair of magnets is an iron shield plate, also embedded in the masonry, and serving to confine the effect of each particular magnet to its own arc. The general tendency of the magnets, when active, is to deflect the arcs downward on to the gradually moving charge, thereby securing an enhanced heating effect.

A flue leads from the top of the furnace chamber to a jacket surrounding the conveyor cylinder, which is thus, with its contents, also subjected to a preliminary drying process, the jacketing being even extended to the hopper itself.

Although of somewhat complex construction, this furnace would certainly appear to be designed with a view to taking

the fullest advantage of the otherwise waste heat of the furnace gases, and its general disposition, in addition to being well thought out, indicates that the inventor is fully alive to the economies attendant on an efficient system of pre-heating the raw materials, and reducing the duties of the electrical portion of the apparatus to a minimum.

The Henrivaux furnace for the electrical manufacture of glass comprises three steps or terraces, composed of a refractory material. Immediately over the surface of each step is disposed a powerful arc, and the raw material, fed from a hopper into the heat zone of the topmost arc, is fused, and flows down, passing in turn through each of the two remaining arcs, and finally reaching a receiver, or trough, into which it drips.

The process is far from efficient in that a considerable quantity of the heat generated is dissipated without doing any useful work.

Modern gas-fired glass furnaces call for a consumption of 1·5 to 2·8 kgs. of coal for every kilogramme of glass produced, whereas the current consumption, in the Henrivaux furnace, for a similar result, is equivalent to 9·3 kgs. of coal. A considerable improvement in the efficiency of the process is, however, predicted.

In F. A. Becker's electric furnace method of glass manufacture, the raw materials are passed between three pairs of carbon electrodes. The first two pairs serve to fuse the materials, with an expenditiure of 100 ampères at 40 volts. The third pair of carbons is located below the other two and maintains the fusion, with an energy expenditure of 50 ampères at 40 volts. Alternating currents are used, and the process is continuous.

Among the most successful of electric glass furnace methods, may be mentioned the Voelker process, which has been exploited on a commercial scale at Plettenberg, Westphalia.

The furnace invented by August Voelker is represented

in Fig. 41, and is a combination of the arc and resistance types, the upper portion A being utilized as an arc furnace for melting the raw materials ; the intermediate B as a resistance furnace for a species of refining process which the molten mass subsequently undergoes before it finally overflows into the lower receptacle or trough C.

FIG. 41.

The arc furnace A is constructed, as usual, of refractory material, and has a dome *d*, which reflects the heat of the arc set up between the two electrodes *e e* on to the raw material, which is fed by screw conveyors *s s* from the hoppers *h h*, and delivered, as shown, just beneath the electrodes.
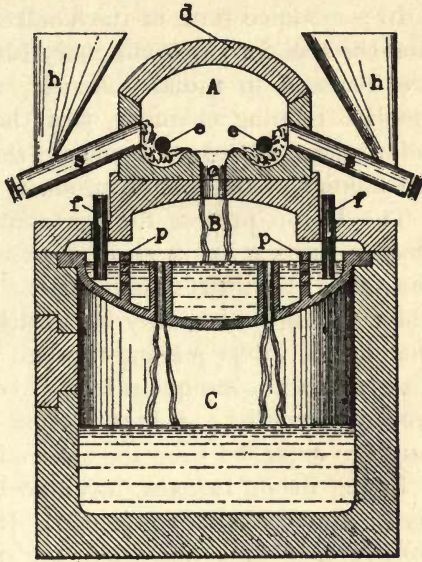
The mass, having been fused by the reflected heat of the arc, flows down the central opening or chimney *c* into the intermediate resistance furnace B, which is subdivided by the vertical perforated partitions *p p* into one central, and two outer, chambers. In these latter are placed the two electrodes *f f* of the resistance furnace, the circuit between them being completed by the molten glass. The object of the partitions is to prevent contamination of the fluid mass by particles which might become detached from *f f*.

In this intermediate chamber the glass becomes more fluid, and the bubbles of air and gas carried over by it from

the first fusion in A are driven off. It then overflows into the cavity C, whence it is drawn off as pure glass, and is ready for use as such.

In a modified form of the Voelker glass furnace construction the arcs for the preliminary fusion of the raw materials are disposed in radial channels, converging to the intermediate refining chamber, their heated gases being burnt below the final reservoir, where they assist in maintaining the fluidity of the molten product.

The Bronn process for the manufacture of glass in the electric furnace has been devised with a view to overcoming several of the drawbacks incidental to a continuous process, chief among which may be mentioned the splitting up of the charge, whilst passing through the furnace, into unequal masses, and a consequent lack of homogeneity in the manufactured product ; contamination of the molten glass by particles detached from the electrodes, etc.

In the Bronn furnace, invented by J. Bronn, of Cologne, these drawbacks are avoided. Its general principles of construction and operation are represented in Fig. 42, where H is a hopper, in which the raw material in the form of a powder is mixed with a suitable binding substance, such as water-glass, hydraulic lime, or plaster, which will not affect the transparency or purity of the resultant glass.

Having undergone the process of mixing, it is fed down the chute C to the rollers R R, between which it passes, and is thereby transformed into a continuous and homogeneous sheet, or rod, as the case may be, the particles being held together by the water-glass or lime before mentioned.

It next passes over a heated roll r, which drives off all moisture, and finally emerges on to the upper extremity of an inclined plane p, forming the hearth or floor of the furnace. Down this it travels at a regular rate, dependent upon the speed of fusion, and consequent glass formation,

passing, for that purpose, under the arcs playing between the electrodes E E, or, if in rod form, travelling down the hearth in like manner between opposite pairs of arc electrodes.

A comparatively recent patent granted to J. C. T. Kess-
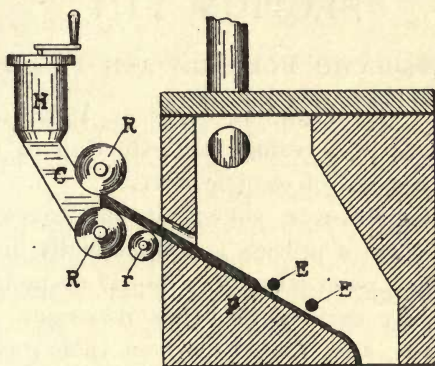
FIG. 42.

meier relates to the application of an electric furnace method as an auxiliary in the casting of glass articles. The extreme fluidity required for the successful casting of molten glass is brought about by arranging a pair of carbon electrodes, through which a current is caused to pass, in the walls of the outlet channel from the ordinary melting crucible to the moulds.

Having first been reduced to a molten condition in the crucible by external heat in the ordinary manner, the glass is then run off through this channel, and, in passing between the two electrodes, completes the circuit and, by virtue of its conducting properties, carries sufficient current to raise it to a temperature of 1,924°C. = 3,500°F., or even higher, at which stage it becomes extremely fluid.

No mention is made of electrolytic effects produced upon the glass by the current in passing, though it seems probable that such would occur with a uni-directional current.

SECTION VIII

ELECTROLYTIC FURNACES AND PROCESSES

Aluminium.—Monkton, as early as 1862, was granted an English patent covering the reduction of alumina by carbon with the aid of electric heat.

Moissan has, however, shown, in the course of his researches, that such a process is commercially impracticable, in that alumina, even when in a liquid or molten state, is not reducible by carbon, it being necessary to vaporize both substances, and, moreover, heat their mixed vapours to a very high degree before reduction is effected ; even then the product is partly aluminium carbide.

Aluminium was first prepared by Wöhler in 1828, by heating aluminium chloride in the presence of sodium. The only commercial process for its extraction, prior to the introduction of the thermo-electrolytic method, was that of heating the double chloride of aluminium and sodium ($2NaCl, Al_2Cl_6$), or the native double fluoride (cryolite), with sodium.

One of the earliest instances of the manufacture of aluminium by electrolytic methods was that of Lacassagne and Thier's primary battery, in which the metal was produced as a by-product of the battery reaction.

The latter consisted of an outer crucible, heated by an ordinary furnace and containing chloride of sodium, in which was immersed an iron electrode. In this was placed a porous pot containing a carbon electrode immersed in chloride of aluminium. The furnace served to bring both salts to a condition of fusion, when a current was available

at the electrode terminals, and, as before stated, aluminium was produced as a by-product.

The price of aluminium in 1855 was approximately £56 per kg., as against its present market price of 2s. 1d. per kg., a reduction which has been mainly brought about by the inception of the electrolytic processes for its extraction from alumina.

Aluminium is one of the most abundant metals in nature, constituting from ten to twenty per cent. of all varieties of clay, in the form of silicates. No method has, up to the present, been forthcoming for the economical reduction of aluminium silicates, and the metallurgist has consequently to fall back upon bauxite, a hydrated alumina, which is found in France, Ireland, and the United States; and cryolite, the native double fluoride of aluminium and sodium, which has the formula, $6NaF.Al_2F_6$. The principal source is Arksut Fiord, West Greenland. These two substances are at present the most suitable raw materials for the production or separation of metallic aluminium.

Modern progress in aluminium manufacture has indicated the desirability of dispensing with a carbon cathode, and employing the molten metal itself in its stead. The yield is about 1 kilogramme per 14 k.w. hours, the power being only a small item in the total cost of manufacture.

The principal expense is entailed in the preparation of the pure alumina from crude bauxite, a process which accounts for fully 40 per cent. of the total cost of manufacture. Crude bauxite contains iron, silicon, titanium, and several other undesirable impurities.

The heat of formation of Al_2O_3 is 392,600 Calories; therefore, according to Thomson's rule, a minimum E.M.F. of 2·8 volts is required at the terminals of the aluminium furnace in order to bring about the separation of the metal from its compound, alumina. This voltage, multiplied by the number of coulombs passed through the furnace, represents the electrical energy which is, during the reaction,

converted into chemical energy, and stored, as such, in the metallic aluminium. It may, when desired, be converted into heat energy by causing the aluminium to again enter into combination with oxygen, as, for example, in the " Thermite " process.

The electrical reduction of aluminium from alumina was first effected at Cleveland, Ohio, U.S.A., the site of the Cowles Electric Smelting and Aluminium Co. The Cowles syndicate was organized in 1886, at Stoke-on-Trent, where electric smelting works were erected. It was re-organized in 1894 as the British Aluminium Company, with works at the Falls of Foyers, in Scotland.

Electrolytic processes for the manufacture of aluminium were patented during the period 1886–1887, by Hall in America, and Heroult in England and France. It was worked on a commercial scale at Pittsburg by Hall as early as 1888.

According to Roberts-Austen, the cost of purified alumina, as manufactured from bauxite, constitutes 45 per cent. of the total cost of aluminium manufacture. Crude bauxite often contains, in addition to alumina, oxides of iron, silicon, and titanium.

One of the disadvantages of the Bayer process (described further on) for extracting alumina from bauxite, lies in the presence of sodium carbonate, one of the auxiliary compounds necessary to bring about the initial fusion. Once mixed with this compound, it is almost impossible to entirely eradicate it from the otherwise purified alumina.

Hall's process for the extraction of pure alumina from bauxite, patented in 1901, has led to the production of a grade of alumina, very different, both in appearance and characteristics, to that resulting from Bayer's method.

In the specifications relating to Hall's patents for the purification of bauxite, two processes are dealt with. The bauxite to be treated is represented as having the following composition—

Alumina	.	.	.	.	.	60 per cent.
Ferric oxide	.	.	.	.	.	18 ,, ,,
Silica	.	.	.	.	.	2-3 ,, ,,
Titanic oxide	.	.	.	.	.	3-4 ,, ,,
Water	.	.	.	.	.	17 ,, ,,

The first method consists, briefly, in calcining the bauxite, after which, from eight to ten per cent. of carbon is added, and the mixture fused in a carbon-lined electric furnace, with carbon electrodes. The fusion is maintained for about an hour, the current being either alternating or continuous. The outcome of thus heating the molten mass in the presence of carbon, is that the impurities are reduced, and sink to the hearth of the furnace in the form of an alloy.

If the percentage of iron present as an impurity be low, or the other impurities, silica and titanic oxide, correspondingly high, it is an advantage to add more iron to the fused mass, either as oxide, or in the metallic state, to aid the separation.

The second method is practically identical, in principle, with the first, the only difference being the substitution of metallic aluminium for carbon as the reducing agent. As before, a preliminary analysis of the bauxite is made, and sufficient aluminium added to combine with the whole of the oxygen known to be present as a constituent of the various impurities. The mass is then subjected to fusion in the electric furnace for about one and a half hours, during which the latter separate out, as in the previous case, but without evolution of gas. The same procedure, in the event of a low iron content, should be adopted here, as in the first case, and the iron may conveniently be associated with the added aluminium in the form of a powdered alloy containing about 50 per cent. of each metal.

The theoretical output of aluminium at maximum efficiency is 2·85 kgs. per 1 k.w. per 24 hours. In actual practice, however, the efficiency of the process is very low, and ·6 kg. of aluminium per k.w. day is probably nearer the mark.

About 2 kgs. of anhydrous alumina are required for the manufacture of 1 kg. of metallic aluminium, from which it will be seen that the cost of the raw material is no inconsiderable item in the total cost of manufacture. The consumption of carbon electrodes is also a source of expense, the theoretical figure, 66 per cent. of the weight of aluminium manufactured, usually increasing, in practice, to 100 per cent., or weight for weight with the metallic product.

The following are two estimates of the cost of aluminium manufacture, the latter being based on the Hall process—

	Per Kilogramme of Aluminium.
Power	4·8d.
Alumina	8·8d.
Carbon electrodes	4·4d.
Labour, superintendence, interest on, and repairs to furnaces	4·4d.
Total	22·4d.
Power	4·6d.
Alumina	13·9d.
Carbon electrodes	3·5d.
Miscellaneous	1·3d.
Total	23·3d.

There is one important point in connexion with the electrolytic manufacture of aluminium, and that is the necessity for maintaining that difference between the specific gravities of the liberated metal, and the fused electrolyte, which will ensure their occupying correct relative positions in the furnace, or, in other words, to keep the aluminium at the bottom.

The following table, published by Richards, shows the specific gravities of the various substances employed in aluminium manufacture, in both a fused and solid state, and it will be seen that the margin of weight, causing the liberated aluminium to remain at the bottom, is not great.

SPECIFIC GRAVITIES.

	FUSED.	SOLID.
Commercial aluminium . . .	2·54 . .	2·66
Commercial Greenland cryolite . .	2·08 . .	2·92
Cryolite saturated with alumina . .	2·35 . .	2·90
Cryolite mixed with aluminium fluoride in the proportion indicated by the formula $Al_2F_6 \cdot 2NaF$ . . .	1·97 . .	2·96
The above saturated with alumina .	2·14 . .	2·98

In the *Zeitschrift für Elektrochemie*, January 2 and 9, 1902, were published some details of laboratory experiments, carried out by Messrs. Haber & Geipert in regard to the electrolytic production of aluminium.

The object of the experiments was to determine the actual E.M.F., current density, etc., necessary to bring about the reaction. They were carried out in the laboratory of the Technical College at Karlsrühe, the apparatus employed being a small carbon crucible, with a central carbon anode arranged axially therein. In this furnace the authors succeeded in obtaining metallic aluminium from an electrolyte, consisting of a mixture of two-thirds aluminium and sodium fluorides, and one-third alumina, the current employed being from 300 to 400 ampères at 7 to 10 volts, representing a current density of 3 ampères per square centimetre.

The central anode was gradually raised as the operation proceeded, whilst the high percentage of aluminium fluoride present rendered the bath very fluid.

The resultant metal contained only 0·05 per cent. carbon and 0·034 per cent. silicon, and had a tensile strength of from 13·7 to 17·3 kgs. per square millimetre.

In 1903, there were, according to Kershaw (*Electrical Review*, March 20, 1903), nine factories engaged in the production of aluminium, either by the Hall or Heroult process; they are located as follows : America, 3 ; United Kingdom, 1 ; France, 2 ; Germany, 1 ; Switzerland, 1 ; Austria, 1.

The aggregate power available at these several factories is between 36,000 and 40,000 H.P., all derived from water.

A reliable estimate places the output for 1901 and 1902 of the :

	1901		1902	
Six European works, at .	. 4,000	tons .	. 3,800	tons
Three American works, at	. 3,240	,, .	. 4,200	,,
Totals .	. 7,240	,, .	. 8,000	,,

In November, 1902, the prices of the Pittsburg Reduction Company were as follows—

No. 1 Metal, guaranteed over 99 per cent.	$16\frac{1}{2}d.$ to $18\frac{1}{2}d.$ per lb.	
,, 2 ,, ,, ,, 90 ,, ,,	$15\frac{1}{2}d.$,, $17d.$,, ,,	
Nickel-aluminium alloy (less than 10 per cent. nickel)	$16\frac{1}{2}d.$,, $19\frac{1}{2}d.$,, ,,	
Powdered aluminium . . .	$45d.$,, $50d.$,, ,,	
Aluminium castings	$22\frac{1}{4}d.$,, ,,	

All the above prices were subject to discounts ranging from 10 to 15 per cent., whilst European competition is stifled by an import duty of $4d.$ per lb. on ingot metal, and $6\frac{1}{2}d.$ per lb. on sheet.

American prices for aluminium rod and wire, ranged from $19d.$ to $26d.$ per lb., according to gauge, a rebate of $1\frac{1}{2}d.$ to $2d.$ being allowed off list price, according to the magnitude of the order.

The (1903) prices of the British Aluminium Company were as follows—

Ingot metal (guaranteed over 99 per cent. aluminium) .	$16\frac{1}{2}d.$ per lb. less	$7\frac{1}{2}$ per cent.	
Ingot metal (98 to 99 per cent.)	$15d.$,, ,, ,,	$7\frac{1}{2}$,, ,,	
,, ,, (No. 4 alloy)	$15d.$,, ,, ,,	$2\frac{1}{2}$,, ,,	
,, ,, (No. 6 alloy) .	$13\frac{3}{4}d.$,, ,, ,,	$2\frac{1}{2}$,, ,,	
Wolframinium alloy . .	$17\frac{1}{2}d.$,, ,, ,,	$2\frac{1}{2}$,, ,,	
Aluminium wire, Nos. 1–14 S.W.G. . . .	$23\frac{1}{4}d.$,, ,, ,,	$2\frac{1}{2}$,, ,,	

The American output of aluminium is controlled by the Pittsburg Reduction Company, with two factories at Niagara Falls, and one at Shawinigan Falls.

The European manufacturers are the Aluminium Industrie Aktien-Gesellschaft, with works at Neuhausen, Rheinfelden, and Lend Gastien ; the Société Electrométallurgique Fran-

çaise, with works at Froges and La Praz ; and the Compagnie des Produits Chimiques d'Alais, with works at St. Michel, France. The only British concern engaged in the industry is the British Aluminium Company, with works at Foyers, N.B.

The United States, represented by the Pittsburg Reduction Company, who control the whole of the patents therein, is, of course, the principal producer. It has in operation at Niagara Falls, plant utilizing some 11,000 H.P., and at Shawinigan Falls, Quebec, operating under the title of the Royal Aluminium Company, 5,000 H.P., the two works being capable of manufacturing 4,500 tons of aluminium per annum. In addition, the former Company has lately purchased a site at Massena, New York, where it is installing a plant of 12,000 H.P.

The British Aluminium Company employs the Heroult process, and has an available plant of 14,000 H.P. The Heroult process is also exploited by the Société electrométallurgique Française, at La Praz. The Compagnie des Produits Chimiques d'Alais, at St. Michel, employ the Hall and Minet process, whilst the Aluminium Industrie Aktien-Gesellschaft, with an aggregate of 14,000 H.P., also utilises the Heroult process.

The following table represents the production of aluminium in the United States, from 1883 to 1902, inclusive.

YEAR.			POUNDS.	YEAR.			POUNDS.
1883	.	.	.	83	1893	.	.	333,629
1884	.	.	.	150	1894	.	.	550,000
1885	.	.	.	283	1895	.	.	920,000
1886	.	.	.	3,000	1896	.	.	1,300,000
1887	.	.	.	18,000	1897	.	.	4,000,000
1888	.	.	.	19,000	1898	.	.	5,200,000
1889	.	.	.	47,468	1899	.	.	6,500,000
1890	.	.	.	61,281	1900	.	.	7,150,000
1891	.	.	.	150,000	1901	.	.	7,150,000
1892	.	.	.	250,885	1902	.	.	7,300,000

The Heroult Process.—In the Heroult process of aluminium manufacture, the lining of the furnace hearth is protected

from electro-chemical action by a layer of cooled, solidified electrolyte.

The voltage theoretically required to bring about the electrolysis of the alumina in the Heroult process, is 2·2. Very good quality carbon is required for the anodes, which are, of course, consumed in the process, and, if at all impure, would tend to contaminate the resultant metal.

The bauxite used in the manufacture of aluminium by the Heroult process at Foyers, is obtained from Larne, in Ireland, and, according to Blount, has the following percentage composition—

Alumina	.	.	.	.	.	.	.	56 per cent.
Ferric oxide	.	.	.	.	.	.	3 ,, ,,
Silica	.	.	.	.	.	.	12 ,, ,,
Titanic acid	.	.	.	.	.	.	3 ,, ,,
Water	.	.	.	.	.	.	26 ,, ,,

100

The method of preparing alumina from this, being an essential part of the Heroult process of aluminium manufacture, a brief description, extracted from *Practical Electro-Chemistry*, by Bertram Blount, is included.

