equation. We know also that Arrhenius has accounted for this by supposing that in such solutions the salts are decomposed into their ions.

It is known, further, that many organic substances, such as the fatty acids, oximes, alcohols, etc., form double molecules or molecular complexes when dissolved in hydrocarbons, chloroform and carbon disulphide, and that these complexes are broken up when these substances are dissolved in water, and to a certain extent also when dissolved in alcohols, ethers, esters, ketones and phenols. The latter class of solvents are to a certain extent also ionizing, since when saturated with hydrochloric acid they act as conductors, while solutions of hydrochloric acid in benzene and other hydrocarbons are non-conductors.

Why water so far surpasses other solvents in its power to allow of this dissociation is not known, but the explanation is easily found if we write water as an unsaturated compound giving oxygen four bonds, thus:

$$H \cdot \underset{\cdot}{\dot{O}} \cdot H.$$

In fact the properties of water indicate almost with certainty that it is unsaturated, for nearly all substances have a tendency to unite with it—are hygroscopic. Numerous hydrates and compounds with water of crystallization exist, and, finally, water is the universal solvent. The supplementary valencies of the quadrivalent oxygen are evidently the cause of the formation of the ions, and the molecular aggregates the reason of the dissociating power of the water.

This notion receives further support when we remember that all those organic solvents which are known as good dissociation media contain oxygen—ethers, alcohols, esters, ketones, phenols, urethane, etc.—while those free from oxygen, such as the hydrocarbons, chloroform, carbon disulphide, carbon tetrachloride have little or no power to cause dissociation.

EDWARD HART.

## THE HISTORY OF ELECTRIC HEATING APPLIED TO METALLURGY.[1]

Sir Humphry Davy is justly regarded as the father of dry electro-metallurgy. After making full allowance for the unusual facilities at his command, it still remains that his intelligent, faithful and extended use of his facilities is worthy of the utmost honor.

---

[1] Read before the Washington Section, Dec. 12, 1895.

It often happens, however, with epoch-making events that a close search reveals previous indications, so in this case it is found that not only was Davy's dry work preceded by a course of wet electro-chemical experiments, as pointed out by Davy himself, but also an important contribution to dry electro-metallurgy had been made long previous to Davy, and that this even preceded the first observed decomposition of water by the current.

In 1795 a Dutch book of 396 pages was published at Haarlem by Martinus Van Marum, entitled "Second Continuation of Experiments by Means of the Teyler Electric Machine."

I have not seen the original book, but various notices[1] of it appeared in the Journals of the time. From these it appears that Van Marum was a thoughtful and exhaustive investigator. His investigations took a wide range and included much outside our title. He, however, not only observed the heat produced by the passage of the current, but he actually measured it. In one instance the temperature of his apparatus, designed for measuring this effect, rose from 61° to 88° in three minutes, and to 112° in five minutes. He volatilized phosphorus in a tube and proved it to be "phosphor gas." He investigated the suitability of metals for lightning rods and determined that copper was twice as good as iron. He oxidized metals by the current and performed various melting experiments. He had a scale to measure the current and at twenty-four 100 feet of iron wire, $\frac{1}{240}$ inch in diameter, melted, while 104 feet melted and separated into globules. He also melted longer pieces, but concluded that such melting tests were not worth the while. Sixty feet of No. 11 wire, $\frac{1}{150}$ in diameter, melted at 24.5, but at the same point thirty-six feet of No. 1 wire glowed its full length, one-half being quite blue and the rest slightly oxidized. Quartz was split up and slightly melted.

Having oxidized the metals by the current, he conceived the idea that the oxides could be again reduced to the metallic state by the application of larger amounts of the current. It does not appear that he actually used electrically produced oxides to test this idea, for he not only did test it, but also actually collected and tested the gas given off.

His furnace, if I may so call it, was a glass tube with platinum electrodes. Into this he put his oxide and passed the current with the following results: Red lead gave lead on the surface of the tube in a few moments that could be gathered up, and in twenty minutes he collected three-quarters cubic inch of gas. White lead gave lead in smaller amounts. Tin oxide gave no metal.

---

[1] *Aeltern J. der Physik.*, **4**, 1; **6**, 37, 360; *Neue J. der Physik.*, **3**, 1; *Pog.*, 1, 68, *et al.*

Red oxide of iron gave no metal. Red oxide of mercury gave mercury and a little gas. He proved that the gas given off was oxygen and credits the decomposition to heat.

In a lecture delivered during the latter part of his life, Sir Humphry Davy gave a history of electro-chemistry, from which I take the following statements:

"The true origin of all that has been done in electro-chemical science was the accidental discovery of MM. Nicholson and Carlisle, of the decomposition of water by the pile of Volta, April 30th, 1800." "In the month of September, in the same year, I published my first paper on the subject of galvanic electricity in Nicholson's Journal, which was followed by six others, the last of which appeared in January, 1801. In these papers I showed that oxygen and hydrogen were evolved from separate portions of water, though vegetable and even animal substances intervened, and conceiving that all decomposition might be polar."

"In 1804, MM. Heisenger and Berzelius stated that neutro-saline solutions were decomposed by electricity, and the acid matter separated at the positive, and the alkaline matter at the negative poles; and they asserted, that in this way muriate of lime might be decomposed; and drew the conclusion that nascent hydrogen was not, as had been generally believed, the cause of the appearance of metals from metallic solutions."

"In 1805 various statements were made, both in Italy and England, respecting the generation of muriatic acid and fixed alkali from pure water. The fact was asserted by MM. Pachioni and Peele, and denied by Dr. Wollaston, M. Biot, and the Galvanic Society at Paris."

"It was in the beginning of 1806 that I attempted the solution of this question, and, after some months labor, I presented to the Society the dissertation to which I have referred in the beginning of this lecture. Finding that acid and alkaline substances, even when existing in the most solid combinations, or in the smallest proportions in the hardest bodies, were elicited by voltaic electricity, I established that they were the result of decomposition, and not of composition or generation; and, referring to my experiments of 1800, 1801, and 1802, and to a number of new facts, which showed that inflammable substances, and oxygen, alkalies, and acids, and oxidable and noble metals were in electrical relations of positive and negative, I drew the conclusions that the combinations and decompositions by electricity were referable to the law of electrical attractions and repulsions."

It is curious that Davy should have overlooked the very early work of Van Marum.

From this work Davy naturally passed to the question of decomposing the fixed alkalies by the current. It is not so much to the work itself, beautiful as it was, to which I wish to direct attention now, as it is to the fact that Davy not only did a vast amount of work and secured wonderful results, but he also clearly pointed out the principles involved, and at this early date enunciated the conditions of successful operation upon which the modern practical applications of electric heat to metallurgical operations rest.

He has so plainly traced the history of his work and pointed out the underlying principles that I cannot do better than quote his own words. He says:[1]

"In the first attempt that I made on the decomposition of the fixed alkalies, I acted upon aqueous solutions of potash and soda, saturated at common temperatures by the highest electrical power that I could command, . . . though there was a high intensity of action, the water of the solutions alone was affected, and hydrogen and oxygen disengaged with the production of much heat and violent effervescence.

"The presence of water appearing thus to prevent any decomposition, I used potash in igneous fusion.

"By this arrangement some brilliant phenomena were produced.

"I tried several experiments on the electrization of potash rendered fluid by heat, with the hopes of being able to collect the combustible matter, but without success, and I only attained my object, by employing electricity as the common agent for fusion and decomposition."

Here is the clearest kind of statement of the value of using the current for the double purpose of fusing the material to be acted upon, and for decomposing it. In modern practice this principle was used, notably in the Heroult process of smelting aluminum alloys, and is now used in the successful processes of extracting pure aluminum, such as the Hall process in the United States and its equivalents abroad.

Continuing, Davy said:[2]

"The substance was likewise produced from potash fused by means of a lamp, in glass tubes confined by mercury and furnished with hermetically inserted platina wires by which the electrical action was transmitted."

This may be considered as a hint at electric heating under pressure, as proposed later by Werderman, de Grousilliers and Menges.

---

[1] Works of Sir Humphry Davy, 5, 58, 59, 60.

[2] Works of Sir Humphry Davy, 5, 61.

And in regard to the production of sodium he said :

"Soda, when acted upon in the same manner as potash, exhibited an analogous result ; but the decomposition demanded greater intensity of action in the batteries, or the alkali was required to be in much thinner and smaller pieces."