" The material is crushed so as to pass a quarter-inch mesh sieve, and is gently roasted in a revolving calcining furnace, the temperature being regulated so as to destroy any organic matter, and ensure that all iron shall be present as Fe_2O_3, and nevertheless not to render the alumina insoluble. The roasted material is powdered so as to pass a sieve having thirty meshes per linear inch, and is digested with a solution of caustic soda of specific gravity 1·45 at a pressure of 70 to 100 lbs. per square inch. After digestion for two or three hours, the solution is diluted to a specific gravity of 1·23, and is passed through filter presses, and afterwards through cellulose filters, consisting of sieves carrying a layer of cellulose pulp, the whole contrivance somewhat resembling the laboratory apparatus known as a Gooch crucible. By this double filtration a satisfactory,

clear liquor is obtained. In former processes for the manufacture of alumina, the alkaline aluminate was decomposed with CO_2, and the alumina was thus precipitated. The disadvantage of this process, apart from the cost of the CO_2, is, that any silica present in solution is also thrown down and contaminates the alumina, and, moreover, the alkali is converted into carbonate, and has to be recausticised before it can be used again for extraction. By Bayer's process, which is that now in use, the caustic solution of alumina is treated with a small portion of alumina, precipitated in a previous operation ; it is thereby caused to deposit about 70 per cent. of its dissolved alumina, if the solution is well agitated and the precipitation allowed to continue for about 36 hours. The clear liquor is drawn off, and the alumina washed in a filter press, and dried to some extent by a blast of air, being then roasted at about $1,100°C. = 2,012°F.$, in order to render it both anhydrous and non-hygroscopic. The latter quality is necessary, as otherwise the alumina would absorb water during storage, and would not be fit to feed into the electrolytic cell.

" The caustic soda solution, diluted by retaining a portion of its alumina, is concentrated in a triple effect vacuum evaporator, to its original specific gravity of 1·45, and is then ready for the extraction of another portion of bauxite. It will be seen that the caustic soda serves merely to pick out the alumina from its accompanying impurities, and to deposit it, as it were at the word of command, in a pure state."

The Heroult furnace in use at Foyers consists of a square iron casing A, Fig. 43, lined with carbon C, and containing the cathode F, which, in the form of a cast-iron plate, rests on the bottom ·of the furnace, and is connected externally with the source of current. The anode consists of a bundle, or fagot of carbon rods B suspended over the furnace cavity and adjustable as to its height and consequent depth of immersion therein.

The furnace is first filled with cryolite, which is speedily fused when the current is switched on, after which powdered alumina is fed in at a regular rate. The difference of potential between the furnace terminals is from 3 to 5 volts, the metallic aluminium collecting at the negative electrode, whilst oxygen gas is set free at the positive, or carbon electrode, with which it enters into combination, forming the gases monoxide and dioxide of carbon. The Current density is 1·9 ampères per square centimetre of cathode surface, amounting to about 8,000 ampères per furnace, and the temperature at which the operation is carried out varies from 750° to 850°C.=1,382° to 1,562°F.
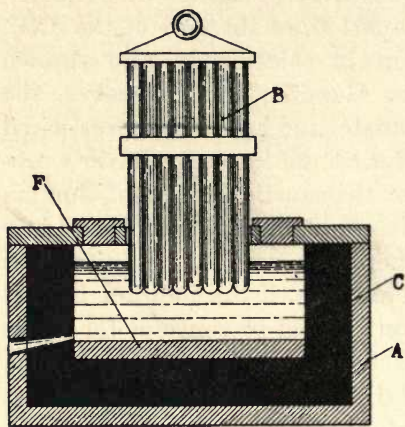
FIG. 43.

The electrolyte employed in the Heroult process consists of a mixture of—

Fluoride of calcium . . .	234 parts by weight.
Double fluoride of aluminium and sodium (cryolite) . . .	421 ,, ,, ,,
Fluoride of aluminium . . .	845 ,, ,, ,,

From 3 to 4 per cent. of a suitable chloride, that of calcium, for example, is added, together with sufficient alumina to form a very stiff mixture.

The Hall Process.—The distinguishing features between the Heroult and Hall processes may be regarded as almost entirely of a mechanical nature, including the method of operation, and such minor details incidental thereto as are essential to the efficiency of the process.

THEIR INDUSTRIAL APPLICATIONS

Mr. Chas. M. Hall, the originator of the aluminium process now exploited by the Pittsburg Reduction Company, first experimented with his process at the works of the Cowles Electric Smelting and Aluminium Company, Lockport, New York, U.S.A.

The furnace hearths are of cast iron, lined interiorly to some considerable thickness with carbon ; they are 6 ft. long by 3 wide by 10 in. deep, and constitute the cathode. The anodes consist of a number of carbon rods, mounted in a special holder, and immersed, at their lower extremities, in the molten electrolyte. Each individual unit of the anode carries a current of 250 ampères, and the total current required for the operation is in the neighbourhood of 10,000 ampères.

The E.M.F. is 5 volts, the power consumed being approximately 65 H.P. The furnaces are worked in series.

The process consists in the electrolysis of purified alumina, dissolved in a molten bath of the double fluoride of aluminium and sodium ($Al_2 F_6.2NaF$). The inventor has published the following data relating to the cost of the materials for the process of aluminium manufacture patented by him—

Alumina	$2\frac{1}{2}d.$ to $3d.$ per pound.
Cryolite	$3d.$,, .,
Hydrofluoric acid . . .	$2d.$ to $2\frac{1}{2}d.$,, ,,
Carbon for lining furnace hearths	$1\frac{1}{2}d.$,, $2d.$,, ,,

The electrolyte used in the Hall process is prepared in a lead-lined vat, by treating a mixture of alumina, cryolite, and fluorspar with hydrofluoric acid ; the mass is then dried and placed in the furnaces, where it is subjected for some time to the heating action of the current, in order to reduce it to a state of complete fluidity before the alumina is fed in.

The proportions most commonly used are—

Aluminium fluoride . . .	677	parts by weight.
Sodium ,, . . .	251	,, ,,
Calcium ,, . . .	234	,, ,,

When fusion has been completely effected, pure alumina

is fed in, in the proportion of 20 per cent. by weight of the solvent, and the like proportion maintained as the operation proceeds. The temperature at which the Hall furnace operates is below $982°C. = 1,800°F.$

The Pittsburg furnaces are tapped once a day, the removal of the molten metal being accompanied by a corresponding increase in the electrical resistance of the furnace charge. Visual indication of the increased resistance is obtained by means of an ordinary incandescent lamp, which is connected in shunt between the electrodes, and, by its increased brilliancy, indicates that the resistance of the fused electrolyte is rising and that fresh alumina must be fed in.

The following rules, to be observed in the thermo-electrolytic manufacture of aluminium, have been formulated and published by Mr. Hunt, President of the Pittsburg Reduction Company.

(1) The solvent, with its dissolved alumina, must be fusible at a moderate temperature.

(2) The solvent must dissolve alumina freely, e.g., must take up at least 20 per cent. at the working temperature.

(3) The critical voltage for the solvent must be higher than that for the alumina.

(4) The specific gravity of the solvent at its working temperature must be lower than that of the aluminium at the same temperature, so that the metal may collect at the bottom of the cell.

Extended litigation has resulted in the Cowles and Bradley patent claims in the manufacturing process, being upheld in the United States Courts, with the result that the Pittsburg Reduction Company is now reported to be under a working agreement with the owners of these patents as to royalties, etc.

Theoretical Considerations.—M. Gustav Gin contributed a theoretical paper on the subject of aluminium manufacture at the Fifth International Congress of Applied Chemistry, the salient features of which may be summarised as follows—

According to Minet, the physical conditions of the fused electrolyte employed should be—

(1) Low fusion point.

(2) Sufficient fluidity during the process to permit the molten aluminium to separate out.

(3) Fusion density to be lower than that of aluminium.

(4) Low vapour tension, and low ohmic resistance.

From a chemical point of view, and for a minimum expenditure of energy, the aluminium compound selected for electrolysis should have a low heat formation value. The E.M.F. required for the electrolysis of fused aluminium compounds may be divided under two headings, viz.—

(1) That necessary to overcome the ohmic resistance of the fused electrolyte, and the polarisation of the electrodes, and secure the required current density, and—

(2) That required to effect the electrolysis and bring about the discharge of the ions.

The first is easily obtainable, whilst the second is a function of the heat of formation, and can also be arrived at by calculation. Minet has proved experimentally that, at the temperature of the molten mass in the aluminium extraction process, aluminium fluoride is completely dissociated into its constituent elements. The following thermal equation therefore applies—

$$Q = J_F + J^{Al\frac{1}{3}}$$
$$= 50,750 + 40,100 \text{ C. gr. d.}$$
$$= 90,850 \text{ C. gr. d.}$$

from which, since 23,067 C. gr. d. are equivalent to one volt, we get $E = 3.93$ volts.

Assuming the fluorine thus liberated enters into combination with carbon at the anode to form carbon-tetrafluoride (CF_4), the equation then becomes—

$$Q = J_F + J^{Al\frac{1}{3}} - J(CF_4^{\frac{1}{4}})$$
$$= (50,750 + 40,100) - 33,400$$
$$= 57,450 \text{ C. gr. d.}$$

from which, $E = 2.49$ volts, a value more nearly in agreement with that obtained experimentally by Minet (2.5 volts).

Passing on to a consideration of the electrolysis of alumina, we have

$$Q = Jo^{\frac{1}{2}} + J^{Al\frac{1}{2}} - J(CO^{\frac{1}{2}})$$
$$= (34,950 + 40,100) - 24,400$$
$$= 50,650 \text{ C. gr. d.}$$

and $\qquad E = 2.19$ volts.

The above calculations have been experimentally confirmed by Gin, who obtained the figure, 2.30 volts, as the mean of four observations in Le Blanc's method of determining potential differences.

The thermal equation for aluminium sulphide is :

$$Q = Js^{\frac{1}{2}} + J^{Al\frac{1}{2}} - J (C^{\frac{1}{2}} S^{\frac{1}{2}})$$
$$= (-6,300 + 40,100) - 4,350$$
$$= 29,450 \text{ C. gr. d.}$$

or $\qquad E = 1.27$ volt.

From these data we arrive at the energy required to produce one kilogramme of aluminium from any of the three compounds mentioned. They are as follows—

$$Al_2F_6 = KF + 8.5 \text{ K.W. Hours}$$
$$Al_2O_3 = Ko + 7.5 \text{ ,, ,,}$$
$$Al_2S_3 = Ks + 4.4 \text{ ,, ,,}$$

where KF, Ko, and Ks are quantities varying between 16 and 19 k.w.

The difference in the energy required by any of these three compounds does not therefore exceed 5 k.w. hours per kg. of aluminium produced, and M. Gin therefore concludes that any future improvement in the economy of aluminium manufacture will depend upon the cost of the raw materials, and not upon a corresponding improvement in the efficiency of the process itself.

Chlorine Smelting with Electrolysis.—The Swinburne-

Ashcroft or " Phœnix " process of so-called chlorine smelt-
ing, which is the joint invention of Mr. Jas. Swinburne,
M.I.C.E., and Mr. E. A. Ashcroft, is a cyclic process for
obtaining various metals from their ores, which can be con-
ducted with little or no loss, and has, therefore, a promising
future in competition with the present wasteful methods
of smelting by reduction processes.

It is appropriately called " chlorine smelting," because
chlorine is the vehicle employed to displace the sulphur
from the sulphide ores under treatment, only to be re-
covered by a subsequent stage in the process, and used over
again.

Various papers and articles dealing with the process have
been published from time to time, including a recent one
by Mr. Swinburne himself, read before the Faraday Society
on June 30, 1903, which deals mainly with the financial
aspect of the process.

The principal features are as follows : The process con-
sists in three main stages, which are thus rendered by Mr.
Swinburne in the form of chemical equations. Employing
the usual chemical symbols for zinc, chlorine, and sulphur,
and substituting M and N for other metals present in mixed
sulphide ores, Stage I. is represented by the equation—

$$ZnS + MS + NS + 3Cl_2 = ZnCl_2 + MCl_2 + NCl_2 + 3S.$$
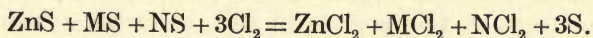
Stage II., after the removal of the sulphur, by—

$$ZnCl_2 + MCl_2 + NCl_2 + 2Zn = 3ZnCl_2 + M + N$$
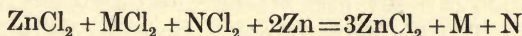
and, finally, Stage III., consisting in electrolysis of the zinc
chloride—

$$3ZnCl_2 = 3Zn + 3Cl_2$$
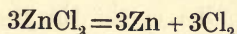
To put it briefly into words, the process consists in first
treating the sulphide ores with chlorine, which displaces
the sulphur, and itself enters into combination with the
metals thus set free to form chlorides, which latter are
then subjected to electrolysis, whereby the metal is sepa-

rated out, and the chlorine recovered, to be used over again.

Take galena as an example.   It may or may not contain silver, and even gold.   It is first treated with chlorine in the presence of heat, which leads to the formation of lead chloride and sulphur, the latter being thrown down or condensed in the form of brimstone, whilst the former, if it be known to contain admixtures of the precious metals, is again treated with metallic lead, which replaces them. The precious metals, if present, form an alloy with the excess of metallic lead present, producing a metallic mixture of any desired richness, limited only by its melting point.

With the exception of a slight loss, which arises in practice, out of the leakage of air into the vats, forming sulphur dioxide, the sulphur is also saved.

The process is precisely similar with other ores, or mixtures of ores, and is especially applicable to such refractory samples as have hitherto presented untold difficulties to the metallurgist.

Though consisting partly in a thermo-chemical, and partly in an electrolytic process, or combination of processes, and therefore not coming, in its entirety, strictly under the category of electrolytic furnace methods, it will be necessary to treat of the process in full, in order to render it clear to the reader.

The crude ores are first crushed, and then fed into a receptacle, called for convenience a transformer, and resembling in general appearance a small blast furnace.   It is constructed of iron, and lined with fire-clay.   Like a blast furnace, it has a small cone at the top, whilst an opening at the base, fitted with a carbon tube, serves for the introduction of the chlorine.   Outside the transformer, connexion is made between this tube and an iron pipe, which conveys the chlorine to it.   The action of the apparatus is continuous, and we will assume that it is partly filled with fused chlorides, and gangue floating on top.

Fresh ore is fed in at the top, and, simultaneously, chlorine is pumped in at the base by way of the iron pipe and carbon tube. It bubbles up through the fused mass, and in its passage combines with the metals present to form chlorides, liberating the sulphur, which passes off as a vapour, and is suitably condensed.

This chemical action produces a great deal of heat, which serves to maintain the contents of the apparatus at the necessary fusion temperature, and thus render it self-heating. The temperature regulation is an important point ; if it be too low, chloride of sulphur is formed, while, on the other hand, if it be too high, some of the chlorides distil over, and are condensed with the sulphur. It is regulated within the limits of practice, which allows a fairly wide margin, by controlling the rate of admission of the chlorine. The size of the transformer is also a controlling feature, and must be such that, when running at full load, sufficient heat is driven off by conduction, and radiation from the outer surface, to keep the contents at or about the required temperature.

In treating Broken Hill slimes, which have already been tried, for purposes of experiment, by Messrs. Swinburne and Ashcroft, a transformer, having a capacity of 10 tons, was successfully employed, but Mr. Swinburne ventures the opinion that a larger size, with thinner lining, would probably yield improved results.

Visual indication as to the state of the transformer contents during the progress of the operation, and whether a further supply of ore is required, may be secured by making a hole at the top of the transformer. The sulphur vapour and gaseous products in passing over through the legitimate outlet to the condensers and chimney create a slight indraft of air at this opening, with the result that sulphur dioxide is formed, and burns with a blue flame. This latter indicates that all is well, and that sufficient ore is present. If there be an insufficiency of ore in the transformer, fumes

of ferric chloride are formed at the top of the chamber, and pass over with the sulphur vapour ; it is necessary to avoid this contingency, and the ore feed must consequently be watched until the process is completed.

When the transformer is full, the supply of ore is stopped, but the process is continued until brown fumes begin to make their appearance. The charge is then tapped off, and permitted to cool.

The intermediate or chemical stage of the process varies with the ores under treatment, depending naturally upon the metals present. It is best described in Mr. Swinburne's own words, the Broken Hill slimes being again taken as an example.

" We now come to the intermediate or chemical stage of the process. This varies with the ore used. We may take the Broken Hill slimes, and imagine there is copper too. This would be about as troublesome an ore as we could have. We have used the Broken Hill ore, and mixed it with a Tasmanian copper ore, but we have chiefly worked on it alone. The fused mass from the transformer consists of chlorides of lead, zinc, iron, manganese, copper, silver and gangue. It is run into water, and through a filter press when cool enough. This takes out the gangue and lead chloride, carrying most of the silver. The gangue is easily separated from the lead and silver chlorides, and these chlorides are then dried and fused in contact with lead, which extracts the silver and any gold ; and then with zinc, which gives lead, practically pure, and anhydrous neutral zinc chloride, which is ready for the electrolysis vats.

" The filtrate from the press contains a little lead and silver, in solution, and copper, iron, manganese, and zinc. The lead and silver are taken out with spongy copper. The copper is taken out as sponge or ' cement ' by zinc, and we have left iron, manganese and zinc chlorides.

" The iron is chlorinated up to the ferric state, and zinc

oxide is added to cause precipitation. This throws down hydrated ferric oxide. This is the base of iron paint, and is marketable, its value depending on the colour obtained. The solution is further chlorinised in the presence of more zinc oxide, and the manganese goes down as peroxide.

" We have now substituted zinc for all the other metals in their chlorides, and have nothing left but zinc chloride. This is evaporated down carefully, and fused. This decomposes some of the chloride, and makes an oxychloride. Steinhart evaporates *in vacuo*, to produce neutral anhydrous zinc chloride. We have not done this ; we find that with cautious boiling down there is not much oxygen in the final result.

" This is got rid of in open preliminary vats, which use inexpensive anodes, which are gradually used up. The consumption is less than if all the oxygen went off as monoxide. The anhydrous neutral chloride from these vats is then added to that from the lead chloride substitution, and is taken to the final electrolysis vats."

The final stage, which constitutes the part actually played by the electrolytic furnace, has for its object, as before stated, the final separation of the remaining metal (zinc), and the recovery of the chlorine.

The furnace itself is a very simple affair, consisting of an iron chamber, lined with fire-brick ; in course of time the fused chloride permeates the pores of this lining, and solidifies therein, so that, in reality, the lining itself ultimately becomes one of chloride.

The cathode is of fused zinc, and the anode of carbon, which latter is not attacked by chlorine. Some care is necessary in the selection of a suitable grade of carbon, but, once found, the anodes stand extremely well, and are permanent, the temperature not being sufficiently high to cause combustion.

In practice, a slight suction is kept on the furnace during

the electrolysis, so that, if there be any leakage, it is in the nature of ingress of air rather than egress of chlorine.

In the experiments which have been conducted up to the present, a comparatively small furnace, consuming 3,000 ampères, has been used ; but a 10,000 ampère furnace is being tried, this being the maximum current density which can conveniently be dealt with. An electromotive force of approximately 4 volts per furnace is necessary to maintain the action.

The furnace used in the experimental trials of the process, carried out at the old Cowles Aluminium works at Milton,
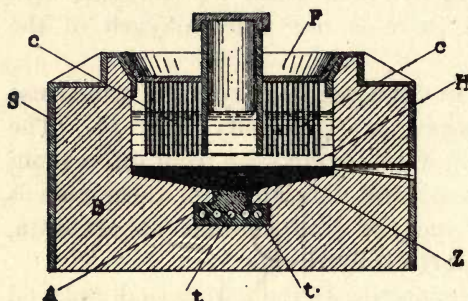
FIG. 44.

Staffordshire, is illustrated in section in Fig. 44. It consists of an outer steel shell S, 6 ft. in diameter, lined for a depth of 18 in. with fire-brick, the inner layers being set in a special cement. The brickwork B forms a cylindrical chamber or hearth H, at the bottom of which is placed the cathode Z, in the shape of a mass of molten zinc, weighing approximately one ton. Electrical connexion with this latter is secured by means of a massive steel block A let into a recess in the brickwork, and connected with the external circuit by fire screwed copper tubes *t t*, which are also made part of a system through which air is caused to circulate for cooling purposes. F is the anode, and consists of an iron cover plate grouted in place with a special heat-resisting cement, and serving as a terminal support for 120 2½-inch hard carbon rods *c c*, which are submerged in the molten electrolyte to a depth of about six inches.

The current required to operate a furnace of this descrip-

tion is from 3,000 to 4,000 ampères at 4 to 4·5 volts, the working temperature being 475°C = 887°F., and the output one ton of metallic zinc per week.

The cost of working the process is, roughly, 30s. per ton of ore, plus the cost of the electrical energy.

Sodium and Caustic Soda.—Dr. Rogers, as early as 1889, studied the possibilities of preparing lead-sodium alloys by electrical means, and actually succeeded in manufacturing an alloy containing 17 per cent. of sodium, by the electrolysis of fused sodium chloride in a 30 lb. crucible. A lead cathode was employed, and the process called for an expenditure of 72 ampères at 21 volts for a period of 2 hours.

To this investigator belongs the credit of having first suggested a basic lining for the furnace used in the electrolysis of fused sodium chloride.

Dr. Borchers's process of sodium extraction by deposition of the metal upon a flowing stream of lead involved a current density of 3·2 ampères per square inch of cathode, the E.M.F. being 6 to 8 volts.

C. T. J. Vautin's process was originally based upon an attempt to obtain caustic solutions and chlorine, but, owing to certain natural and unforeseen tendencies on the part of the various constituents of the electrodes and electrolyte, the system, when tried at Keighley, Yorkshire, in 1893 to 1894, proved commercially impracticable.

Vautin, however, suggested the maintenance of fusion of the electrolyte by electric heat, and both this suggestion, and that of Dr. Rogers concerning basic linings for the furnaces, constitute two at least of the essential features of Acker's successful solution of the problem.

The Vautin process consisted in the electrolysis of fused sodium chloride, employing a lead cathode, which was intended to alloy with the sodium at the moment of liberation, and thus protect it from further action, electrolytic or otherwise.