In modern practice the benefits to be derived from alloying the separated metals, at the moment of their reduction, with another metal, is an essential element of the Cowles and Heroult aluminum alloy processes, and also of various processes of the electrolytic production of caustic soda, notably Castner's process. Here too Sir Humphry Davy was early in the field with both work and word.

After describing various obstacles and the conditions necessary in decomposing the alkaline earths as an essential to success, he says :[1]

"Or of combining them at the moment of their decomposition by electricity in metallic alloys, so as to obtain evidence of their nature and properties.

"Barytes, strontites and lime, slightly moistened, were electrified by iron wires under naphtha, by the same methods and with the same powers as those employed for the decomposition of the fixed alkalies.

"I had found in my researches upon potassium, that when a mixture of potash and the oxide of mercury, tin or lead was electrified in the Voltaic circuit, the decomposition was very rapid, and an amalgam or alloy of potassium was obtained ; the attraction between the potassium and the common metals apparently accelerating the separation of the oxygen.

"The idea that a similar kind of action might assist the decomsition of the alkaline earths, induced me to electrify mixtures of these bodies and the oxide of tin, of iron, of lead, of silver, and of mercury, and these operations were far more satisfactory than any of the others.

"These experiments were made previous to April, 1808.

"The earths were slightly moistened, and mixed with one-third of oxide of mercury, the mixture was placed on a plate of platina, a cavity was made in the upper part of it to receive a globule of mercury, of from fifty to sixty grains in weight, the whole was covered by a film of naphtha, and the plate was made positive and the mercury negative, by the proper communication with the battery of 500.

"The amalgams obtained in this way were distilled in tubes of plate glass, or in some cases tubes of common glass."

In modern practice the crucible or containing vessel is usually

---

[1] Works of Sir Humphry Davy, 5, 104, 107, 108, 111.

used as one of the electrodes, generally the negative. Sir Humphry Davy did the same, but like Siemens, made his crucible the positive pole, and in this particular case used external heat for fusing his charge. He says:[1]

"I fused a mixture of one part of silex and six of potash in a platina crucible, and preserved the mixture fluid, and in ignition over a fire of charcoal; the crucible was rendered positive from the battery of five hundred, and a rod of platina, rendered negative, was brought in contact with the alkaline menstruum.

"I tried similar experiments with mixtures of soda and alumina, and soda and zircone, and used iron as the negative y electrified metal."

The work of Sir Humphry Davy was followed by the work of Children, 1809-1815. In his first communication[2] he dealt mainly with the difference in the results produced by a battery consisting of a small number of large plates, and one consisting of a large number of small plates. The most interesting part of this paper, in tracing the history of metallurgical electric heating, is experiment 6, which is undoubtedly the first description of the passage of an electric current through a mixture of ore and resistance material, although it yielded no results. This principle was afterwards very successfully employed by the Messrs. Cowles. In this experiment of Children a mixture of sulphate of barium, red oxide of mercury and clay was submitted to the action of the current.

In his second paper[3] he described his work upon the relative conductivity of wires of various metals, and found that elevation of temperature affected the result.

He subjected various oxides, mostly of the rarer metals, to the action of the current, with varying results, some simply fused more or less, some were also reduced to metal. He also tried some experiments in simple melting.

His crucible consisted of a bit of boxwood charcoal, hollowed out on top with a little mercury in the cavity, serving as one electrode; upon this was placed a piece of the oxide; the other charcoal electrode was then brought near.

In this paper is also described Pepys celebrated experiment to determine that the diamond was really carbon. For this purpose a soft iron wire was bent and split by a saw; into the split some diamond powder was placed and bound in by fine wire, and the whole covered by leaves of talc. The current was then passed through the wire. The heat produced was not high, but the iron was carburized.

---

[1] Works of Sir Humphry Davy, 5, 119-120.

[2] Phil. Trans., 1809, 32.

[3] *Ibid.*, 1815, 363.

From this time on for over thirty years nothing seems to have been done in electric heating, although there were a few applications of the currant to metallurgical processes in connection with external or other heat, such as the English Patents No. 9,946 of 1843, to A. Wall, for the use of the current in the blast furnace, and No. 10,362 of 1844, and No. 10,684 of 1845, to Napier for treating copper ore by the current in crucibles.