The practical difficulties which led to the abandonment of the process were the destruction of the containing vessel by the combined action of the contents at high temperatures, and the failure of the cathode surface to remain active once the action had been started, owing to the formation of a crust of the lead-sodium alloy, which impeded further combination between the two metals ; the sodium subsequently set free either burning away on rising to the surface of the fused electrolyte, or re-combining with the nascent chlorine to form sub-chlorides.

Leon Hulin, in 1890, commenced experimenting at Môdane, France, independently of Vautin, and without knowledge of what had already been accomplished in the igneous electrolysis of sodium chloride. In order to get over the crust formation difficulty, which led to the failure of Vautin's process, a compound electrolyte was employed, containing a definite proportion of lead chloride. Electrolysis resulted in the simultaneous liberation of lead and sodium at the cathode, which immediately combined to form the alloy, and, in this condition, were immune from the action of the chlorine set free at the anode.

The electrolyte consisted of the mixed chlorides of lead and sodium, whilst the anodes were also compound, consisting of carbon and lead, the latter, or metallic portion, being connected in circuit with a controlling resistance or rheostat, by means of which the proportion of the main current passing through it could be controlled, and the amount of lead dissolved and deposited similarly governed.

The Hulin process has been worked on a limited industrial scale at the paper works of MM. Matussière et Forest, Môdane. Four furnaces were employed, the terminal E.M.F. of each being 7 volts, and the current density between 1·5 and 2·5 ampères per square centimetre of cathode surface. The best results were obtained with a current density of 1·9 ampères per square centimetre. A composite lead-carbon anode was used, the metallic portion

only conveying a fraction (12 per cent.) of the total current, and by its combination with the chlorine liberated serving to maintain the requisite proportion of lead chloride in the electrolyte. The yield per k.w. hour is said to have been 108 grammes chlorine, and 72 grammes sodium, or 2·48 kgs. chlorine, and 1·66 kgs. sodium per k.w. day of 23 hours.

According to Kershaw, the theoretical voltage required in the process is 4·2, and the yield, per k.w. hour, 356 grammes of caustic soda and 314 grammes of chlorine. Against these may be set the actual figures obtained in practice, viz., 7, 150, and 129,
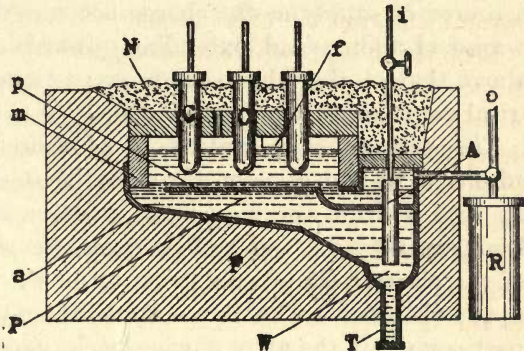
Fig. 45.

respectively, showing a current efficiency of 69·3, and an energy efficiency of 41·5 per cent.

The Acker electrolytic furnace, for the manufacture of caustic soda from fused electrolytes, as exploited by the Acker Process Company at Niagara Falls, is shown in diagrammatic section in Fig. 45. It consists, essentially, of a rectangular trough-like structure or hearth F, having a steel base s, refractory side walls m of magnesia, and a removable horizontal false bottom, or dividing partition p, also of steel. A flue f provides for the escape of the chlorine gas evolved during the process, which may be used for the manufacture of bleaching powder, whilst one end of the structure slopes to a well W fitted with an injector A, for the introduction of steam under pressure. The catho-

dic or negative electrode connexion with the source of current is made through a metal tube T communicating with the well W. The anodes C C are cylindrical graphite rods, projecting vertically through the cover to within a short distance of the steel partition p. N is a mass of the raw material, sodium chloride or common salt, which is packed on top of the furnace, and performs a triple duty, viz., that of conserving the heat generated, hermetically sealing all except the legitimate gas outlets, and providing a source of supply as the charge becomes exhausted. P is a mass of molten lead, extending upwards to a level slightly above that of the false bottom, or partition p, and in electrical connexion with the cathode.

The process of operation is as follows : Steam being admitted to the injector through the inlet pipe i, carries up with it, from the base of the injector well, a mixture of lead, caustic soda, and hydrogen gas, the resultant products of the electrolytic process going on in F. On reaching the upper chamber above the well, W, these three constituents part company, the alloy flowing back, over an inclined partition, into the main furnace F, whilst the caustic liquid passes over into the receiver R. Hydrogen gas is available at the outlet o, and may be utilized for a variety of purposes, chief among which may be mentioned its application to an oxyhydrogen burner or burners for the preliminary fusion of the charge.

The following facts, in connexion with the Acker process, as carried on at Niagara Falls, were published by the inventor in the course of a paper read by him before the American Electro-Chemical Society at Philadelphia, in 1902. Each furnace has four anodes, and consumes a total current of 8,000 ampères or 2,000 ampères to each anode, representing a current density of 3 ampères per square centimetre.

The efficiency of the process is 100 per cent., and the works have been in continuous operation since 1900, with but few temporary accidental interruptions.

The only trouble experienced is said to have been in the electrode connexions at the carbon-copper junction, the metal being gradually corroded or eaten away. An improved method of construction has, however, minimised this drawback.

The anodes consist of graphitised carbon blocks, and are manufactured by the International Acheson Graphite Company. There are four to each furnace, each block having a section approximately 7½ by 14 inches, and carrying 2,000 ampères. They are unattacked by the electrolyte, the only weak point being the junction between the metal terminal clamps and the carbon. This is protected by a sleeve of basic cement.

The furnaces are lined with magnesite bricks, placed loosely in position, without cement, but held together firmly by the solidified electrolyte, which permeates them when in a fused condition, and, on solidifying, locks them rigidly together.

In 1902 Acker furnaces to the number of forty-five were in operation, consuming 3,250 E.H.P., or 8,000 ampères at 300 volts. Each individual furnace requires a current of 8,000 ampères at 7 volts terminal E.M.F., or 75 E.H.P., and produces, on an average, 290 kgs. of anhydrous caustic daily.

The successful conduct of the process consists in continuously removing the sodium alloy as quickly as it forms, the reason being that it is unstable in the presence of the fused salt.

The steam from the injector performs a double office, in that it sets up a rapid circulation, and also oxidises the sodium of the alloy formed, producing fused, anhydrous, sodium hydrate (NaOH).

The chlorine gas evolved during the process is drawn off by means of a fan, and utilized in the manufacture of bleaching powder. The furnaces are of cast iron, lined to a level above that of the fused lead ; they are arranged in pairs, one on either side of a common flue.

The Elliott-Cresson Medal of the Franklin Institute has been awarded to Mr. Chas. E. Acker for his electrolytic method of manufacturing caustic soda and chlorine as described above.

The advantages of the Acker process, as compared with other purely electrolytic methods, are thus epitomised by the Committee who recommended the award—

(1) Its directness.

(2) The very heavy current sent through each pot.

(3) The absence of the evaporation of caustic and boiling down to dryness.

(4) The absence of water solutions, requiring special pumps, and a complicated circulating system.

(5) The absence of mercury.

The disadvantages, on the other hand, are—

(1) A large power consumption, 6·75 volts, in place of 4·5.

(2) The rapid destruction of the apparatus.

(3) The rapid destruction of the anodes.

(4) The more arduous work of the pot-men.

Calculations on the part of the committee show the following distribution of the total energy required, throughout the various stages of the process—

54 per cent. is usefully applied to chemical separation of the sodium from the chlorine.

9 per cent. in fusing the salt.

Lost by radiation, 37 per cent.

In the later types of furnace for the application of the Acker process of caustic soda manufacture, a more rapid circulation of the fused lead is secured by means of a bladed propeller, which revolves at the bottom of the injector well. The effect of this additional feature is said to be a more concentrated product, in that less steam is required than was the case in the original apparatus, where it was depended upon to produce the requisite mechanical agitation of the lead.

Castner's sodium process consists in the electrolysis of

fused sodium hydrate. An iron pan, or crucible, contains the electrolyte, which is initially fused by a furnace below it. The cathode, of nickel, passes vertically up through an opening in the base, and is surrounded, at its upper extremity, by an annular anode, also of nickel. The fused condition of the electrolyte is partially maintained by an excess current, and, for the remainder, by the auxiliary combustion furnace. Sodium is set free, in liquid form, and rises to the surface of the molten mass, whence it is periodically removed.

Temperature regulation needs to be very exact, as, if the heating effect be only slightly in excess of that required, recombination of the liberated sodium takes place, and no metal is set free.

The current efficiency of the process is from 70 to 90 per cent., and it is in commercial operation at Runcorn, in this country, Niagara, U.S.A., and in Germany and France.

The Niagara plant consists of some 120 furnaces, each of which requires a current of 1,200 ampères, at an E.M.F. of 5 volts to operate it.

The total output of sodium in 1897 was 260 tons.

Commenting, in *Zeitschrift für Elektrochemie*, about the beginning of 1903, on the Castner process for the extraction of sodium, Professor Le Blanc and Herr Brode remark that neither the inventor nor those associated with the conduct of the process on an industrial scale understand exactly what goes on in the furnace during the reaction. They therefore conducted experiments with a view to ascertaining this, and summarise their results as follows—

(1) Molten sodium hydrate, containing water, shows two decomposition values : 1·3, and 2·2 volts. When water is absent, the lower of these two values disappears.

(2) At the lower E.M.F., hydrogen and oxygen are separated ; at the higher E.M.F., sodium and oxygen. The yield of oxygen is never quantitative, but it increases with the current. The yield of hydrogen is quantitative under

2·2 volts, so long as no free sodium is separated at the cathode. When no water is present in the hydrate as an impurity, only sodium is obtained, with an E.M.F. above 2·2 volts. This fact proves that pure molten sodium hydrate contains only the ions Na and OH, and that neither O nor H ions are present in the electrolyte.

(3) Molten caustic soda quickly arrives at a state of equilibrium as regards moisture exchanges with the atmosphere. Normally it contains a considerable amount of water ; if it contains no water, it is strongly hygroscopic.

(4) Molten caustic soda, containing free sodium as an impurity, yields hydrogen at the anode, in addition to oxygen, on electrolysis with high current densities. This evolution of hydrogen can only result from the separation and discharge of OH ions.

The same authorities are responsible for the statement that potassium cannot be similarly separated by electrolysis of its fused hydrate, as claimed in the Castner patent, but that oxidation has to be guarded against by depositing a layer of petroleum on the surface of the fused mass, when globules of metallic potassium are set free.

G. P. Scholl has improved upon the original method by effecting an economy in the current required, and, at the same time, eliminating the evolution of hydrogen, which takes place at the cathode in Castner's process. He adds to the fused electrolyte some 50 per cent. of sodium sulphide, and reduces the voltage of the operation to that required for the decomposition of the sulphide only ; theoretically, 1·8 volt. Sodium is, as before, set free at the cathode, whilst the liberated sulphur, reacting with the fused caustic, again forms sulphide of sodium, which is again electrolysed, and so the cycle goes on, fresh caustic being added from time to time in quantities proportional to the sodium set free. The process is said to effect a considerable economy in current, as compared with the original Castner method.

The *Fischer* process for the electrolytic manufacture of

sodium is represented diagrammatically in Fig. 46, where C, is a shallow crucible, or furnace hearth, divided into two portions by a central partition p, which does not extend quite to the bottom. The electrodes E E$_2$ are horizontally disposed, being introduced through the walls of the crucible. The anode E is a carbon rod, whilst the cathode E$_2$ is a metal tube, placed with its axis on a level with the surface of the fused electrolyte. The side of the crucible containing the negative tubular electrode E$_2$ is kept cool by a water jacket, not shown in the figure. The raw charge consists of a mixture of 79 parts by weight of potassium chloride, with 59 of sodium chloride, or common salt. The resultant s o d i u m contains an admixture of about 1 per cent. of potassium, and is drawn off through the tubular electrode E$_2$.
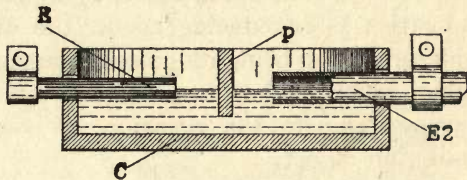
FIG. 46.

The *Darling* electrolytic furnace, which is employed in the manufacture of nitric acid and metallic sodium from nitrate of soda, is of comparatively simple construction. The anode consists of an outer iron vessel, within which are placed two concentric cylinders of perforated iron. A shunt connexion between these latter and the outer iron anode protects them from injury during the action of the furnace, whilst the space between the two perforated walls is filled in with powdered magnesia.

The fused salt, sodium nitrate, is contained within the inner of the two cylinders, the cathode, a carbon rod, being immersed in it. Nitric acid gas is set free in the outer space between the walls of the anode and the concentric cylinders, and is conveyed, by an outlet pipe, to condensing apparatus, where it is converted into the liquid acid. The sodium, on the other hand, rises to the surface of the fused

salt contained within the inner perforated cylinder, whence it is removed at intervals by means of a ladle, and placed in tin vessels containing a small quantity of paraffin, which effectually protects it from the action of the atmosphere. The fall of potential between the terminals of each furnace, whilst the operation is in progress, is 15 volts. A current of 400 ampères per furnace is required.

The Darling process is worked by Harrison Bros. & Co., of Philadelphia.

Calcium and Strontium.—Calcium, as is well known to the chemist and metallurgist, is of great value in various industries as a reducing agent, the only drawback to its widespread use being its present comparatively high market value, which renders it unsuitable for all but experimental purposes, where the question of cost is, within certain limits, no object.

The high price charged for the metal calcium is due to the expensive method of production, which consists in subjecting a dilute solution of calcium chloride to electrolysis in the presence of a mercury cathode ; an amalgam of calcium with mercury is thus obtained, from which the mercury is subsequently driven off by the aid of heat.

Apart from the cost of the process, pure calcium is never produced by this method, there being always a small percentage of metallic mercury present in the resultant product.

Messrs. Borchers and Stockem, recognising the need for a cheaper and more efficient method of production, turned their attention to the possibilities offered by an electric furnace method, and have recently succeeded in designing an electrolytic furnace in which pure metallic calcium is readily manufactured from its fused chloride.

The fundamental principle involved consists in the employment of a small cathode, and correspondingly large anode, between which the fused mass is brought to a red heat, when the metallic calcium makes its appearance around the former as a spongy mass. On removing this

latter from the furnace, and immersing it in petroleum, a porous residue is obtained, some 50 to 60 per cent. of which consists of pure calcium. The mass is compressed or squeezed whilst still warm, in order to get rid of the chloride with which it is saturated, and a product containing fully 90 per cent. of pure metal is the result. The latter is then fused in an hermetically sealed chamber, and thereby converted into a firm silvery mass of metallic calcium. Calcium is claimed to have been produced by this method at a cost of approximately 3s. per kilogramme, about 1/5,000th of the cost of the original process.

To pass on, however, to a consideration of the furnace employed ; let us turn our attention to Fig. 47, which represents a section of the latter. It consists of an outer carbon cylinder C built up of several longitudinal sections, each keyed into its neighbour, and the whole held together by a metal ring or band B, which, at the same time, constitutes a terminal connexion, the carbon cylinder being the anode.
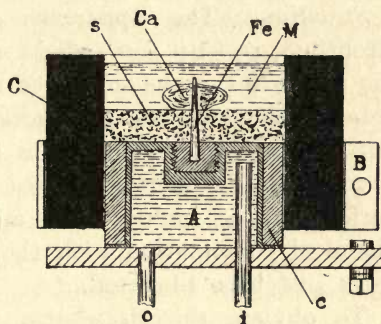
FIG. 47.

The upper portion of the cylinder is open, whilst its lower end is closed by a fire-clay cylinder c surrounding and insulating a metal chamber A, which performs the double office of a circulating water tank for cooling purposes, and a support for the cathode Fe, which consists of an iron rod placed axially with regard to the cylindrical anode, and screwed at its base into the upper portion of the cooling chamber A. Inlet and outlet pipes i and o respectively, serve to convey the water to and from the chamber, whilst it is protected from the heat of the furnace by a layer of

fluor-spar s, which, owing to its high melting point, remains solid during the operation of the furnace.

The mass of calcium chloride M is placed above this, the action of the furnace being started by several thin carbon rods, placed radially, like the spokes of a wheel, between the iron cathode Fe and the inner surface of the carbon cylinder. The heat set up by the flow of current through these rods serves to start the fusion of the upper layer of chloride, and they are subsequently removed, leaving the process of electrolysis to continue through the initially fused mass.

The position taken up by the resultant spongy calcium is indicated in the figure by Ca.

Strontium.—The apparatus for the manufacture of strontium, is, with some slight modifications, incidental to the properties of the separated metal itself, similar to that detailed above for the production of calcium. Unlike the latter, strontium separates out from its compounds in the form of small spherical masses, which tend to rise to the surface of the molten salt, and there again enter into chemical combination with the chlorine from which they have just been liberated.

To obviate this drawback, the iron cathode is made shorter, such that its upper extremity only reaches to a point just above the lower edge of the cylindrical carbon anode. The latter rests upon a cylindrical fireproof structure of insulating material, such as fire-clay, which, in turn, is supported in a cup-shaped depression in the upper portion of the cooling chamber. The latter is, in the strontium furnace, given a larger diameter than the carbon anode, and it is in the central depression or basin, around which the anode rests, that the metallic strontium collects during the action of the furnace, and is solidified by the cooling effect of the circulating water.

The temperature of the operation in Borchers' and Stockem's electrolytic manufacture of metallic calcium, is

a red heat, above the melting point of calcium chloride, but below that of metallic calcium.

Dr. K. Arndt, commenting on the former method for the manufacture of metallic calcium, in *Zeitschrift für Elektrochemie*, November 13, 1902, states that he has obtained a similar result with simpler apparatus.

His furnace consisted of a coated iron crucible, a carbon anode, and, as cathode, a thick iron wire. With this comparatively simple outfit, he succeeded in obtaining metallic calcium in large well-fused pieces, capable of being easily worked with a file or hammer. An analysis of samples showed 99 per cent. calcium, and 1 per cent. silicon, but no iron or aluminium.

Arndt's furnace for the separation of metallic calcium by igneous electrolysis, consists of an iron crucible, lined interiorly with a paste made up of kaolin and water. The base is additionally protected by a layer of calcium fluoride, the whole being dried for a period of twenty-four hours in a warm place. The anode is a carbon rod, and the cathode, an iron wire, sheathed to within 4 c.m. of its lower extremity in a porcelain tube.

The furnace is cooled by conduction and radiation, being mounted, for that purpose, on a massive cast-iron base. It is filled with anhydrous calcium chloride, and the action started by striking an arc between the anode and an independent carbon rod held in the hand, until the temperature has risen sufficiently to permit the current to flow through the alternative path provided by the fused electrolyte. The current is then maintained constant at an E.M.F. of from 20 to 25 volts, the reaction taking place quite quietly. The product is obtained in large well fused masses, a fresh surface of which is nearly white, but quickly assumes a yellowish tinge. The metal is readily workable, and is of 99 per cent. purity.

Manganese, and its alloy with iron, commonly known as ferro-manganese, has lately proved a subject for extensive

electric furnace operations, both experimental and industrial.

The Simon electric furnace process of ferro-manganese manufacture, which has been successfully applied in France, is electrolytic. It consists in the electrolysis of a mass of fused calcium fluoride, in which oxide of manganese has been previously dissolved. In this respect it bears a resemblance to the aluminium extraction processes of Heroult and Hall.

Careful temperature regulation is here, as in many other furnace processes, an essential feature of the operation, metallic manganese being volatile at a temperature but slightly in excess of its melting point.

A raw charge having the following composition is fed into the furnace—

Oxide of Manganese	.	.	.	.	.	6 parts.
Silica	.	.	.	.	.	.	6 ,,
Lime	.	.	.	.	.	.	3 ,,
Magnetic oxide of Iron	.	.	.	.	.	0·6 ,,

Under the thermo-electrolytic action of the furnace, the oxide of manganese is reduced in part by electrolysis, and also by chemical combination of its oxygen with the carbon of the electrodes. The results are found to be most favourable when carbon is mixed with the oxide before its introduction into the furnace. The product has the following composition—

Manganese	.	.	.	.	.	.	84·00 per cent.
Iron	.	.	.	.	.	.	8·30 ,, ,,
Silicon	.	.	.	.	.	.	0·20 ,, ,,
Carbon	.	.	.	.	.	.	7·10 ,, ,,
Phosphorus	.	.	.	.	.	0·10 ,, ,,

It may be added that, should silicon and phosphorus be present in the bath as impurities, they combine with the fluorine as the result of secondary reactions and pass off as volatile by-products.

The above process, as carried out in practice, involves a power expenditure of 3,475 k.w. hours per ton of ferro-manganese, each furnace having a capacity of at least

150 k.w., and a terminal E.M.F. of 30 volts. Of this, only 7·5 volts is actually required to effect the electrolysis, the balance being neccessry to ensure the passage of the current required to maintain the general high temperature of the mass.

In 1902 it was decided to erect a plant for the manufacture of ferro-manganese by this method, at Orlu, in the Pyrenees. The cost of production, with cheap water power available, was estimated at £8 3s. 6d. per ton. Further particulars are wanting.

Metallic *Lead* has been prepared, though not on a commercial scale, by electrolysis of its fused salts. The apparatus and method are due to Borchers ; the furnace is of cast iron, and is in two parts, separated from one another by a water-cooled insulating joint, which, by virtue of its lower general temperature, is surrounded and protected from the action of the fused salt and metal by a coating of solidified salt.

One side of the furnace, comprising the anode, is placed at an angle, its inner surface being interrupted by a series of deep horizontal grooves or corrugations, serving to retain a portion of the molten lead, which is constantly flowing over them from a reservoir above, and is simultaneously run off from the hearth of the furnace by way of a siphon.

The furnace, or electrolytic vat, is itself placed in a flue of an auxiliary furnace, which maintains its contents in a state of fusion. The electrolyte consists of a mixture of potassium and sodium chlorides, and lead oxychloride ; the resultant lead collects in the cathode side of the hearth, whence it is continuously removed by a second siphon.

Borchers employed a current density of one ampère per square centimetre, at a pressure of 0·5 volt, the yield being 5 kilogrammes of metallic lead her 1 e.h.p. hour.

Magnesium is produced by the electrolysis of fused carnallite, a double chloride of magnesium and potassium,

which gives up its water of crystallisation, and assumes a clear fluid condition at a temperature below 700°C = 1,292°F. The electrolysis is carried out in a closed chamber, an inert gas being passed through during the process. Chlorine gas is evolved, whilst metallic magnesium is set free, and floats on the surface of the electrolyte. It is essential that these two products of the reaction be kept separate from one another, and that the magnesium be not allowed to come into contact with oxygen, hence the necessity for passing an inert gas through the furnace chamber. A current density of ·15 ampère per square centimetre of cathode cross-section is required to bring about the electrolysis.

Zinc —Borchers has experimented on the extraction of metallic zinc by electrolysis of the fused chloride, but the process, owing to certain difficulties in the way of its practical application, has never been commercially developed. The electrolytic furnace consisted of a leaden vessel, with close-fitting lid, hermetically sealed in position by solidified zinc chloride. A zinc lining, bent to fit the interior of the crucible, formed the cathode, whilst the anode consisted of a vertical carbon rod

Means were provided for replenishing the charge of zinc chloride and conducting away the chlorine gas evolved. Extraneous heat was requisitioned to start the fusion, which was subsequently maintained by the passage of the current, together with the heat of the reaction.

M. Gin has succeeded in preparing *Vanadium* and its compounds by an electrolytic furnace method which he described in a paper before the 1903 International Congress of Chemistry at Berlin. The principle of the process depends upon the great conductivity of vanadium trioxide, and on the facility with which the tri-fluoride is formed, when the trioxide is reacted upon by fluorine in the presence of carbon.

The most important preliminary to the actual process

is the preparation of the anodes. Vanadium trioxide, prepared by calcining vanadic acid in the presence of carbon, is mixed with a suitable proportion of retort carbon and powdered resin, and the mass worked up, under heat, to a plastic paste. The latter is then subjected to hydraulic pressure, under which it is extruded in either cylindrical or prismatic form, through dies.

The shaped rods, thus formed, are then subjected to a high temperature in an hermetically sealed oven. The resultant electrodes are said to be capable of withstanding a current density equal to 0·7 of that of carbon electrodes of the same section. A bundle of these rods constitutes the anode, whilst the cathode is a block of iron.

The electrolyte consists of fused vanadium fluoride, and, under the action of the furnace, vanadium is set free at the cathode and fluorine at the anode. The latter again enters into combination to form a fresh quantity of vanadium fluoride, and the electrolysis is repeated. The most suitable current density is said to be 2 ampères per square centimetre of anode section, and 6 ampères per square centimetre of cathode section, the terminal E.M.F. being 11 to 12 volts.

For alloys containing more than 25 per cent. vanadium, the cross section of the anode should be appreciably less than the total active surface of the anodes.

Iron-vanadium alloys, and an increased fluidity, may be obtained by adding fluoride of iron to the fused mass, but, if no iron be added, almost pure vanadium is available, which, however, has to be removed from the furnace in a solid state, owing to the difficulty of tapping its semi-liquid mass.

The equations representing the two stages of the reaction are—

$$6F + V_2O_3 + 3C = 2VF_3 + 3CO$$

and

$$2VF_3 = 2V + 6F.$$
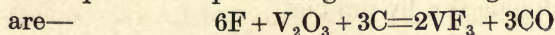
SECTION IX

Miscellaneous Electric Furnace Processes

"*Alundum*," as distinguished from corundum is an electric furnace product, the process, invented by Jacobs, being exploited by the Norton Emery Wheel Company, of Niagara Falls, who utilize some 500 H.P. in its manufacture, the daily yield being from 4 to 5 tons.

The process consists in thoroughly calcining bauxite in ordinary furnaces, after which it is fused in an electric furnace of the arc type, and crystallizes, on cooling, as alundum.

Baryta is another electric furnace product. It is manufactured at Niagara, from barytes, by the United Barium Company ; a suitable reducing agent, e.g., carbon, is added to the barytes, and the mixture subjected to electric heat in 500 k.w. furnaces, from which the product, a mixture of oxide and sulphide of barium, is tapped off.

The equations representing the reactions which take place are as follows—

$$4BaSO_4 + 4C = BaS + 3BaSO_4 + 4CO.$$
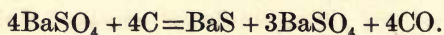
The barium sulphide then reacts with the sulphate. forming anhydrous baryta, thus—

$$BaS + 3BaSO_4 = 4BaO + 4SO_2.$$
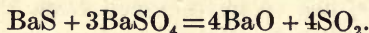
The mixed product is separated by aqueous solution, the baryta crystallizing out as barium hydrate $Ba(OH)_2 + 8 H_2O$, whilst the sulphide is a by-product.

The charge consists of a mixture of ground barytes and coke, mixed in the proportions of four molecular equivalents of each. When heated in the electric furnace, a

reaction occurs between the carbon and barium sulphate, according to the above equation, 25 per cent. of the latter being reduced to barium sulphide. There is thus created a mixture of approximately three molecular equivalents of barium sulphate with one of the sulphide, and a secondary reaction occurs, in which barium hydrate is formed, only 2 to 3 per cent. of unconverted sulphate remaining, and a small quantity of the sulphide.

The maximum output is 8 tons of product per 24 hours, which is tapped off periodically, and dissolved in hot water. The insoluble impurities are removed by filtration, and the barium hydrate crystallized by cooling, whilst the sulph-hydrate remains as a by-product.

The crystallized barium hydrate is washed with a cold water spray, and subsequently dried and fused, in which latter condition it is poured into iron drums, and solidifies, on cooling, into masses of approximately 250 kgs. apiece, containing less than 1 per cent. of impurities.

The principal applications of barium hydrate are in the sugar industry, water purification, tanning, and the manufacture of pigments.

The plant of the United Barium Company at Niagara has a capacity of 60 tons of the hydrate.

Barium Cyanide is another commercial electric furnace product. It is manufactured by the Cyanide Company at Niagara Falls. As a raw material, barium carbide, mixed with coke, is used, and subjected to heat in the electric furnace, whilst, at the same time, a current of producer gas is passed through the mixture, with the result that the necessary combination with nitrogen is secured.

Calcium Cyanide.—A patent has been taken out by a German Company, on an electric furnace process for the production of calcium cyanide. A mixture of lime and coke is raised to a temperature of 2,000°C. = 3,632°F., whilst nitrogen gas, or air, is passed over the mixture. The necessary proportion of nitrogen enters into chemical com-

bination with these ingredients to form the cyanide, which is stated to be of value as a fertiliser.

An electric furnace process, for the casting of articles from refractory materials, e.g., fire-bricks, tiling, conduits, etc., has been devised by Mr. Chas. B. Jacobs. It consists in subjecting acid silicates, such, for example, as the compound represented by the formula $Al_2O_3.$ $2SiO_2$, to continued fusion in any ordinary electric furnace. As a result, a certain proportion of the silica is volatilized, and the residue, a tough mass, of waxy appearance, having distinct physical properties, may be run into moulds of any desired form.

As an example of the energy necessary to effect the fusion, it is stated that a current of 1,500 ampères at 100 volts will suffice to melt 90 kgs. of the charge in 20 minutes, the continuation of the fusion for another 40 minutes being sufficient to volatilise 50 per cent. of the silica.

Silicides.—The silicides of the alkaline earth metals, calcium silicide ($CaSi_2$), barium silicide ($BaSi_2$), and strontium silicide ($SrSi_2$), were discovered by the Ampère Electro-Chemical Company, in July 1899. They are the silicon analogues of the alkaline earth carbides, and are manufactured in the electric furnace under similar conditions, though at a rather higher temperature than is called for in the formation of the carbides.

The raw materials consist of carbonates, oxides, sulphates, or phosphates of the alkaline earth metals, mixed with silica and carbon, in the requisite proportions to bring about the reduction ; or, as an alternative mixture, silicates of calcium, barium, and strontium, mixed with sufficient carbon to combine with the oxygen present in the compounds.

The resultant silicides, according to Jacobs, are white, or bluish white, of metallic appearance, and with a distinct crystalline structure. They oxidise slowly in air, at normal temperatures, and more rapidly when heated, yielding silicon dioxide, and the oxide of the particular alkaline earth metal content.

Like the carbides, they decompose when brought into contact with water, evolving hydrogen gas, according to the equation—

$$BaSi_2 + 6H_2O = Ba(OH)_2 \cdot 2SiO_2 + 10H.$$
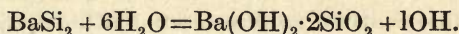
The following are the quantities of hydrogen gas, which are obtainable from one pound of chemically pure silicides, on treatment with water—

One pound calcium silicide .	.	. 18·73 cubic feet
,, ,, strontium silicide	.	. 12·36 ,, ,,
,, ,, · barium silicide .	.	. 9·15 ,, ,,

at 0°C. = 32°F., and 760 mm. pressure.

As a hydrogen producer, barium silicide is stated to be the cheapest and most convenient source, it being only necessary to introduce the material into an ordinary acetylene gas generator, and decompose with water in the usual way.

All the silicides are strong reducing agents, and that of barium has been largely used for the reduction of indigo by making the indigo blue into a thin paste with water, and introducing the barium silicide, which has been previously ground fine; the solution of indigo white, thus produced, may be applied directly to the fibre of the substance to be dyed.

If kaolin, or china clay, be subjected to heat in the electric furnace, and, simultaneously, to the action of a current of hydrogen gas, silicon hydride is formed, according to the equation—

$$Al_2Si_2O_7 + 8H = SiH_4 + 2H_2O + Al_2SiO_5.$$
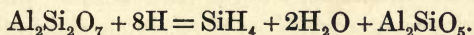
If continued still further, the reaction results in the reduction of the aluminium silicate to aluminium oxide, either of which are of value as abrasives. The silicon hydride ignites spontaneously on coming into contact with air, forming silicon dioxide and water vapour. The former, being in a state of extreme comminution, is valuable as a polishing powder for fine metal work.

Combination Processes.—Several inventors in the electric

furnace field have essayed to combine, efficiently and practically, two processes in one and the same operation, using the same furnace structure, and collecting the products independently. Such combination methods can hardly be regarded as successful in a commercial sense, in that the conditions essential to one process are seldom, if at all, allied, or in any way similar to those governing the successful conduct of another.

The natural consequences of an attempt to combine two such processes in one and the same operation are therefore impracticable complication of the furnace, and commercial inefficiency of one or both processes.

An instance of such combination methods is that suggested by Mr. A. Dorsemagen, of Wesel, Germany, for combining carborundum manufacture and the reduction of zinc ores. In order to effect this, silicate of zinc is substituted for the sand of the usual carborundum furnace charge, with the result that carborundum is formed in the usual way, or said to be formed, whilst the metallic zinc, liberated from combination with the silica, distils over into a suitable receiver.

In order to bring about this double reaction, a special form of furnace construction, differing materially from the ordinary open carborundum furnace, is an obvious necessity ; such a furnace must be closed in on all sides, and the material of its walls must be impervious to zinc vapours. It seems hardly likely that the manufacture of carborundum, comparatively inefficient as is the simple procedure at present adopted, would prove commercially feasible if worked in conjunction with the electrical reduction of zinc ore, which latter is, to electro-metallurgists, still in the nature of a partially solved problem.

Other combined electric furnace processes worthy of mention, are that of Rathenau, for the manufacture of iron silicides by the addition of iron to the charge of a calcium carbide furnace ; this method, which has for its object, the purification of the resultant carbide, has already been

described, and cannot be regarded in the light of a commercial failure, in that it effects the desired object, whilst the by-product is useful, and does not involve unnecessary complication of the furnaces.

The same applies to Heibling's simultaneous manufacture of chrome-iron and calcium carbide, which is also a purification method pure and simple ; the latter, which forms as a slag, depriving the chrome-iron of carbon as an undesirable impurity.

Desjardins has also proposed the joint production of water glass and phosphorus by treating, in the electric furnace, a mixed charge of sodium phosphate, silica, and carbon.

Joudrain, Billaudot, Jacobsen, Hilbert, Bradley, Read, and Jacobs, have patented joint processes for the simultaneous manufacture of calcium carbide and phosphorus. The process, in general, consists in treating calcium phosphate in the furnace with excess of carbon, the latter reacting with the calcium to form carbide, and the liberated phosphorus distilling over.

The disadvantages incidental to such a combination are, that in addition to complicating the carbide furnace construction, calcium phosphide is formed conjointly with the carbide, and any acetylene gas subsequently generated from the latter is contaminated with phosphoretted hydrogen.

The last three inventors enumerated above recognize this fact, and claim, in their patent specification, the manufacture of calcium " carbophosphide," a mixture of carbide and phosphide of calcium in such proportions that, when reacted upon by water, a spontaneously inflammable mixture of gases is produced. This compound is especially suitable for the " marine light," a modern auxiliary in naval and military operations, and is therefore in demand.

M. Gustav Gin, whose name is associated with modern research into the possibilities of electric smelting, has devised a joint process for the simultaneous production of iron alloys, and alkaline oxides ; e.g., ferro-silicon and baryta.

The process is carried out in two stages, the first of which does not necessarily entail the use of an electric furnace in that a very high temperature is not required. A mixture of broken quartz, barium sulphate, and charcoal, is subjected to moderate heat, with the resultant formation of barium silicate. The latter is then mixed with metallic iron or its oxide, and carbon, and again subjected, this time to a high temperature, in the electric furnace. Ferrosilicon and barium oxide are formed, the latter being collected as a sublimate.

An English patent, dated May 9, 1901, was granted to A. H. Cowles and the British Aluminium Company on a double electric furnace process, in which an alloy, or carbide of aluminium, and metallic sodium, are produced simultaneously in one operation of the furnace.

The latter has one wall which is pervious to gases, and forms a partition between the furnace proper and a condensing chamber, where the metallic sodium is collected. In the furnace is placed a mixture of sodium aluminate and carbon; under the influence of electrical heat the sodium is set free, and passes, as a vapour, through the porous wall into the condensing chamber, where it is duly condensed and collected as metallic sodium. The aluminium combines with the carbon to form aluminium carbide, or, if a non-volatile metal be present, unites with it to form an alloy. An alloy of sodium may be similarly produced by including a volatile metal among the constituents of the furnace charge.

SECTION X

LABORATORY FURNACES AND EXPERIMENTAL RESEARCH

Some interesting and instructive laboratory furnaces for experimental use have been designed for, and are in use at, Owens College, Manchester.

They were aptly described and illustrated in a paper read by Prof. R. S. Hutton before a meeting of the Institution of Electrical Engineers, November 25, 1902.

A 40-kilowatt Moissan arc furnace, which is typical of arc furnaces with indirect or reflected heat, is shown in section in Fig. 48. It consists of two blocks, A and B, of Monk's Park bath stone, one, A, forming the cover, or domed lid, and the other, B, the body of the furnace.

These two blocks are grooved semi-circularly where they fit together, in order to form a circular channel for the reception of the carbon electrodes E E, which pass horizontally through the walls, and meet at the centre, with the exception of an arcing space, which is situated just above the centre of the recess or hearth in the lower block B. This latter is from 2½ to 4 in. in diameter, and in it is placed a carbon crucible C, resting on a layer of powdered magnesia, which isolates it from contact with block B. A clearance space is also left around the crucible as shown ;
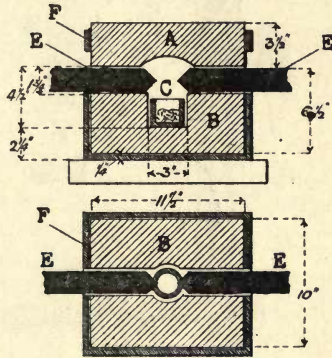
FIG. 48.

this facilitates the heating, and also prevents combination between the carbon of the crucible and the limestone, which might otherwise take place under the influence of the intense heat generated. F F are iron bands, which serve to hold the blocks together, and prevent them from splitting, whilst, at the same time, they afford a ready means of lifting either the entire furnace, or its cover, by means of attached eyebolts. The remaining dimensions of the furnace are indicated in the sketch.
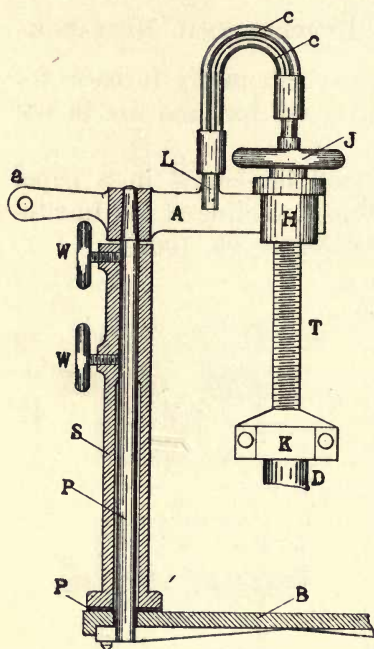
FIG. 49.

Another form of experimental arc furnace in use at Owens College comprises a vertical construction, which, with some slight and easily effected modifications, can be adapted to a variety of purposes. It is represented in Fig. 49, and consists of a rectangular cast-iron base, B, some 19 in. long, by 14 in. wide, strengthened by cross ribs cast on to it below, and provided at one corner with a levelling screw, and at the other with a $\frac{3}{4}$-in. clamping bolt, to serve as a terminal connexion.

Rising vertically from the centre of one of the lesser sides of this base, is a hollow cast-iron standard, S, $2\frac{1}{2}$ in. in diameter, flanged at its lower extremity, and bolted to the base B, a sheet of vulcanized fibre F being interposed for the purpose of insulation. A steel plunger P, $1\frac{1}{4}$ in. in diameter, fits inside this standard, and is capable of vertical

adjustment therein, being firmly secured in any desired position by the hand wheels and set screws W W Clamped at right angles to the upper extremity of this plunger is a cross bar or bracket A, which carries, at its outer end, the screw feed adjustment H, and clamp K, of the upper carbon D. Means for two terminal connexions to the pillar and carbon holder are provided, that shown at a being employed in cases where the current exceeds 600 ampères.

The carbon holder K is fitted with a set of clamping collars of varying diameter, which will accommodate carbons up to 3 in. ; it is carried by a phosphor bronze stem T, $1\frac{1}{2}$ in. in diameter, and square threaded (four to the inch) for feed adjustment. About 12 in. vertical adjustment is obtainable through this construction, and is effected by means of the hand wheel J. The electric circuit to the upper carbon is not completed through the screw threads and bushing, but is provided by four $\frac{1}{2}$ in. flexible cables c c clamped to a lug L cast on the bracket, and to the upper extremity of the phosphor-bronze stem.

The hearth or crucible may be varied to suit the operation it is required to perform, and is supported on, or clamped to the cast-iron base B, with its centre immediately in line with the axis of the upper carbon electrode.

A 40-kilowatt experimental carbide furnace, with parallel electrodes is also described by Prof. Hutton. It is a very simple affair, as the diagram, Fig. 50, will indicate. E E are the two parallel electrodes clamped side by side, but insulated from one another in a cross-bar or yoke B. Electrical connexion with the carbons is secured by flat copper straps c c, which also serve as supports for the carbons and yoke piece, and are slung, by a second upper yoke, to a crane C. They slide in recesses provided for them in the bracket D, and are thus prevented from swaying. The furnace hearth is either built up of fire-brick, or takes the form of a cast-iron pot, the
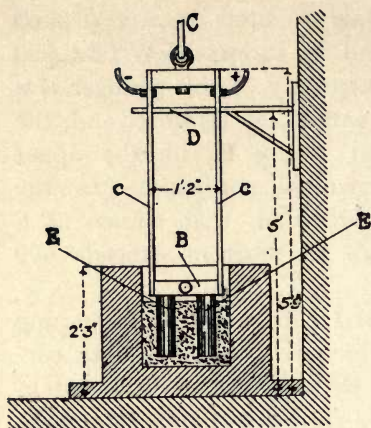
FIG. 50.

material under treatment providing a sufficiently refractory lining.

A novel feature of the laboratory equipment at Owens College, consists in a high pressure electric furnace, which can be adapted to any of the many and varied electric furnace processes, and is designed to operate under a pressure of 200 atmospheres. It consists of a massive steel cylinder which can be used either in a horizontal or vertical position.

Screw gearing, actuated through high pressure glands, serves to feed the electrodes together inside, whilst two small windows at opposite ends of a diameter are constructed to withstand the maximum pressure, and permit inspection of the interior during the progress of an experiment, or may be replaced, if so desired, by gas inlet and outlet pipes, where it is desired to conduct an operation in an atmosphere of any given gas. The whole cylinder is water-jacketed, the actual hearth of the furnace consisting of a refractory lining contained within, and supported by a cast-iron enclosure, between which and the outer steel cylinder the water circulation takes place.

Suitable valves and pressure gauge connexions are also provided.

The furnace was constructed by Messrs. Lennox, Reynolds, and Fyfe, to designs provided by the College authorities.

The Physical Chemistry department of the McGill University, Montreal, is equipped with two electric furnaces. They have a current capacity of 100 ampères at 110 volts, and are principally employed in the analysis of refractory compounds.

A convenient resistance, crucible furnace, for the determination of the cooling curves of steel, and of melting points, has been devised by H. M. Howe, Ph.D., for the School of Mines, Columbia University.