In 1848 and 1849 Despretz[1] published a series of articles in which he described the effect of combining the heat from three different sources, the electric current, the blowpipe and a burning glass. He clearly illustrates the difference between temperature and quantity of heat, the great difference there may be in the temperature of the source of heat and the temperature attained by the material heated, and that the loss of heat from the material heated may be supplied by a source of heat at a comparatively lower temperature and allow a higher temperatured source of heat to exert its full heating effect. Thus on heating magnesia by the current at his command it simply became pasty, but on adding to this the heat of the burning glass it immediately volatilized in white fumes.

He determined that it is easier to volatilize carbon than to melt it; also that lime, magnesia and oxide of zinc behave in the same way. He melted alumina to a transparent glass; he also melted titanic acid in various forms, oxide of iron and disthen.

He suggested the use of the current for melting metals practically, and melted eighty grams of palladium and 250 grams of platinum.

In his last communication Despretz described an arrangement in which a quantity current was passed through his crucible while a separate series current was passed through the contents.

In 1849 an English patent No. 12,772 was granted to Staite & Petrie, in which the current was applied to the treatment and fusion of iridium.

In 1853 an English patent No. 5 was granted to Watson & Prosser for the use of the current in converting iron into steel by which the time of conversion was to be shortened, and the quality of the steel improved. In one case the current was passed through the enclosing trough, and in another the poles were put into the cementing material surrounding the bars. These propositions seem to resemble some of the modern ideas of producing heat, but it is not clear that Watson & Prosser used sufficient current to produce any considerable heating effect.

Although I have not yet been able to locate the exact date, I mention here the Grove furnace which has been called the pro-

---

[1] *Compt. Rend.*, **28**, 755; **29**, 48, 545, 709; **30**, 369.

totype of the incandescent furnace. It consisted of a carbon crucible set in mercury, making the current connection, while the cover served as the other electrode. It was mentioned in La Lumiere Electrique, **19**, 350, and Scientific American Sup., April 24, 1886.

We come now to the first real attempt to employ the electric current to heat and act upon a charge of ore in a practical way. It is found in the invention of M. Pichon, patented in France, March 16, 1853, covered by English patent[1] No. 700 of 1853. In this process iron or other ores are mixed with carbon and shaken down between two or more pairs of electrodes through which the current is passing, when it melts, and after which it drops into an externally heated recepticle below.

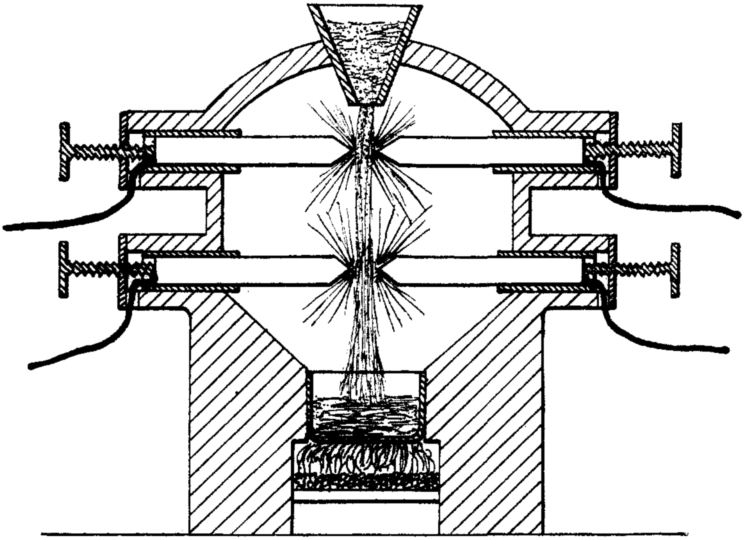

Fig. 1. Pichon's Furnace.

The description of this furnace (Fig. 1.) in Practical Mechanics Journal speaks of the electrodes as being very large, but I think that feet should be read inches.

In 1854 Duvivier[2] placed a piece of disthen in the electric flame and produced globules of metal.

There is another long break after 1854 in our subject, strictly speaking, although there were many metallurgical propositions in which the current was employed, but they were either wet processes, or else flame heat was employed.

---

[1] See also *Practical Mechanics J.*, **6**, 257, and Dingler, 131, 415.