It is represented in sectional elevation by Fig. 51, and consists of a cylindrical structure M of magnesia, made in two semi-cylindric halves in order to permit ready access to the interior, in which is placed the magnesia crucible C. Surrounding this crucible, and embedded in a groove in the magnesia blocks M, specially prepared for its reception, is a spiral platinum coil P, of U-shaped section, the edges of the U fitting closely against the outer wall of the crucible. The extremities of this heating spiral are led out of the furnace at *a* and *b* for connexion to suitable terminals, whilst an inlet pipe *p* provides for the introduction of any desired gas into the interior of C. A magnesia lid L is fitted over the top, and luted on with fire-clay. S is a removable stopper, making a fairly close joint

Fig. 51.

with the lid, and serving for the introduction, through a central vertical bore, of the insulated and protected twin leads *l* of the thermo-couple T, which, situated in the centre of the crucible, and, consequently, of the heat zone, serves to indicate the temperature.
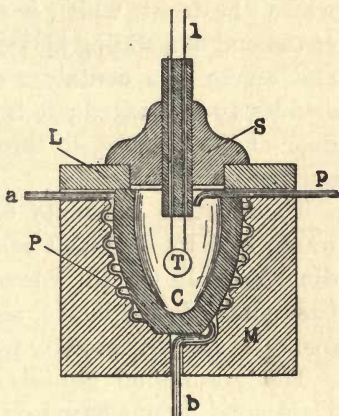
Small leakages through the various points of entry of the platinum wires and thermo-couple connexions are counterbalanced, in the main, by packing, and also by maintaining a suitable pressure of gas at the inlet pipe *p*.

A special taper mandrel, grooved to correspond with the interior groove in the magnesia blocks M, is utilized for

the introduction of the spiral, the two halves of M being brought together so as to encircle it, and the mandrel itself subsequently withdrawn by a left-hand screw motion, leaving the wire in its place in the groove.

A simple and convenient form of electric oven, or furnace for dentists and laboratory use, is the invention of Mr. August Eimer. It takes the form of a rectangular base plate and semi-cylindrically domed cover, both of refractory material. One end is permanently closed by a semi-circular plate, which forms the back of the furnace, whilst the front, which is removable, is vertically mounted at the end of a sliding plate, which covers the furnace hearth, and serves as a container or tray, for the reception of the articles to be heated ; it is removed, bodily, with the front door of the furnace, in the centre of which is an inspection aperture.

The heating elements consist of wires threaded backwards and forwards, at regular intervals, through longitudinal holes in the thickness of the domed cover. A sliding base plate, fitting inside, and constituting the hearth of the oven, also carries similar wires embedded in it.

The Hammond dental muffle, invented by Dr. J. F. Hammond, is not based on any new fundamental principle, its novelty lying more in the elaboration of detail, and provision for interchangeability of parts, and consequent freedom from serious breakdown.

It is heated on the resistance principle, the heater being a platinum wire coil, embedded in, and protected by, a fireclay foundation. The heat developed is retained by a heat-conserving jacket, consisting of alternate layers of sand, fire-clay, and metal, arranged concentrically round the central hearth. A mica door is provided for convenience in the introduction of the objects to be heated, and also provides a ready means of watching the process, whilst the whole is mounted on a convenient base with the necessary controlling resistance and switch.

The principle novelty consists in the arrangement of the resistance coil itself, which is provided, at regular and frequent intervals with loops, projecting outwards through the walls of the furnace.

These loops permit the necessary expansion and contraction of the wire, due to heating and cooling, whilst any incidental interruption in the circuit is readily located and repaired.

A resistance muffle, invented by J. Weiss, presents some points of similarity to the laboratory crucible of H. M. Howe, described in another paragraph. It has, for its object, the rendering of all parts, such as are subject to wear and tear, readily accessible for repair and replacement. To this end, the muffle itself, which is tubular in form, with the platinum resistance wire wound in a groove around its outer periphery, is encased, bodily, in a foundation block, which is divided, vertically, into two halves, along a plane corresponding with the axis of the muffle. The latter is flanged at its two extremities, the flanges fitting into corresponding recesses in the supporting block, whilst a recess in each block, somewhat larger than the outer diameter of the muffle, provides an air-space, and prevents undue heating of the casing, such as would otherwise result from direct contact with the platinum resistance.

The extremities of the latter are led out to terminals on the upper surface of one of the two casing blocks, and the whole, when mounted up and ready for operation, is held together by a suitable frame or strap, furnished with a set screw.

In the form of dental muffle, or laboratory resistance furnace, devised by R. Winter, a considerable reduction in the size of the heating units, and correspondingly lessened liability to fracture under extreme variation of temperature, are secured by embedding the resistance wires in porcelain tubes, and supporting the latter in horizontal grooves in opposite interior walls of the furnace, even spacing being secured by lateral projections.

The electric furnace in miniature has been adapted to the requirements of microscopical research. The apparatus was described by Prof. C. Doelter to the Vienna Academy of Sciences. An electric oven, 2 in. high, is mounted on the object stand of the microscope, and yields temperatures up to $1,200°C.=2,192°F$. In use, the lens is separated from the heated object by about 1 in. Even at the highest temperature of the subject under examination, however, both microscope and objective are kept quite cool by a special arrangement of asbestos plates, and a spiral tube carrying ice-cold water.

A. Kalähne has experimented with various stoves of the embedded resistance type, with a view to determining their limitations, and energy consumption. The results of his researches were published in *Ann. der Physik*, No. 6, 1903, in the form of graphic curves, of which the vertical ordinates represented watts consumed, and the horizontal ordinates, temperatures attained, in degrees Centigrade.

Six different furnaces were tested, of which two were provided with double coils, whilst the remaining four had only one coil apiece. As regards the foundations, or bodies of the furnaces, which were in tube form, five were of porcelain, 40 to 70 c.m. long, three being glazed interiorly, but not exteriorly. A sixth tube, 20·2 c.m. in length, was of Marquardt composition.

Kalähne found asbestos a preferable material to fire-clay for covering in the resistance wires, which were of nickel. If fire-clay be employed, its different coefficient of expansion leads to cutting or tearing of the resistance wire at high temperatures. Asbestos possesses the additional recommendation that it can be easily renewed.

Application of the Electric Furnace to Scientific Research.— By no means the least important of the many uses to which the electric furnace has been applied is that of an auxiliary to scientific research, especially among such refractory

substances as the diamond, and metals with exceedingly high melting points.

As an example of what can be done with the aid of electric heat, tantalum, which has hitherto been known only as a somewhat impure powder, having a density of 10·50, has now been produced from tantalic acid in the electric furnace by Henri Moissan. The acid was reduced to metallic tantalum by heating electrically in the presence of sugar carbon as a reducing agent, and the product, which shows a density of 12·79, has a brilliant metallic lustre. It scratches quartz, is infusible in the oxy-hydrogen blow-pipe flame, has a crystalline fracture, and is classed with the metalloids.

At the Fifth International Congress of Applied Chemistry, held in Berlin, W. Hempel described some experiments on melting-point determinations at high temperatures, which had been carried out with the aid of an electric furnace built up of carbon rods surrounded by Kieselguhr. With this apparatus the melting-point of magnesia was found to be in the neighbourhood of $2{,}250°C. = 4{,}082°F.$, and of lime, $1{,}900°C. = 3{,}452°F.$

With the Heraeus platinum-foil tube furnace the melting-point of 99 per cent. manganese was investigated and found to be $1{,}245°C. = 2{,}273°F.$

The Heraeus platinum-foil tube furnace, and the new quartz tubes, supplied by Heraeus, of Hanau, and by Siebert and Kuhn, of Cassel, have provided means for the conduct of numerous experiments on the volatilization of metals, hitherto impossible with glass tubes.

The advantages of quartz for this purpose are—

1. That it will stand a very high temperature without softening, and vessels made of it can consequently be exhausted of air, even when simultaneously subject to extremely high temperatures.

2. One portion of a quartz vessel may be cooled whilst the other is glowing, thus rendering it possible to evaporate

metals in the hotter region of the tube, and condense them in the cooler portion, without risk of fracture, whilst gas-tight connexions with the cooler portions can be made with the aid of a mixture of two parts wax and one part wool grease.

Metals, *per se*, do not attack quartz, but their oxides do, so that a certain amount of care is essential, especially in dealing with lead.

The quartz vessels are L-shaped, and the metal is, as a rule, placed in a bulb, blown to the top of the L, and bent back.

With this apparatus Drs. F. Krafft, Kuch, and Haagn, of Hanau, have conducted a series of experiments to determine the boiling, volatilization, and distillation temperatures of various metals. The full text of their researches is published in the *Berichte der Deutschen Chemischen Gesellschaft*, vol. XXXVI. The vacuum employed is described as one suitable for cathode glows, whilst the temperatures were determined by the aid of platinum—platinum-rhodium thermo-couples.

The following are a few of the more interesting results obtained by these investigators : Zinc began to distil distinctly at 430°C. = 806°F. without melting, and distillation afterwards continued at a temperature of 300°C. = 572°F. The boiling zinc displayed the Leiden-frost phenomenon, which was also observed in the case of cadmium. The latter began to evaporate at 320°C. = 608°F., and distilled visibly at 448°C. = 838°F. Selenium was easily volatilized at 380°C. = 716°F. Tellurium distilled and boiled briskly at 540°C. = 1,004°F. ; lead volatilized sufficiently at 801°C. = 1,472°F., to form a mirror which could be melted, and at 1,160°C. = 2,120°F. it boiled regularly and distilled. Antimony was volatilized at 670°C. = 1,238°F., and distilled at 780°C. = 1,436°F. ; bismuth volatilized at 540°C. = 1,004°F., and distilled at 1,140°C. = 2,084°F. ; tin could not be volatilized at

1,100° C. = 2,012°F., however. Silver began to volatilize at 1,200°C. = 2,192°F.; at 1,340°C. = 2,444°F. it distilled at the rate of 0·09 grammes in 12 minutes. Copper began to distil at 1,315°C. = 2,399°F. Gold was the most refractory metal experimented with; it formed a mobile liquid at 1,180°C. = 2,156°F.; at 1,300°C. = 2,372°F. some silver distilled over from the impure gold, whilst at 1,375°C. = 2,507°F. sufficient gold had distilled to produce a gold mirror.

The high temperature researches carried out by Moissan with the aid of the electric furnace are detailed in his book *Le Four Electrique*, to which the reader is referred for particulars of his experiments. He is essentially a scientific enthusiast, and pursued his investigations with a view of adding to the scientific knowledge of the day. His work, which is mainly of a laboratory and experimental character, has nevertheless been instrumental in suggesting several of the industrial electric furnace processes which are in operation to-day.

With the aid of furnaces devised by himself, Moissan has succeeded in fusing, distilling, and crystallizing many of the most refractory substances, among which may be mentioned magnesia, lime, platinum, and carbon.

In connexion with the last-named element he has conducted extensive investigations into the properties of its allotropic modifications, and last, but not least, has actually succeeded in manufacturing diamond.

His researches in the preparation of carbides, borides, and silicides, resulted in quite a quantity of hitherto unknown compounds, among which may be mentioned the now familiar calcium carbide and silicon carbide (carborundum) of commerce.

Moissan originally described the carbides of calcium, strontium, and barium as opaque, except when obtained in very thin sheets.

He has since modified this description in accordance

with the results of later experiments (*Comptes Rendus*, December 5, 1898). He ascribes the opacity of calcium carbide to impurities, principally iron, which are present in the mass. When obtained in an absolutely pure state it is as transparent as lithium carbide or sodium chloride.

That this is so may be demonstrated by a simple experiment. A mixture of metallic calcium and amorphous carbon, obtained by the rapid combustion of acetylene, is heated to a dull red, yielding a white product, pure calcium carbide, which, under the microscope, proves to be a collection of transparent crystals.

In this connexion Moissan further points out that, under these conditions, the heat of combination between the carbon and the calcium is sufficient to fuse the carbide, a result never yet achieved in commercial practice.

The reddish-brown tint of commercial carbide may be reproduced in this pure white mass by heating it with a small quantity of iron.

The carbides of potassium, K_2C_2, and lithium, Li_2C_2 may also be obtained in transparent crystalline plates, whilst aluminium carbide Al_4C_3 sometimes crystallizes in transparent plates, having a yellowish tinge.

MM. Moissan and Kouznetzow have succeeded in preparing, by direct reduction in the electric furnace, a double carbide of chromium and tungsten, having the formula, $W_2C.3Cr_3C_2$, which is so hard as to scratch glass, topaz and ruby, though not diamond. It is unattacked by acids, either individually or mixed, but is dissolved by fused chlorate and alkalies.

Messrs. Tucker and Moody have succeeded in producing the borides of zirconium, chromium, tungsten, and molybdenum, by heating these metals in conjunction with borax, in the electric furnace. The current required was from 200 to 275 ampères. Attempts were made by the same experimenters to prepare borides of copper and

bismuth in a similar manner, but were not attended with success.

Bolton has succeeded in bringing about a direct union between carbon and chlorine by striking an arc between two carbon electrodes in an atmosphere of the latter gas.

Hutton has conducted a series of experiments on the fusion of quartz, and the results of his efforts were embodied in the form of an article in the *Electro-Chemist and Metallurgist*, May, 1902.

He first employed an open arc to effect the fusion, and found that reduction took place in the immediate neighbourhood of the arc, giving rise to a black stain on the surface of the quartz, which, however, disappeared on holding the mass away from the centre of the flame for a short time.

He subsequently continued his experiments with a closed furnace, using one of the Moissan type, modified by cutting openings in its side walls to permit the passage of a carbon vessel charged with quartz, in a line at right angles to the arc. A current of 300 ampères at 50 volts was employed, and thick-walled quartz tubes, having an internal diameter or bore of about $\frac{1}{8}$ in., were easily cast in a rough carbon mould, a carbon core at the centre securing the correct position of the bore.

The charge for the mould consisted of broken quartz, not too finely powdered, and the resultant tubes were easily withdrawn from the carbon mould and freed from the cores. They were not quite free from air-bubbles, but were improved in appearance by subsequent re-heating under the arc, the tube being meanwhile rotated.

The new quartz tubes for laboratory research at high temperatures have considerably extended the field of investigation. Metals may be boiled and evaporated in them at temperatures up to $1,200°C. = 2,192°F.$, and, with care, up to $1,400°C. = 2,552°F.$, even in a high vacuum, and the tubes containing metal at the former temperature

may be safely removed from the furnace, cooled, and replaced, without fear of breakage. Using an electric furnace, it is possible to regulate the temperature, within two or three degrees, between 18° and 1,400°C. = 64° and 2,552°F., whilst the air-pump connexions to the tubes may be hermetically sealed with wax without risk of melting, although within a few inches of the intense heat.

SECTION XI

TUBE FURNACES

Mr. H. N. Potter, of New York, has devoted considerable attention to the perfecting of a series of tube furnaces, in which the hearth takes the form of a refractory conducting tube, through the walls of which the current is passed in a longitudinal direction, heating them in its passage.

There are several difficulties connected with the efficient operation of this type of furnace, among which may be mentioned—

1. The attainment of an even heating effect in all parts of the tube.

2. Interchangeability of parts, whereby those most subject to wear are rendered easily replaceable.

3. Satisfactory terminal connexions, which shall allow for the necessary expansion and contraction of the tube itself.

These are the main difficulties which Mr. Potter has realized, and set himself to overcome, and we will now proceed to consider the various forms of tubular furnace construction advocated by him, and the manner in which they severally contribute towards the desired result.

The discovery of the Nernst principle has, as already stated, opened up another promising field for electric furnace construction, to which the tubular type readily lends itself; the several improvements with which we shall now proceed to deal are equally applicable to furnaces on the Nernst principle, and to the older forms of carbon tube.

Equalization of Heating Effect.—Mr. Potter suggests three

distinct forms of construction for the tube, with a view to securing a uniform distribution of heat to all parts of the latter. His first construction consists of a simple tube, the terminal connexions to either extremity of which are subdivided. Thus, a series of equidistant points to the number of six, or upwards, are marked off around the annular surface at each extremity of the tube ; separate and distinct terminal connexions are made to each of these points, and the current may be derived from a transformer with subdivided secondary winding, the number of subdivisions being equal to the number of pairs of terminal points to the furnace tube.

The second type of tube to secure equal heating takes the form of a partially divided cylinder ; longitudinal divisions or grooves, spaced at equal distances apart, around the external periphery of the tube, serve to concentrate the flow of current along definite lines, represented by the intervening sections of tube.

The third form of construction consists in a total longitudinal subdivision of the tubular walls into a number of similar parts, the intervening spaces being filled in with refractory insulating plates after the manner of a dynamo commutator.

A further improved construction of tube furnace, designed by Mr. Potter with a view to the additional strengthening of parts, prevention of distortion of the tube under the effects of heat, and conservation of the heat produced, is shown in Fig. 52. It comprises a carbon tube C, which may or may not be provided with an interior removable lining T, also tubular ; carbon terminal discs D D, and a series of annular ribs r r of the same material, which are slipped over the tube, and serve as an additional support thereto. The spaces between the ribs r r are filled in with magnesia m, covered by a layer of asbestos, and the whole is enclosed in a glazed earthenware jacket J. As may be readily imagined, this provides a very rigid

construction, whilst the loss of heat, resulting from radiation, is comparatively small.

Terminal Connexion and Mounting of Tubular Furnaces.—Mr. Potter has also tackled this problem, and the resul-

Fig. 52.

tant design is that of a form of terminal connexion and mounting for tubular furnaces, which enables the latter to be placed in any position, and allows for the necessary expansion without resultant disturbance of the electrical connexions.

It is represented in Fig. 53, where C is the carbon tube, as before ; D D terminal discs, or rings of the same material, the outer surfaces of which are double-tapered as shown, to form a seating for the metal clamping rings *r r*, held together, and in good electrical contact with the carbon, by the bolts *b b* ; A A are sheet metal diaphragms, through which the bolts *b* also pass, thus securing them to the terminal rings of the tube. The outer edges of the diaphragms are clamped between metal end plates *p p*,

Fig. 53.

and the flanged extremities of an outer casing B, suitable insulation being inserted at the joint. The flexibility of the metallic diaphragms A permits the necessary expansion of the tube under heat,
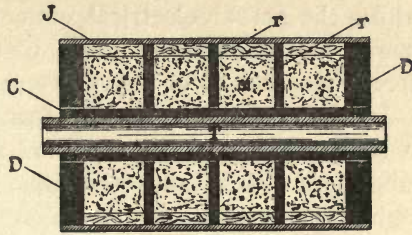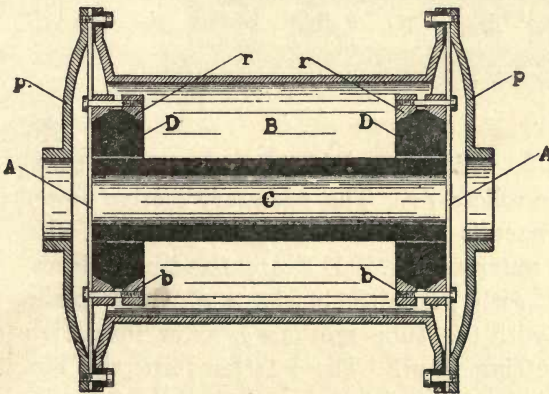
whilst the actual electrical connexions from the source of energy are made to the end plates p, and are thus rendered independent of any movement in the tube itself.

Another departure in tube furnace construction consists in the provision of an additional source of heat within the tube itself ; this takes the form of an arc between two carbon electrodes, the position of which is adjustable longitudinally along the axis of the tube, so as to bring the arc to any desired point.

A revolving tube furnace, boasting the above combination of arc and resistance principles, is represented in Fig. 54. The tube proper consists of separate graphite sections g g, pieced together to form a complete cylinder, and surrounded by an insulating jacket j, which latter is, in turn, enclosed in a sheet metal casing c. Around the periphery of the casing are arranged two annular metal
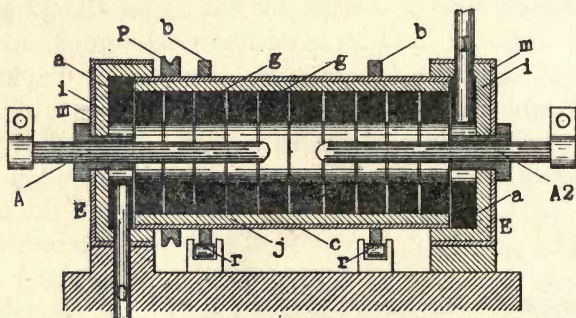
Fig. 54.

bearing pieces b b, which serve as journals to the tube, being mounted on rollers r r. The necessary motive power to rotate the furnace is supplied through a pulley P, also mounted on the outer casing. E E are fixed end pieces, or covers, lined with graphite blocks a a which make rubbing contact with the tube sections g, outer insulation i, and metallic casing m m. These latter form the terminal attachments for the resistance portion of the furnace.

The arc electrodes A, A2 are introduced through in-

sulating bushes in the centre of the end covers, E E and, as stated above, are adjustable as regards their axial position in the furnace. I and O are inlet and outlet orifices respectively for the introduction of the raw material, and withdrawal of the product. They penetrate the stationary end covers, as shown, and, the tube being preferably mounted at an angle, the process is rendered continuous, the charge passing through by virtue of rotation and gravitation from one end of the tube to the other.

Mr. Potter's design for a tube furnace on the Nernst principle, especially adapted to the baking of " glowers " for Nernst lamps, comprises a simple tube, formed from a mixture of the electrolytic oxides of magnesia, or zirconia, and yttria, fitted with terminal connexions, and enclosed in, and strengthened by an encircling jacket, consisting of one only of the oxides named above.

Over this again is wound the heater coil, a layer of mica being interposed between them. The actual heat is developed, once the action is started by the coil, in the inner tube of mixed oxides, the outer jacket remaining, to all intents and purposes, a non-conductor, whilst, at the same time, its chemical similarity to the furnace tube proper prevents any detrimental action from taking place between them.

This notion of a single oxide for a protective and supporting jacket is one of the essentials of Potter's patent, any other refractory substance being unsuitable on account either of its electrolytic properties when heated, or of its tendency to unite chemically with the substance of the furnace tube proper.

A resistance tube furnace on the Nernst principle, devised by Drs. Nernst and Glaser, is illustrated in Fig. 55. The resistance heater is in the form of a hollow cylinder, or tube R, composed of the usual electrolytic oxides, preferably a mixture of magnesia, with traces of calcium carbonate, silica or kaolin, and alumina. It is, like one

of the tube furnaces already described, enclosed in a second cylinder C, of loose oxides, held in place by an outer casing J, which serves to retain the heat. The electrodes are an especial feature of the construction, and consist of oxide of iron F packed closely round the two ends of the tube in annular form, which latter is preserved, and the oxide held in position by iron hoops *f*, secured and drawn together by bolts and nuts. A refractory lid L is provided, and the furnace stands on a base B. The raw material to be treated therein may either be placed directly in the tube, in which case it is lined interiorly with magnesia, or in a separate crucible *c*, supported by a removable portion of the base. The action of the furnace is started by a preliminary heating of the tube, either with a gas flame, as in torch-actuated Nernst lamps, or by a carbon resistance rod introduced axially through the tube and heated by the passage of the current.
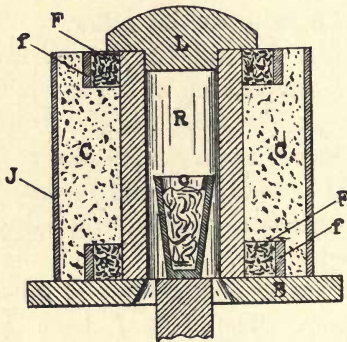
FIG. 55.

The Eddy tube furnace, invented and patented by A. H. Eddy, was specially designed for the fusion of enamels upon earthen and metallic ware, a process calling for extremely fine temperature regulation, and freedom from ash and combustion vapours. It consists of a series of tubes, composed of such electrolytic oxides as conduct when heated. Axially within these tubes, but not in electrical contact with their inner walls, are arranged carbon rods, which, heated by the current, serve for the preliminary heating of the tubes themselves.

The combinations of tubes and rods are mounted in batches, of varying number, between water-cooled ter-

minal blocks. The furnace itself is constituted by arranging a number of these combinations transversely across a long, narrow hearth, over which, and beneath the tubes, are packed the articles to be heated.

Varying gradations of temperature at different points along the length of the furnace are secured by connecting the several sections in series, their respective heating capacities being regulated by the number of tubes comprising them.

The initial heating of the tubes is effected by the passage of a current through the carbon rods, thus heating the tubes, which, in turn, become conductors, and shunt a portion of the current. The rods may subsequently be entirely withdrawn, when the maximum heating effect is obtained within and around the substance of the tubes themselves.

What is known as an electric combustion furnace, being a combination of an ordinary combustion tube, with electrical means for starting and maintaining high degrees of temperature therein, has been designed by Mr. W. M. Carr. It consists of a combustion tube proper, with copper gauze at 'one extremity and granular oxide of copper between perforated platinum discs at the other, surrounded by an electrical portion, which serves to produce and maintain the necessary heat.

It comprises a porcelain cylinder surrounding the combustion tube, and having three heating coils wound upon it, one at either extremity, and the other at the centre. A heat conserving jacket of magnesia encloses the whole apparatus. The mode of operation is as follows : The material to be treated is placed in a platinum boat at the centre of the inner combustion tube ; by means of independent switching arrangements, a current is first passed through the two end coils in series, and raises the tube and its contents to the required temperature, the latter being subsequently maintained, so long as desired, by all three coils connected in series.

The usual means are provided for the introduction of oxygen gas to, and the withdrawal of the products of combustion from, the tube.

A convenient form of laboratory resistance furnace, exhibited by Mr. Otto T. Louis, at the Conversazione of the American Institute of Electrical Engineers, in 1901, has a tubular construction, and consists of several terra cotta cylinders, each about two inches in diameter, and half an inch in thickness. Around these are wound the heating resistance spirals, consisting of platinum wire, about No. 23 S.W.G. Switching facilities are provided, whereby the wire, which is arranged in four distinct circuits, can be connected in series to start the furnace, and then, as the resistance rises with increasing temperature, in parallel to maintain the heat.

A so-called electric oven, or small resistance furnace of the tube type, is employed in the German Reichsanstalt for the calibration of thermo-couples used in high temperature thermometry.

It consists of four concentric porcelain tubes, the outer being glazed, and jacketed with asbestos. The inner tubes are composed of a very refractory material, devised by Hecht. The second tube serves as a mandrel or base for the heating resistance, which, in the form of wire, is wound upon it. For procuring temperatures up to $1,400°C. = 2,552°F.$, a pure nickel wire, having a diameter of 2 m.m., is used, and is protected by a layer of fire-clay paste laid on so as to embed the turns. For higher temperatures a platino-iridium wire is used, which increases the range to $1,600°C. = 2,912°F.$ Above this the wire fuses into the porcelain.

Temperature regulation is effected with a great degree of accuracy by means of an adjustable rheostat, the sliding contact of which moves over and makes contact with a constantan band.

The thermo-couples are calibrated in sets by a com-

pensation method, being mounted, for the purpose, in small circularly gapped sockets of platino-iridium. The errors do not exceed 0·1 per cent.

The power consumed in the furnace is low, being sixty watts for a temperature of 200°C. = 392°F., and rising to 1,540 watts for 1,300°C. = 2,372°F.

Observations on the melting-point of the element manganese were carried out at the beginning of 1902 by Heraeus, of Hanau, in a specially constructed furnace of the tube pattern, devised by this firm. The furnace consisted of a porcelain tube, 16 m.m. in diameter and 30 c.m. long. Around a portion of this tube is wound, spirally, the heating resistance, in the shape of a strip of platinum foil.

Efficient and gradual regulation of the temperature is secured by means of an adjustable resistance connected in series with the foil. With this arrangement a temperature of 1,400°C. = 2,552°F. could be attained within three minutes of switching on the current, whilst the maximum temperature available was 1,600°C. = 2,912°F.

Addressing a meeting of the German Electro-Chemical Society in the same year, Dr. Haagn, chemist to the firm of Heraeus, expatiated upon the advantages of this new form of laboratory tube furnace construction.

The heating resistances in previous furnaces of a similar type have been wire, and Dr. Haagn estimates the weight of platinum required when foil is used to be only $\frac{1}{16}$ to $\frac{1}{10}$ that necessary in a wire resistance.

Referring to the tubes, the same authority stated that glass or porcelain was preferable to magnesia, as a safeguard against electrolytic dissociation and consequent injury to the platinum heater in the neighbourhood of the cathode. Above a temperature of 1,500°C. = 2,732°F., the same effect is observed even with tubes constructed of the best Berlin porcelain, but, with specially manufactured tubes, a temperature as high as 1,700°C. = 3,092°F. has been maintained for a short period without injury.

Dr. Haagn recommends this type of furnace for use in chemical and physical laboratories, and points out its applicability to such operations as ash determinations, organic combustion analysis, the direct determination of carbon in steel by the Lorenz method, etc.

A subdivision of the special heating resistance, with suitable provision for separate terminal connexions to each section, largely increases the range of utility of this furnace, in that it enables the heating of various sections of the tubular hearth to be carried out independently or together, at the will of the operator.

The platinum foil employed in the Heraeus tube furnace is 0·007 m.m. thick. The furnace is easily regulated by means of a series resistance. These furnaces can be made for any voltage up to 220, but, for very high temperatures, low voltages are said to answer best.

A modification of the Heraeus furnace, for heating porcelain tubes, etc., was described in the *Journal de Chimie Physique* (1903, I. 177) by M. A. Guntz. The foundation consists of a tube of refractory earths, several millimetres thick ; 60 m.m. longer, and with an internal diameter or bore, from four to five m.m. larger than the external diameter of the tube or article to be heated. This tube is given several coats of a paste made up of magnesia and alumina, mixed either in the proportion of equal molecules of the two oxides, or eight molecules, of magnesia to one of alumina, to which some gelatinous alumina, or a weak solution of aluminium acetate, is added as a binding material.

An alternative paste is made up of one part strongly ignited alumina ; one part of alumina obtained by incomplete calcination of ammonium alum, and one part calcium aluminate, prepared by heating to redness, equal weights of alumina and pure chalk. No appreciable trace of silica should be present in the ingredients.

The layers of paste are dried naturally in air, as the result of which, they adhere well. The dimensions of the

platinum wire required to produce a pre-determined heating effect are then calculated from the equation—

$$E = 4 \cdot 4R \frac{1}{S} \times C$$

Where E represents the maximum available voltage,
    ,,   C   ,,   ,,   current,
    ,,   S   ,,   ,,   section of the wire,
    ,,   1   ,,   ,,   length of the wire,
and   R   ,,   ,,   resistivity of one metre of platinum wire, having a cross-section of one square millimetre, a quantity which requires to be ascertained for the particular sample available.

Having thus found the length and diameter, a simple calculation will serve to determine the number of turns to be coiled on the tube ; suffice it to say that, unless a specially rapid heating effect be desired, neighbouring turns should not be less than 5 m.m. apart. Having determined the number and pitch of the spirals, a suitable thread or groove, about ·5 m.m. deep, is chased in the prepared coating of the tube. The platinum wire is laid in place in the groove thus prepared for its reception, the two end turns being double, and tied, or otherwise secured in place.

A number of coats of the original paste are then applied over all, to a thickness of four or five millimetres, the whole being then encased in a sheet of asbestos. A weak current is first passed through the spiral, warming it sufficiently to drive the moisture out of the paste, which should remain firm. In the event of cracking, the openings must be filled in with paste. A final jacket of asbestos sheet, on which are mounted suitable terminals, completes the construction.

SECTION XII

Terminal Connexions and Electrodes

The terminal connexions to the electrodes of electric furnaces have long been a source of trouble to the operator, and an object for the application of the inventor's genius and forethought. There are several important points to be considered in the design of an efficient terminal connexion to carry the large currents met with in electric furnace work.

(1) They must possess a certain amount of flexibility in order to allow of the necessary adjustments.

(2) They must establish good electrical connexion with the electrode on the one hand, and with the conducting cables on the other.

(3) They must not become unduly heated when the furnace is at work.

(4) They must not be of such a nature as to radiate a considerable percentage of heat and thereby lead to a serious reduction in the efficiency of the furnace.

Many and varied are the designs which have been evolved from time to time, with a view to meeting all these requirements in one and the same device, and, although some considerable improvement in the means for transmitting the current to the furnace electrodes has undoubtedly been effected during the last few years, there is still a good deal of room for more, and those interested in furnace industries might do worse than turn their attention at spare moments to the improvement of this important accessory, which, if badly designed, is quite capable of wasting several horse-power in a plant of moderate capacity.

One of the earlier Cowles' furnaces was provided with a somewhat novel terminal arrangement, which has since fallen into disuse. It consisted of a species of metallic gland or stuffing box, filled with copper shot, through the centre of which passed the electrodes. These latter set up a good rubbing contact with the shot, and, through them, with the metallic sleeves ; a contact which was, in fact, improved by use, in that the motion of the electrodes, in feeding them forward into the furnace, revolved the shot, and brought fresh clean surfaces into contact with one another.

In furnaces having a suspended electrode it is frequently arranged that the support for this latter shall also serve to convey the current to it. This construction answers very well for furnaces of moderate size, but is not suitable for larger types, in that the two governing features, conductivity and strength, do not increase in like proportion.

A form of terminal connexion, devised with a view to overcoming this difficulty, has been patented by Fausto Morani, his apparatus consisting of a supporting frame for the electrode, which is separate and distinct from the electrical connexion thereto. Both attachments are furnished with means for the circulation of water for cooling purposes.

E. G. Acheson, one of the recognized leaders in the field of electric furnace work, has also attacked the problem, his latest design of terminal for resistance furnaces being capable of dealing efficiently with so large a current as 37,500 ampères, and this with a total cross-section of only 1,152 square inches, representing an approximate current density of 32·5 ampères to the square inch.

A transverse section of the terminal is shown in Fig. 56. It comprises 72 square blocks C C of graphitized carbon, each having a cross-sectional area of 16 square inches. These are placed in block form, as close together as possible, and end on to a copper plate A, to which they are clamped by studs S, and nuts N. One of the attachments is shown in section in the figure, and it will be seen that the portion

of the stud *s*, which screws into the carbon block C, is larger in diameter than the portion projecting through the copper plate, thus furnishing a shoulder which butts up against a raised portion of the latter, and takes all strain, arising out of the clamping, off the carbon itself.
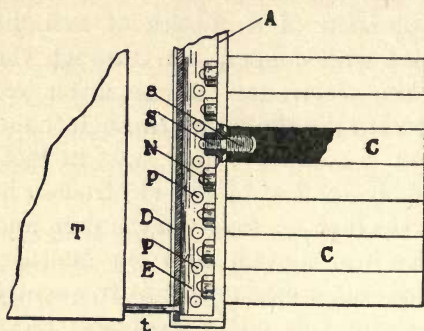
FIG. 56.

The copper plate A constitutes one wall of a flat water tank, the remaining wall D being of sheet metal. The sides and bottom of the tank are formed of flanged pieces E, into circular openings *p p*, in which, a series of cable ends, forming the main electrical connexions to the electrode, are sweated. A tank T, in which a constant level of water is maintained, communicates with the flat tank or base of the electrode by a pipe *t*, and a constant circulation of cooling water is thus secured.

The following are among the difficulties experienced in designing an efficient and convenient form of terminal connexion for electric furnaces employing carbon electrodes.

In the first place, metal has a higher expansion co-efficient than carbon ; consequently the heat conducted from the furnace itself, together with the hot gases produced, and which tend to make their escape, among other places, at the point of entry of the electrodes through the furnace walls, both tend to expand the metal portions to a greater extent than the corresponding parts of the carbon electrodes. A small air-gap is consequently created between the two, and the electrical resistance at the surfaces of contact rises very rapidly. This, in itself, sets up a further heating effect, which may, in extreme cases, be heightened by arcing,

set up between two widely separated points, which ultimately tends to destroy the connexion entirely from an electrical point of view.

Chavarria Contardo's patent form of terminal connexion for electric furnaces is both ingenious and convenient, in that it permits the necessary sliding movement of the carbons, to compensate for combustion and wear, without disturbing the electrical connexions thereto.

Cylindrical carbons are employed, and they slide in water-jacketed sleeves, let into the wall of the furnace structure. Electrical connexion with the sleeve is rendered secure, and a low resistance path provided for the current, by prolongations of the metal sleeves, consisting of a series of bronze segments, which encircle the carbon electrode, and are maintained in intimate contact with it by means of set screws. A thin packing of sheet copper is usually interposed between the bronze segments and the surface of the carbon, for the better protection of the former.

Some saving in space, and length of active circuit, may be effected by employing hollow segments, which are themselves water-cooled, thus avoiding the necessity for the complete metal sleeve alluded to above.

The connecting cable is either in multiple, or, if in single form, is split up into a series of strands corresponding with the number of bronze segments, one such strand or cable being connected to each segment by a suitable mechanical joint, thus ensuring an even distribution of the current through the mass of the electrode.

This construction not only permits, as already stated, a sliding feed adjustment of the electrodes, but also a constant feed, even when a length of carbon becomes too short to be of any further use by itself. The procedure then consists in making a joint outside the furnace, between it and the new electrode and rendering the same secure by a species of graphitic cement.

The Cowles' form of terminal connexion for open furnaces

consists in a metal socket for the reception of the carbon electrode. A water-cooling jacket is arranged in close proximity to the metal socket, and an inlet pipe is fitted in such a position that the ingoing water strikes against that wall of the jacket which adjoins the electrode socket.

An outlet is also provided so that a constant circulation may be maintained.

A form of water-cooled terminal connexion, designed by O. Imray, is adapted to electrodes of the suspended type. The carbon block forming the electrode is suspended from a species of metal cross-head, above, by yoke pieces, shaped to suit the block, and secured to the supporting cross-head by bolts and nuts. The length of the yoke pieces is such that the cross-head and its attached parts are sufficiently removed from the heat-zone which surrounds the upper part of the carbon electrode.

Electrical connexion with the carbon block is secured by a metal capping, which either butts up flat against its upper extremity, or is shaped so as to encircle the block for a short distance down. This capping is connected with the cross-head by a central metal tube, and is water-jacketed as regards its surface of contact with the carbon. The upper end of the tube is jointed to the main conductor, whilst axially through its centre runs a second smaller tube or inlet for the water supply, which it delivers, as already stated, just above the metallic wall which is in contact with the carbon. Openings or outlets for the water are provided in the outer tube, and provision is made for a complete circulatory system, whereby the yoke pieces themselves are also kept cool.

In conjunction with this patent is described a special form of outlet for molten furnace products. Instead of the usual tapping hole, with its attendant drawbacks, slits are made in the wall of the furnace, and lined, for protection, with steel, or equally suitable metal, which is, in turn, water-jacketed.

The form of water-cooled terminal construction originally adopted for the Pictet carbide furnaces at Ingleton, is shown in Fig. 57. The main cable M, consisting of stranded No. 19 B.W.G. copper wire, made up to a cross-section equal to three square inches of solid copper, is compressed into rectangular form, with dimensions, $2\frac{1}{2}$ by 2 in., and sweated into the metal socket S, which is water-jacketed as shown. The square extremity of the carbon electrode C, 6 by 6 in., is socketed into the other extremity of the terminal, which is mounted on a travelling carriage A, moved along the slide B, as occasion requires, by means of a screw and hand-wheel W. 2,000 ampères were effectually dealt with by this form of terminal construction.
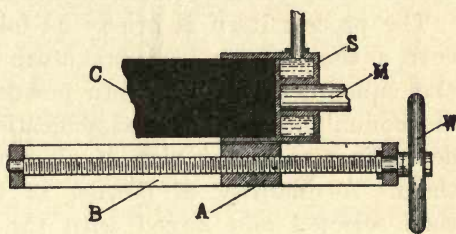
FIG. 57.

Electrodes.—As may be readily imagined, the consumption of electrodes in the electric furnace, especially where such furnaces are worked on an extensive scale, as in carbide manufacture, is by no means inconsiderable.

Several firms have, in consequence, taken up the manufacture of electrodes for use in their own furnaces. Among these may be mentioned the Société des Carbures Métalliques, which owns carbide factories situated at Notre Dame de Briancon, Le Castelet, Bellegarde, and Berga. The electrode factory is situated at the first named, and the following essential features of the manufacturing process are extracted from an article on the subject by M. G. Strauss, which appeared in the *Revue Général de Chimie Pure et Appliqué* in 1901.

The raw materials are retort carbon, petroleum coke, and coal tar. The first named is obtained in varying qualities, and calls for thorough mixing to ensure homogeneity

in the finished product. The second, petroleum coke, is a porous residue, produced in the distillation of crude petroleum. It is employed specially in the manufacture of very hard and dense electrodes such as are used in electrolytic furnaces with fused electrolytes, and is very pure. The coal tar, used as a binding material, is either produced in process of refining ammonia, from which it distils over at a temperature of from 240° to 330°F. =115° to 166°C., or it may take the form of a mixture, artificially prepared, by dissolving pitch at steam heat in a heavy tar oil.

The process itself is briefly as follows. The carbon or coke, as the case may be, is first crushed in special machinery, and subsequently sieved into powders of varying degrees of comminution, their classification and ultimate use depending upon the size of electrode to be made from them. A quantity of powder of the required grade is then selected and mixed with the requisite quantity of coal tar, in steam-jacketed vessels, after which the mixture is ground under heavy edge runners. From the grinding process it emerges as a thin, flat, plastic cake, ready for compressing and moulding into shape. To this end, it is formed, by hydraulic pressure, into " cartridges," or ingots, which may weigh anything from 180 kgs. to a ton, according to the size of electrode required. The latter are finally shaped by extrusion from a die under enormous hydraulic pressure, amounting to as much as 2,000 tons for the larger sizes.

All that remains before the electrodes are finally ready for use in the furnaces, is to stove them, a process carried out in a Siemens regenerative furnace, worked continuously, the electrodes being packed for the purpose in muffles, and the interstices filled in with carbon dust. This final stoving occupies a period of several days.

To ensure a satisfactory product, periodical tests for electrical conductivity are made, by fastening a sample of the electrode in a vertical position in a metal mould. Molten

lead is then poured in at either end to establish electrical contact with the carbon surfaces, and holes, drilled in the two lead castings, at a certain pre-determined distance apart, serve as mercury cups for terminal connexion to the testing apparatus, which takes the form of a Thomson low resistance bridge.

The conductivity is an extremely variable quantity, depending in turn upon the nature of the raw materials used, and upon each and every stage of the manufacturing process.

Current density and temperature have a most important bearing upon the life of electrodes, more particularly anodes, in an electrolytic bath. Graphitized carbon is less susceptible to disintegration than ordinary carbon. The Castner alkali process was originally worked with carbon electrodes graphitized by the inventor's own process, which consisted in packing ordinary carbons in carbon dust, and subjecting them to a white heat in an electric furnace.

Graphitized carbon electrodes, as manufactured at Niagara Falls, under the Acheson patents, are now largely used in electrolytic works.

The electrodes used in the manufacture of aluminium must be free from silica and silicates, which, if present as impurities, lead to the formation of silicon fluoride, by reaction with the fluorine, thus robbing the bath of the latter element. Silica also is liable to reduction by the lower strata of aluminium in the bath, a reaction which would destroy the purity of the product. Hydrocarbons may be present in the carbon electrodes used for aluminium manufacture, and have no deleterious effect ; the carbon should, however, be free from ash.

In carbide manufacture, on the other hand, the presence of hydrocarbons and silica in the carbons of the electrodes is immaterial, but phosphate impurities are debarred, as they lead to the formation of calcium phosphide, with the result that the acetylene gas generated from the resultant

carbide is rendered impure by admixture with phosphoretted hydrogen.

The choice of suitable carbon electrodes for the various electric furnace operations detailed in this book, though seldom thus regarded, is, in reality, one of the most important features in electric furnace design, contributing, as it does, in no small measure, to the efficiency of the process, purity of the product, and last, but by no means least, as a reference to some of the cost statistics already given, will show, the cost of the process.

Carbon exists in various polymeric forms, amorphous carbon, sp. gr. 1·7 ; graphite, sp. gr. 2·25 ; diamond, sp. gr. 3·5 ; and various other equally well-known varieties.

The following is an account of the method of electrode manufacture as adopted by the British Aluminium Company, and furnished by Mr. John Sutherland to the *Electro-Chemist and Metallurgist*, for April, 1901.

" Carbon electrodes for the reduction of aluminium may be made from any form of pure carbon. The materials generally used by the various carbon works are retort carbon, petroleum coke, soot, anthracite, and Ceylon graphite. The crude material is first dried or roasted, to eliminate water, or any organic impurities, and then ground in a roller or ball mill. The ground carbon is then passed to the mixer, where it is thoroughly mixed with anhydrous tar, in sufficient quantity to make it bind together properly. The mixers in use are various, but those made by Werner and Pfleiderer seem to answer best. The mixture of tar and carbon having been thoroughly incorporated, so that each grain of carbon has its own coating of tar, is ready for formation into blocks, which is effected in an hydraulic press, and the carbons may be either squirted, or pressed direct.

" The next step in the process is the baking of the carbons, which is done in a furnace, heated, preferably, by gaseous fuel. The style of furnace is not important, pro-

vided the goods are not heated or cooled too quickly, and a high temperature is obtained. During the baking, the carbons are packed in carbon powder to protect them from oxidization.

" *Good carbons* should emit a distinct metallic sound when struck, and should not be porous. Unfortunately there is no distinguishing test for electrodes ; the only means to determine between good and bad ones is to put them through the ordinary process in the electric furnaces, and observe their behaviour therein."

Mr. F. A. Fitzgerald, of the International Acheson Graphite Company, has pointed out (Paper before Niagara Falls Convention of American Electro-Chemical Society) that in both electro-chemical and electro-metallurgical processes, involving the use of carbon electrodes, the determination of the density of the latter is an important point, in that the general efficiency of the electrode depends upon the nature of the carbon, and consequently on its density. It is desirable to know both the real and apparent densities, for, having given these two quantities, the porosity of the electrode can be arrived at by calculation. In this connexion, it may be added that the *real density* is that of the carbon composing the electrode, whilst the *apparent density* is the ratio of the weight of the electrode to its volume taken as a whole. The *porosity* is the ratio of the difference of the volume of the electrode taken as a whole, and the volume of the carbon of which it is composed, to the volume of the electrode taken as a whole.

Owing to the retention of air by amorphous carbon and graphite, the determination of the real density is not easily accomplished. Mr. Fitzgerald employs a volumeter, fitted with a rubber stopper and air-pump connexion. The volumeter, partly filled with kerosene, is placed in a water bath and a reading taken. A specimen of the electrode to be tested is weighed and placed in the volumeter, which is then exhausted of air by means of the pump. When the

maximum attainable vacuum has been reached, and maintained for a period of ten minutes, the pump is disconnected and a reading again taken, after which the operation is repeated until two equal consecutive readings are obtained. Then the difference between this last and the original reading of the volumeter represents the actual volume of the sample, and the real density is calculated from it.

The apparent density of the *same* sample is now determined by coating it lightly with shellac, and immersing it in water in the volumeter, which then indicates the apparent volume by displacement ; the apparent density is arrived at, as before, by calculation.

Mr. Fitzgerald also points out that, in view of the fact that, for electro-metallurgical purposes, electrodes of pure graphite are preferable, it is desirable that some test be instituted to determine whether such electrodes are entirely composed of graphite, or whether they include amorphous carbon in their composition, in which latter case they are especially subject to disintegration.

Mr. C. M. Hall, the inventor of the aluminium process which bears his name, has devised a method of baking carbon electrodes, especially those intended for aluminium manufacture, in an electric furnace of the resistance type. To this end, the carbons are disposed either in horizontal or vertical rows, around a carbon core, from which they are insulated, and from one another by a refractory and non-conducting powder, such as bauxite, purified alumina, magnesia, etc. The core is preferably made up of granular charcoal or coke, but a fused electrolyte is also suggested.

By passing a suitable current through the core, the carbons are raised to a temperature of 1,647° to 2,202°C. = 3,000° to 4,000°F., very little current actually passing through the carbons themselves. The following data are suggested. A core, 4 or 5 ft. in length, and 12 by 30 in. in cross-sectional area, requires to have developed therein 400 to 500 H.P., by an alternating current at 35–40 volts.

SECTION XIII

EFFICIENCY AND THEORETICAL CONSIDERATIONS

The efficiency of a simple electric furnace is the ratio of the heat energy of the electric current usefully applied to bring about the operation of the furnace, to the total heat energy generated.

The heat energy usefully applied in an electric furnace operation is absorbed by one or both of two requirements, viz. :—

(1) The heat energy necessary to raise the temperature of the furnace charge to that point at which the desired reaction occurs.

(2) The heat energy taken up by the reaction itself.

Both quantities can be determined by calculation ; the former, from the mass, specific heats, latent heat of fusion, and temperature, whilst the latter can be obtained from known thermo-chemical data.

The efficiency of an electric furnace is governed by many factors, for the greater part incidental to the particular process and type of furnace under consideration. Such general determinants as size, temperature of reaction, radiation, disposition of terminals, etc., may, however, be cited as controlling factors, especially the first named, size, or dimensions of the furnace.

A little consideration will serve to show the importance of this point. The capacity or cubic contents of a furnace increase approximately as the cube of the linear dimensions, whilst the surface available for radiation, one of the principal channels through which heat energy is lost or wasted,

only increases as the square of the linear dimensions; in other words, the possibility of radiation losses does not increase in direct proportion to the increase in capacity of the furnace, so that a large furnace is far more efficient than a small one. The general tendency therefore should be towards an increase in the dimensions and capacity of electric furnaces, only limited by mechanical or other considerations.

The subject of electric furnace efficiency was most ably dealt with by Prof. J. W. Richards, Ph.D., in a Paper read before the American Electro-Chemical Society in 1902. For purposes of discussion, Prof. Richards classifies electric furnaces generally under two main heads, viz.—

(1) Those in which the charge is simply heated without any chemical change taking place ; and

(2) Those in which, beside the heating of the charge, there is also a chemical change.

A further subdivision is based upon the solid or fused condition of the charge. We thus have four sub-headings, viz.—

(1) Heating without fusion and without chemical change,
(2)   ,,   with   ,,   ,,   ,,   ,,   ,,
(3)   ,,   without ,,   ,,   with   ,,   ,,
(4)   ,,   with   ,,   ,,   ,,   ,,   ,,

which include nearly all the furnaces and furnace operations described in this book, always excepting, of course, the electrolytic section, in which the efficiency of the electrolysis itself is a controlling feature, and must be duly considered in arriving at the total efficiency of the furnace or process.

As an example of No. 1 of the above sub-headings, we have the Acheson graphite furnace, in which anthracite coal is converted into graphite. Chemical changes do, of course, accompany the process, in the shape of progressive formation and decomposition of carbides, but, from the point of view of efficiency, they are negligible, in that the

heat energy absorbed exactly counterbalances that evolved. The actual conversion of amorphous carbon into graphite is accompanied by the evolution of heat, and therefore once the temperature of reaction is reached, actually assists the current in bringing about the desired result.

Roughly speaking, 5,450 kgs. of anthracite are converted into 4,550 kgs. of graphite by an expenditure of 1,000 H.P. for twenty hours. The heat actually evolved by the reaction itself is some 10 per cent. of that supplied by the current ; the total heat energy is therefore 110 per cent. of the heat energy available from the current, of which 82·5 per cent. is utilized, showing an efficiency of $82·5 \div 110 = 75$ per cent.

Passing on to a consideration of the allied Acheson process of graphitizing electrodes, described in the resistance furnace section, 3,175 kgs. of electrodes, embedded in the same weight of granular carbon, call for an expenditure of 1,000 H.P., the efficiency of the process being 38 per cent.

Class No. 2, above, is exemplified in the Jacobs process of fusing calcined bauxite. The process is one of simple fusion, carried out in a cylindrical crucible or hearth, by the heat of the arc, there being no accompanying chemical action. The efficiency, with a 1,360 kg. charge, is 74 per cent.

Carborundum manufacture is cited as an example in Class 3, with a calculated efficiency of 76·5 per cent.

Under Class 4, the manufacture of calcium carbide is the best known example, with a net calculated efficiency of 63 per cent.

The principal difficulty attendant on the calculation of the efficiency of many electric furnace processes is the present scarcity of data concerning the specific heat of the various substances treated, at high temperatures. An extensive scheme of research in this direction would doubtless result in an increase of reliable data ; it is, however, a matter of time, and, until this information has been gathered

together, the calculation of electric furnace efficiencies must necessarily be approximate, rather than exact.

Summarizing the facts at his command, Prof. Richards sets down a general figure of 60–75 per cent. as the average commercial efficiency of furnaces varying in power from 200–1,000 H.P.

Taking the case of the Acker process, the 8,000 ampères consumed in each furnace should yield, theoretically, 287 kgs. of caustic per twenty-four hours. In actual practice, with a yield of 264 kgs., the current efficiency is 93 per cent. The voltage theoretically required for the electrolysis of fused sodium chloride is 4·2, therefore the total or energy efficiency of the process is in the neighbourhood of 55 per cent. This low efficiency is in part due to the heat energy consumed in fusing the cold salt, and bringing it up to the reaction temperature.

The general principle and disposition of a commercial electric furnace would not, at first sight, appear to lend itself very readily to theoretical consideration ; nevertheless, Mr. F. A. Fitzgerald, in a Paper entitled " Note on Some Theoretical Considerations in the Construction of Resistance Furnaces," which he read before a Niagara Falls meeting of the American-Electro-Chemical Society in 1903, treated his hearers to a mathematical disquisition on the theory of resistance furnaces, taking as his subject the well known Acheson type, used in the manufacture of carborundum, graphite, etc.

In all these furnaces, the electrical resistance is a variable quantity, usually diminishing towards the end of a run, and it is obviously impossible to effect regulation in the interior of the furnace, except, perhaps, in the case of that particular example used in the graphitizing of electrodes, where some little adjustment is possible by varying the spaces between neighbouring piles of electrodes under treatment.

Regarding the distribution of heat in these furnaces

Fitzgerald reasons as follows : If a cylinder (core) with radius, p^1 and length L, is kept at a constant temperature, θ_1, the quantity of heat, Q, passing through the surrounding material, the inner surface of which is at the temperature θ_2 per second, is $Q = 2\pi p^1$ LK $(\theta_1 - \theta_2)$, where K is a constant. Thus—$\theta_1 - \theta_2 = \dfrac{Q}{2\pi p_1 LK}$.

If the material outside the core is also a cylinder, with a radius p_2, a heat conductivity of K_1, and a temperature at its outer surface of θ_3, $Q = \dfrac{2\pi LK_1(\theta_2 - \theta_3)}{\log \dfrac{p_2}{p_1}}$

while between the outside of the cylinder of material under treatment and the walls of the furnace, the passage of heat per second is similarly—$q = \dfrac{2\pi Lk\ (\theta_3 - \theta_4)}{\log \dfrac{p_3}{p_2}}$

or, if $p_2 - p_3 = t$, and is very small—

$$q = 2\pi Lk\ (\theta_3 - \theta_4)\ \frac{p_2}{t}.$$

Now, since the efficiency of the furnace is $\dfrac{Q - q}{Q}$, K, and $\theta_3 - \theta_4$ must be kept small to make q small. Graphite and electrode furnaces, however, cannot be made indefinitely large, because the last equation shows q to vary directly as the product of L, and p_2.

In the case of the carborundum furnace, the chief equation may be written—

$$\log \frac{p_2}{p_1} = \frac{2\pi LK_1\ (\theta_2 - \theta_3)}{Q}.$$

To make the largest amount of carborundum, K_1 must be as great as possible, this being effected by having the mixture surrounding the core, of high density, for then the crystal mass formed will be also dense.

$-\theta_3$ should also be large; but the latter is fixed at a temperature just below that of the formation of carborundum, while θ_2 can only be raised to a point short of its decomposition. As regards the outside of the carborundum cylinder, nothing can be done to diminish k, but $\theta_3 - \theta_4$ may be kept small by having a good thickness of raw material always present. Since the value of p_2 increases with the length of the run, a point will eventually be reached where $q = Q$ in the efficiency equation, so that a time comes when no more carborundum is made. To work efficiently, the furnace must be stopped long before this happens.

According to MM. Gin and Leleux (*Comptes Rendus*, 126, pp. 36), the temperature of the arc, when employed for heating purposes, may be computed from the equation—

$$t = \frac{1}{A} \left(\frac{1}{S}\right)^2 \frac{p}{c}.$$

where p is the resistance of the envelope of gas,

c is the specific heat of gas per unit of volume,

s is the sectional area of the electrodes,

t is the temperature of the arc.

Expressed in words, this formula tells us that the temperature (t) increases directly as the square of the current density, and directly as the ratio of the total resistance of the gaseous envelope to the specific heat per unit volume of the same.

M. Gin has since supplemented this formula by others (*Elektrochemische Zeitschrift*, May, 1902) representing temperature changes and efficiency of the arc furnace, assuming, contrary to the above reasoning, that the medium surrounding the electrodes, in the neighbourhood of the arc, is a conductor. They are as follows—

Let l be the length of the separating medium

s	,,	diameter	,,	,,	
p	,,	resistance	,,	,,	
c	,,	specific heat	,,	,,	based

on unit volume.

Then the amount of energy converted into heat in unit time is C^2R, and the corresponding heat evolved is

$$\frac{l}{A}\left(\frac{l}{s}\right)^2 \ pls.$$

If the arc be surrounded by a heat insulating substance, the equation becomes $\frac{l}{A}\left(\frac{l}{s}\right) pls = clst$, from which it will be seen that the temperature of the arc in the mass, will increase in proportion to the square of the current density, a condition which holds good, whether the intervening medium between the electrodes be in a gaseous or fluid state.

M. Gin's formulae for calculating the temperature of a resistance furnace are somewhat complicated, and are, moreover, based on certain assumptions, which render results more or less approximate.

In applying the following equations, the quantities must be expressed in gramme-calories.

Let Cs be the mean specific heat of the core, or other substance, in a solid state.

Cf be its latent heat of fusion.

Cl be its mean specific heat in a fluid state.

Cr be the heat absorbed as a result of the chemical changes.

P be the weight of the substance passing through the furnace in unit time, when in full operation.

Tf be its temperature of fusion.

Let Tr be the temperature at which the reaction occurs, and Σ be the total superficial area of the exterior of the furnace from which radiation occurs.

Then—

$$EJ = 1 \cdot 16 \ [P \ (CsTf + Cf + Cl \ (Tr - Tf) \ + Cr) + K \ \Sigma \ STr].$$

From this, Tr can be approximately calculated. Since $K \Sigma S$ is a constant for one type of furnace, it may be written K ; then, omitting CsTf, the equation simplifies down to—

$$EJ = 1 \cdot 16 \ [P(Cf + Cr + Cl \ (Tr - Tf) + KTr].$$

whilst the effective work of the furnace is represented by the formula—

$$\frac{P\,[\ Cf + Cr + Cl\ (Tr - Tf)]}{P\,[Cf + Cr + Cl\ (Tr - Tf)] + KTr,}$$

from which it follows that the lower the temperature at which the desired reaction takes place, the lower will be the thermal efficiency of the furnace, whilst the latter will increase in proportion to the heat absorbed by the various changes, both chemical and physical, taking place in the substance of the furnace charge as a result of the reaction.

SECTION XIV

MEASUREMENT OF FURNACE TEMPERATURES

It is necessary for the sake of uniformity, as also for purposes of research, and the general advancement of scientific knowledge concerning the reactions which take place in the electric furnace at high temperatures, that some convenient and reliable means be provided for indicating, and, if necessary, recording, the temperature at which any particular operation is being carried out. The provision of such means for high temperature measurement is by no means so simple as would appear at first sight.

Owing to the extremely high degree of heat which a furnace of the electrical variety is capable of evolving, it is impossible to introduce anything in the nature of a thermometer structure into the furnace itself, without risk of its speedy destruction, either by fusion or combustion.

The ordinary types of thermometer which depend, for their action, on the expansion, under heat, of a column of liquid are, of course, out of the question, and it becomes necessary to fall back upon some method, which either permits the use of a very refractory material in the thermometer bulb proper, or, for still higher temperatures, involves a comparison by simple observation, between the temperature of the furnace and that of a known standard, which can be safely manipulated from a point external to the furnace itself.

So far as our present knowledge carries us, the only two reliable and exact methods of direct furnace temperature measurement depend upon a portion of the apparatus being

subjected to the direct heat of the furnace, and their range is, in consequence, somewhat limited. Some very accurate and valuable records of temperature have nevertheless been obtained by their aid. They are both of an electrical character, and depend for their action, the one upon the rise in electrical resistance of a short length of platinum wire, when subjected to heat, and the other, upon the electro-motive force set up at the hot junction of a refractory thermo-couple.

Much valuable work in the perfecting of these two thermo-electric methods of high temperature measurement, and the means for accurately indicating and recording the temperatures registered by them, has been done by Profs. Callendar and Griffiths, their various designs being worked out and manufactured on a commercial scale by the Cambridge Scientific Instrument Company. No work on the industrial application of high temperatures would be complete without a description of these various forms of apparatus, and we will therefore proceed to briefly discuss them in their bearing on electric furnace work.

Of the two methods of electric thermometry, just considered, the resistance method yields the more accurate results up to about $600°C. = 1,112°F.$; whilst, on the other hand, the thermo-couple method has a greater range, and permits the measurement of high temperatures in very small enclosures. Its comparatively negligible time lag also renders it especially suitable in cases where a continuous record of rapidly varying temperatures is desired.

Reverting for the moment to a consideration of the platinum resistance thermometer, Professor H. L. Callendar, in an article in the *Philosophical Magazine* for December, 1899, adduces several reasons for its adoption as a practical standard for high temperature measurements, chief among which may be cited the facility for establishing such a standard in any part of the world, it only being necessary to send a few grammes of the standard wire in an ordinary

letter to any desired spot in order to reproduce the scale with great accuracy.

A paper by Mr. H. M. Tory, on his investigations into the probable order of accuracy obtainable in comparing high temperatures by means of commercial samples of platinum wire, was read by Professor Callendar before the Physical Society on June 22, 1900. Five different samples in all were subjected to comparison, each wire being directly compared with a pure platinum standard by winding the two side by side on the same thermometric tube. It was found that between 400° and 1,000°C. =752° and 1,832°F., the fundamental coefficients of the wires varied within 40 per cent. of the maximum value, but that the temperatures registered by them, when calculated on the platinum scale by means of the ordinary formula, did not differ by more than 9° at 1,000°C.

Curves were plotted from the results obtained, having the platinum temperatures of the standard wire as abscissae and the difference between the temperatures indicated by the two wires under comparison, as ordinates. Within the limits of observation these were all straight lines, thus indicating that it is only necessary to determine two constants in order to compare a commercial platinum resistance thermometer with the standard, and therefore with the scale of the gas thermometer usually accepted as a primary standard. These two constants are obtainable from observations at the boiling point of sulphur and the freezing point of silver, permitting the construction of a practical thermometric scale, which, between 0° and 1,000° does not vary from the gas scale by more than two or three degrees.

In No. 435, *Proceedings of the Royal Society*, C. Chree treats of some important investigations carried out at Kew Observatory with a view to determining the accuracy of platinum resistance thermometry. Six of these thermometers were tested by means of a Callendar-Griffiths resist-

ance bridge, and no less than thirteen possible sources of error were discovered. Among the principal ones are thermo-electric currents, set up at the various junctions; heating of the resistance wire by the battery current employed in taking the temperature resistance measurements; errors in the temperature coefficient for the particular sample of platinum wire used; insufficient immersion in the substance or space, whose temperature it is required to measure, and excessive time lag, or slowness in acquiring the temperature of the surrounding medium.

The effects of insufficient immersion, resulting in heat being conducted away through the leads and external connexions is, for commercial work, negligible, though it may, if the total immersion be less than 10 c.m., amount to as much as $0.01°C.$, or even more.

The time lag calls for more consideration, especially if the thermometer tube be only inserted in the furnace at intervals, and thus not left continually immersed.

The six thermometers tested were found to take from four to five times as long in acquiring the temperature of the surrounding furnace atmosphere, as a mercurial thermometer.

So important a value has the platinum resistance method of high temperature measurement acquired of late years, that in 1887 Professor Callendar, by dint of elaborate and careful investigations which he then made into the possibilities of this method of thermometry, introduced the scheme of "Platinum Temperatures," or the Platinum Scale, which is a standard for the platinum resistance method of thermometry, just as the Fahrenheit, Centigrade, and Réaumur scales are standards for the previously existing mercurial instruments. These platinum temperatures are obtained from the formula—

$$pt = \frac{R - Ro}{R1 - Ro} 100$$

where pt is the platinum temperature, corresponding with

the ohmic resistance R of a given wire, the resistance of which at 100°C. and 0°C. = 212°F. and 32°F. are R1 and Ro respectively.

The researches of Professors Callendar, Dewar, Fleming, Griffiths and others show that this law holds good for all temperatures between −200°C. and 1,300°C. = −328°F. and 2,372°F., irrespective of the extremes and rapid variations of temperature to which the wire may be subjected, provided it be carefully annealed ; and that the platinum wire invariably offers the same resistance at the same temperature.

So far, however, as the actual variation of resistance with temperature goes, the law appears to be of a complicated nature.

Among others, J. D. Hamilton has investigated this subject, and in the *Philosophical Magazine* for December, 1897, he suggests the formula—

$$(R + a)^2 = p\ (t + b),$$

where a, p, and b are constants, and R and t the resistance and temperature respectively. This most nearly represents the results hitherto obtained. The constants have, however, to be individually obtained for each wire by a series of careful observations.

Messrs. Crompton & Co., of Chelmsford, in this country, and Messrs. Hartmann & Braun, of Frankfort, both manufacture a direct reading electrical thermometer based on the platinum resistance principle. The indicator itself, resembles a direct-reading ohm-meter, and consists of two intersecting coils, mounted, and capable of rotation in a non-homogeneous magnetic field. A standard resistance of known value is included in the circuit of one coil, whilst the other is connected with the coil of the resistance thermometer. The latter, for high temperatures, is constructed, as usual, of platinum, whilst, for lower degrees of heat, a " nickelin " wire is employed. The scale is graduated

directly in degrees, and has a range extending up to 1,200°C., the highest temperature that can be measured by its aid.

For regular and constant use an open scale in the neighbourhood of the most usual temperatures under measurement can be obtained by a suitable adjustment of the shape of the pole pieces.

The current required to actuate the indicator is only 0·03 ampère at 5 volts.

Messrs. Siemens Bros. also manufacture a convenient form of platinum resistance pyrometer, in which the resistance wire is wound upon a refractory cylinder, and protected, for the greater part of its length, by an iron tube ; being additionally safeguarded at its active extremity, which is exposed to the direct heat of the furnace, by a platinum shield. An increase in the resistance of the platinum spiral, from 10 ohms to 44·9 ohms, corresponds with a rise in temperature from 14°C. to 1,205°C. =58°F. to 2,204°F. Two methods of reading the indications are provided by the makers, either one of which can be adopted. One consists of a differential galvanometer and a set of resistance coils, which, used in conjunction with a battery, give the required resistance in ohms, the corresponding temperature being read off a scale supplied with the instrument. The other apparatus consists of a Wheatstone bridge combined with a D'Arsonval galvanometer, the variable arm of the former being arranged in the form of a circle, traversed by a sliding contact arm, carrying an index which moves over a circular scale calibrated to read directly in degrees Fahrenheit.

The use of the thermo-couple for high temperature thermometry was proposed as far back as 1826 by the late M. Becquerel. He adopted it for the measurement of the underground temperature in the Natural History Museum of Paris ; an iron-copper couple was employed, one junction of which was situated in the underground area, whose temperature was desired, whilst the other was immersed

in a bath, the temperature of which was capable of regulation either by artificial heating or cooling, and could be measured by means of an ordinary mercurial thermometer. A galvanometer was included in the thermo-couple circuit, and the temperature of the bath regulated until its deflection became zero, a sure indication that both junctions were at the same temperature. The temperature of the bath, and consequently of the underground space, was then measured by means of an ordinary mercurial thermometer.

M. Henri Becquerel, the grandson of the above, has suggested a more direct method of using the thermo-couple for this purpose, which he designates as the " Sliding Scale " method. A high resistance D'Arsonval galvanometer is included in the circuit from the thermo-couple, and has its scale graduated to read directly in degrees of temperature. In setting up the instrument to indicate the temperature of a given enclosure, such as a furnace, the scale is so placed that the zero or undeflected position of the galvanometer mirror indicates upon it the temperature of the room in which it is placed, and which has been previously determined by means of an ordinary mercurial thermometer. Any subsequent deflection then gives the required temperature of the other junction directly, and without the necessity for calculation, or for keeping the cold junction at zero by immersion in an ice bath.

In *Comptes Rendus*, April 28, 1902, M. D. Berthelot gives some very interesting and practical information respecting the calibration of thermo-couples for use in high temperature thermometry. According to him, the cheapest and most satisfactory couple is formed of platinum, in conjunction with a 10 per cent. alloy of platinum and iridium. To ensure regularity in the curve of comparisons, the calibration should be carried out in an atmosphere of air, nitrogen, or carbon dioxide gas.

Between the temperatures of 400° and 1,100°C. = 752° and 2,012°F., the curve denoting the relationship between

Log. E.M.F. and Log. temperature is to all practical intents and purposes a straight line.

M. Berthelot employed, for his limiting temperatures, the melting point of zinc (419°C. = 786°F.) and the melting point of gold (1,064°C. = 1,947°F.), the latter being determined automatically by the insertion of a piece of that metal between the elements at the hot junction, and reading the E.M.F. at the instant before the circuit is interrupted by the fusion of the gold.

The Reichsanstalt apparatus for calibrating thermo-couples for high temperature measurement is described in the portion of the book dealing with laboratory furnaces.

Mr. H. J. Robinson, in letters to the *Electrical Review*, March 6 and April 17, 1903, calls attention to some of the drawbacks incidental to the use of thermo-electric pyro-meters as at present constructed, and points out how they may be in part eliminated. His experience appears to have been gained in the use of platinum, platinum-rhodium, or iridium thermo-couples, made up of wires ·018 in. in dia-meter, threaded through porcelain insulators, and protected by a steel tube, merging, at its outer end, into a water-cooled terminal box. In this type of pyrometer, the primary trouble was experienced at the hot junction, which is effected by fusing the ends of the two wires together.

Mr. Robinson found it more conducive to a constant reading, when the ends forming the hot junction are tightly twisted together for about a quarter of an inch, and fused or not fused, in addition, as the case may be. Another source of trouble was the rapid deterioration of the wires, owing to the hot furnace gases entering the tube ; this was circumvented by an extra sheathing of iron steam pipe, slipped over the steel protecting tube, and its open extre-mity welded up. This latter procedure also reduces the trouble consequent on the liability of the platinum to become brittle or " short " with continued usage. In this connexion, he has found heating the wire white hot in air

a number of times, by passing a suitable current through it, to be efficacious. A 120-volt supply was utilized, the current being switched on and off about twenty times, which removed all tendency to brittleness. The wire should be well cleaned before replacing in its mounting.

Consequent on Mr. Robinson's letters came a communication from Mr. S. Weiss containing a suggestion that the steel protecting tube, and water-cooled terminals be dispensed with altogether, and the pyrometer mounting made entirely of fire-clay, some 3 or 4 ft. in length, a form of construction which, in the writer's opinion, is impracticable on the score of weakness and liability to fracture. Mr. Weiss further states that such a fire-clay tube may be rendered impervious to furnace gases by washing it over with a mixture of pure kaolin and water, mixed to the consistency of cream.

The possibilities of thermo-electric pyrometry are limited by the fusing temperature of the metals employed in the construction of the thermo-couples, and by the fact, recently pointed out by Nernst, that all substances, commonly employed as refractory insulators, become good electrical conductors at high temperatures.

As we travel higher in the temperature scale, we have to fall back, as already stated, upon other methods, all of which are founded on more or less direct comparison with a negotiable standard situated outside the furnace.

One of the simplest and most ingenious of these methods, which is also, unfortunately, limited as to its range of applicability, consists in the comparison, by observation, of the degree of incandescence of an electric lamp filament with that of the heated interior wall of the furnace, an inspection opening being provided for the purpose in the wall of the latter.

The apparatus in general resembles a telescope, mounted on a light tripod, and placed with its axis in line with the opening in the furnace wall. A small, low-voltage, incandescent electric lamp, fed with current by two or more dry

cells, or small accumulators, is fitted within the tube of the telescope, the current through it, and, consequently, its degree of incandescence, being regulated by means of a rheostat and switch.

The method of taking a temperature observation consists in viewing the incandescent filament of the lamp against the glowing background of the interior furnace wall ; if the filament appear black, or dark, then its condition of incandescence, and consequently its temperature, is lower than that of the furnace ; whereas if it appear as a white or light line, its temperature is higher than that of the furnace interior. By means of the regulating resistance and switch, the current through the lamp is regulated until the filament, as viewed against the incandescent furnace wall, apparently disappears. This signifies that the two are in an equal state of incandescence, and, consequently, that their temperatures are equal. The actual temperature of the filament is then read off from a scale, previously prepared by experiment, which gives the relation between the current passing, as registered on an ammeter included in the circuit, and the temperature.

The range of this ingenious device is limited to 1,980°C. = 3,600°F.

The optical pyrometer has lately been elaborated and constructed on a more practical basis by Dr. H. Wanner. It is being manufactured and marketed by Messrs. Emier & Amend, of New York, and is applicable to temperatures of 4,000°C. = 7,232°F., or above.

The following is Dr. Wanner's description of the apparatus and principle involved—

" The law, as established experimentally, permits at least for a certain group of glowing bodies (the so-called theoretically ' black bodies '), measurement up to the highest temperatures. When a compact body is heated, the rays emanating from the same may be observed by the human eye, and the body's colour will change, with

rising temperature, from dark red to light red, to yellow, and to bright white. This means that at first mainly red rays are observed, to which, at the higher temperatures, the other spectrum colours, orange, yellow, etc., are added, until the rays appear white.

" In analyzing the rays by a prism it is found that with the rise of temperature, some single colour, for instance, red, undergoes a rise in intensity, which can be measured progressively with a specially constructed photometer. If we know the law for the mutual relation between the determining factors (the temperature and the light intensity of the single colour, and its wave length) we are enabled to measure high temperatures by the photometric measurement of the light intensity of a certain colour.

" The apparatus to be applied is therefore a photometer, containing at the same time a prism, to separate a single colour. A spectrum is produced in the ordinary manner with the aid of a slit, lenses, and a prism, from which, by means of a diaphragm, the light of a certain wave length is separated, and the measurement of the light intensity is made by polarization. To that part of the apparatus which faces the radiation to be examined, a small incandescent lamp is attached, the light of which is used for comparing the intensity of the light to be measured.

" On looking through the apparatus one observes the circular field of vision, divided into two halves (like in a one-half shade sugar-testing polariscope), one of which is illuminated by the small incandescent lamp, and the other by the light of the glowing body being examined. Both halves of the field show red colour. On turning the eye-piece containing the Nicol prism both halves of the field of vision can be easily brought to equal intensity, and on a circular scale the number of degrees are read. The actual temperature is found from a table which accompanies each instrument. The temperatures given on the table have been calculated by means of the law mentioned before.

"The entire procedure is so simple that it can be readily learned by any foreman or intelligent workman within a short time. The whole apparatus is 30 c.m. long, built like a telescope, and can be easily handled without a support. It does not matter how great the distance is from which the measurements are taken, if only the field of vision is properly illuminated by the light emanating from the body to be examined.

"The exactness of this new method depends solely on the accuracy of the observer, and on the degree to which the body under test approximates what is called in the theory of radiation, a 'black body.' Errors due to lack of experience of the observer are practically eliminated, for various parties, who have been asked to take measurements, and who used this apparatus for the first time, have obtained the same correct results. The nearest approximation to the theoretical 'black body' are the insides of the closed furnaces, as muffles, etc., the glow of which is observed through a small opening, which, however, must not be covered by glass or mica during the measurement. The measured temperature is equal to the real one within a few degrees."

Another method of high temperature determination, which verges more nearly on direct measurement than the foregoing, is based, in principle, on Stefan's law, which runs to the effect that the radiation from an absolutely black body is proportional to the fourth power of its absolute temperature. By an "absolutely black body" is meant, in this case, one which receives and retains all the heat imparted to it, and only gives it out again by radiation, and not by reflection from its surface.

Kirchoff has shown that the interior walls of an enclosure, such as a furnace, which are at a high uniform temperature, behave as an absolutely black body, according to the above definition, and its existence as such is not materially altered by the presence of the small orifice necessary for taking

the temperature observation. Given, then, an absolutely black body, in this case a portion of the incandescent wall of the furnace, it is possible to concentrate, and measure, a certain small definite proportion of the radiated heat, and by this means determine the temperature.

The apparatus for achieving this in practice also takes the form of a species of telescope, with an objective of fluor-spar. The latter substance is chosen for this purpose by the inventor, M. Fery, because its absorption of radiant heat is very small, and the consequent error from loss, due to the passage of the rays through it, is correspondingly small. In actual practice, the sensitiveness of the device is decreased by about 10 per cent.

The radiant heat thus concentrated by the fluor-spar objective is received upon the junction of a miniature thermo-couple placed at the focus ; the resulting E.M.F. is measured, and, by simple computation, gives the required temperature of the furnace. The lens is disposed for parallel rays, and a diaphragm cuts off all but a certain pre-determined cone, which is allowed to reach the thermo-couple, thus rendering the device independent of its distance from the furnace.

M. Fery's apparatus has been standardized by comparison with a Le Chatelier pyrometer, and exhibited an error well below 1 per cent., between temperatures of 914°C. and 1,450°C. = 1,677°F. and 2,642°F. respectively. Owing to the minuteness of the mass to be heated (less than 1–100th of a milligramme) there is practically no time lag, the apparatus following quick variations in the temperature under measurement with surprising accuracy. Neither has any difficulty been experienced with the zero, which is very constant.

The temperature of the positive arc carbon, as measured by this device, was found to be 3,490°C. = 6,314°F.

M. C. Fery has also experimented with a somewhat similar method of high temperature measurement by radiation, which is based on Wien's complex law.

λm T $=$ A, where λ is the wave length, T the absolute temperature, and m refers to the maximum energy radiated at a particular wave length.

This gives the radiation in terms of any chosen wave length, instead of the total radiation as in the previous method founded on Stefan's law.

M. Fery has compensated the complexity of Wien's formula by a method of considerable ingenuity. He reduces the standard radiation to equality with that under measurement by interposing an acute-angled prism of absorbent glass, in the path of the rays. This prism is so displaced as to interpose varying thicknesses. The absorbing power of the prism also follows a formula of the Wien type, and is such that the displacement is inversely proportional to the temperature under measurement. The latter is thus read off from the degree of displacement of the prism, when the two radiations have been equalized.

By this method, temperatures of 3,867°C. and 3,897°C. $=$ 6,992°F. and 7,046°F., in red and green light respectively, have been obtained for the positive carbon of the arc. There is thus a discrepancy between these values, and the 3,490°C. $=$ 6,314°F. obtained by the previous radiation method, and it is accounted for by the fact that carbon does not behave as an absolutely black body at the temperature of the arc.

As far back as 1858 Balfour Stewart demonstrated that the emissivity and the absorptive power of a body at a given temperature, are equal for any radiation. This is known in England as Stewart's, and on the Continent as Kirchoff's, law, having been independently proved by the latter.

By "absorptive power" is meant that portion of the total radiation received by a surface, which is absorbed, whilst the "emissivity" of a body at a given temperature, for any given radiation, is the ratio of the quantity of that radiation which it emits, to the quantity of the same radia-

tion emitted by an ideal black body at the same temperature and under the same conditions.

In 1879 Stefan evolved the law which is known by his name, and is to the effect that the total radiation from any ideal black body varies as the fourth power of the absolute temperature. In 1884, a theoretical proof of this law was furnished by Boltzmann, who based his reasoning on one of Maxwell's fundamental laws regarding the electro-magnetic theory of light, viz., that a beam of light exerts, in the direc-direction of propagation, a pressure, per unit of area, equal to the energy in unit volume of the radiations. Following closely on the deductions of Boltzmann, came two laws, formulated by Wien, and expressed by the equations : $\lambda T = a$ constant, or $\lambda mT = a$ constant, and $EmT^{-5} = a$ constant. The former, which is known as the "Law of Displacement," has it that any monochromatic radiation is moved towards the shorter wave length by a rise of temperature.

It has remained for MM. Lummer and Pringsheim to supply the connecting link between theory and practice, which they have recently done, by proving experimentally the truth of these various relations between radiation and absolute temperature. These investigators, taking the mean of several readings, have proved the constant, for an ideal black body to be $\lambda mT = 2,940$.

These two investigators (*Berichte der Deutschen Physikalischen Gesellschaft*, I., 1903) state the three laws relating to black radiation to be as follows—

(1) $\int_0^\infty E\lambda d\lambda = \sigma T^4$ (Stefan-Boltzmann Law).
(2) $\lambda mT = A$ (contained in Wien's Displacement Law).
(3) $EmT^{-5} = B$.

where $E\lambda d\lambda$ is that portion of the black radiation contained between λ and $\lambda + d\lambda$ at the temperature T of the gas thermometer scale ; λm is the wave length for which, at this

temperature, the emissive power Eλ, in the normal spectrum, reaches its maximum E*m* ; *m* is the maximum energy radiated at a particular wave length, whilst σ, A, and B are constants, determinable with sufficient accuracy.

By means of a specially constructed carbon tube resistance furnace, the interior of which represented the theoretical black body, and the radiation from which was measured simultaneously, by several different methods, including a surface bolometer, spectrum bolometer, and spectrum photometer, the above experimenters have succeeded in verifying the foregoing laws, and rendering them applicable to absolute temperature measurement up to 2,300°C. = 4,172°F., thus extending the possible range of correct thermometry by about 1,000°C. = 1,832°F.

In order to apply the laws of radiation to the exact measurement of high temperatures, all that is necessary is to expose a bolometer or radiation meter to an orifice in the heated furnace cavity, which is equivalent to an " absolutely black body," and, by this means, measure the radiant energy given off by it.

R. Ferrini has suggested the application of calorimetric methods to the measurement of high temperatures, the latter being calculated from results obtained with a calorimeter. The following table gives the number of kilogramme calories necessary to raise the temperature of a kilogramme of platinum, or nickel, from zero, or freezing-point, to a given temperature—

FINAL TEMPERATURE. DEGREES C.	CALORIES ABSORBED BY 1 KILOGRAMME.	
	PLATINUM.	NICKEL.
100	3·23	12
200	6·58	24
300	9·95	37
400	13·64	50
500	17·35	63·5
600	21·18	75
700	25·13	90
800	29·20	103
900	33·39	117·5
1,000	37·70	134
1,100	42·13	—
1,200	46·65	—
1,300	51·35	—
1,400	56·14	—
1,500	61·05	—
1,600	66·08	—
1,700	71·23	—
1,800	76·50	—

Then the following formulæ apply for the computation of the temperature. Let m be the weight of the metal, M that of the water, t_1 the initial, and t_2 the final temperature of the water, c the specific heat of the metal at t_2, and Q, the heat required to cool the body from the unknown temperature, T down to zero, and we have—

$$m\ (Q - ct_2 - t_1),$$

whence $$Q = ct_2 + \frac{M}{m}\ (t_2 - t_1)$$

Having thus determined Q, the value of T may be ascertained from the table within 100 degrees. If greater accuracy be required, the following equations are applicable—

For platinum—

$$T + 52·84\ T - \frac{Q}{0·06} = 0·$$

For nickel—

$$T = \frac{1 + Q}{13}$$

The results obtained are said to be correct between 700° and 800°C. = 1,292°, and 1,472°F., whilst the errors introduced when the temperatures are exceeded, are negligible.

For experimental, or laboratory work, the method is worthy of consideration, but would appear altogether too complicated for adoption on a commercial scale.

There is another way of estimating high temperatures, which can, however, hardly be regarded in the light of temperature measurement, in that it is of assistance only in giving visible indication of the fact that a certain pre-determined temperature has been reached.

It was devised by Prof. Seger, as a rough, practical test for the pottery manufacturer, to determine the temperature of his baking ovens, and consists of the well-known "Seger Cones," or "Pyramids." As the result of a series of exhaustive fusion experiments, Prof. Seger succeeded in producing a series of systematic mixtures of pure silicates, aluminates, etc., each having a different melting point, and each mixture differing, in its melting point some 20° or 30°C., from the one next above or below it in the scale. A series of fifty-eight different mixtures or compositions were thus worked out, with fusing points, which varied from dull red, 590°C. = 1,094°F., to the melting point of platinum, 1,850°C. = 3,362°F., in steps of 20° or 30° C. = 68° or 86° F. These mixtures, moulded into conical or pyramidal form, are known as "Seger Cones," and the method of using them to ascertain when a certain pre-determined temperature has been reached, is to place one or more of the cones, which, on the Seger scale of temperatures, represent most nearly the desired temperature at different points of the furnace cavity, suitably supported and protected by refractory slabs.

When the fusing temperature of the composition of which the cone is constructed has been reached, it softens, and collapses, its upper portion, or apex, curving over. The degree of curvature, if the temperature be not unduly exceeded, is, to the experienced eye, an additional gauge of the exact degree which has been reached. Observation holes in the walls of the furnace, and in line with the cones,

are, of course, essential, and should be protected by mica to prevent indraughts of air from vitiating the results.

The following table represents the chemical composition of Seger cones over a limited portion of the scale, between $1,330°C. = 2,426°F.$ and $1,530°C. = 2,786°F.$, inclusive—

PYRAMID NUMBER.	CHEMICAL COMPOSITION.		ESTIMATED TEMP. DEGREES C.
10 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$1.0\ Al_2O_3\ 10\ SiO_2$ . . .	1,330
11 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$1.2\ Al_2O_3\ 12\ SiO_2$ . .	1,350
12 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$1.4\ Al_2O_3\ 14\ SiO_2$ . .	1,370
13 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$1.6\ Al_2O_3\ 16\ SiO_2$ . .	1,390
14 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$1.8\ Al_2O_3\ 18\ SiO_2$ . .	1,410
15 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$2.1\ Al_2O_3\ 21\ SiO_2$ . .	1,430
16 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$2.4\ Al_2O_3\ 24\ SiO_2$ . .	1,450
17 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$2.7\ Al_2O_3\ 27\ SiO_2$ . .	1,470
18 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$3.1\ Al_2O_3\ 31\ SiO_2$ . .	1,490
19 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$3.5\ Al_2O_3\ 35\ SiO_2$ . .	1,510
20 . . .	$\left\{\begin{matrix} 0.3\ K_2O \\ 0.7\ CaO \end{matrix}\right\}$	$3.9\ Al_2O_3\ 39\ SiO_2$ . .	1,530

For full particulars, the reader is referred to the original pamphlet, describing the cones, which was published by the *Thonindustrie Zeitung* (Berlin).

Although essentially a rough and ready method of recording high temperatures, the system has one great advantage ; any workman, of average intelligence, can be entrusted with the carrying out of temperature investigations by its aid.

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