[2] *Compt. Rend.*, **38**, 1066.

In 1866 Le Roux[1] published an exceedingly interesting and suggestive, but all too brief, communication upon the action of the arc upon lime and strontia. He decomposed lime and strontia in the arc and studied the reactions spectroscopically. He determined that the metals calcium and strontium were reduced, and carefully distinguished between the spectrum of the metals themselves and the spectrum of the white light resulting from the incandescence of the oxides. He asks the questions: Is the separation of the metals the result of electro-chemical decomposition? Is it due to vapor of carbon? Is it due to dissociation from heat alone? But he does not answer them.

We have seen that up to this time considerable work of a scientific character had been done from time to time in the field of dry electro-metallurgy, and that some suggestions at least had been made for the practical application of the current in this field. Undoubtedly, however, the cost of the current at this time was prohibitive. In looking over the field we can see the germs of modern processes, and easily imagine that if the early workers had been supplied with cheap current they would have carried their work very much farther, and developed practical electric metallurgical processes of value, but it remains as a fact that they did not have cheap current, and did not invent modern electric metallurgy.

With the development of the dynamo in the seventies came a wave of activity in the application of the current to metallurgy in the late seventies, and early eighties.

Before considering this growth in detail it is well to look at the advantages to be derived from the current as a heating agent. In doing this a sharp distinction between quantity of heat and degree of temperature should always be kept in mind. Unfortunately these terms are often used, even by persons who really know better, and who thereby mislead those who do not know better, as if they were synonymous. This is not at all the case. We may have an enormous quantity of heat developed at a low degree of temperature of which the pile of rotting apples is the old and familiar example. On the other hand, we may have a very high temperature developed by a small quantity of heat. A good blowpiper can melt fine platinum wire in a small blowpipe flame. While the combustion of a given quantity of fuel will always supply the same quantity of heat the temperature developed may vary enormously. When we carry this consideration farther and apply it to the practical application of heat, this difference becomes much more marked and pronounced. For instance, a mixture of iron ore and carbon may be supplied with any quantity of heat at a low temperature without reduc-

---

[1] *Compt. Rend.*, 30, 1150.

ing the metal; or a mixture of bar iron and carbon may be heated indefinitely to a low temperature without producing steel, but once the proper degree of temperature is reached the required reactions take place. On the other hand, the proper temperature once attained, a sufficient quantity of heat at the right temperature must be supplied to carry on operations. While the good blowpiper can readily melt a fine platinum wire in his flame yet he cannot even soften a stout laboratory rod of platinum.

In practical work we are farther limited by materials of construction, their fusibility, their heat conduction and radiation.

The temperature attainable by ordinary combustion is limited by the temperature of dissociation of carbon and oxygen, which has been put at 2500° to 2600° C., but at such temperatures combustion is slow and losses of heat large, so that the practically attainable flame furnace temperature is probably about 1800° to 2000° C., while the practical oxyhydrogen blowpipe temperature may be several hundred degrees higher, but where the flame must not come in contact with the materials under treatment, and the heat must pass through the walls of a crucible or muffle, we must be content with a very much lower temperature.

With the electric current the conditions are changed. The first and most striking factor is the enormous temperature that can be both experimentally and practically reached. What the maximum temperature attainable may be has not yet been established, but temperatures about 3800° C. have been measured by Moissan and Violle. The second factor is that the heat can be developed right at the point where it is utilized, and the losses reduced to the minimum. This is especially advantageous in replacing muffle and crucible heating, as is also the fact that the heat is secured without the introduction of enormous quantities of products of combustion. Again, the temperature is under most perfect control, and can be adjusted with the utmost nicety. There are also minor advantages in the cleanliness and compactness of the operations.

It remains, however, that the cost of the current limits its practical application even now to a few special cases, and this is likely to remain so until the dream of the electrician of converting coal directly into current be realized.

In 1875 an English patent, No. 4,043, was issued to G. L. Fox for heating a crucible by the heat generated by resistance to the passage of the current, but curiously enough his resistance material was placed outside his crucible, and the heat had still to pass through the walls of the crucible.

In 1878 a voluminous French patent, No. 122,227, was issued to M. Repieff, in which arrangements of electrodes for electric furnaces are shown. In the electric light part of his patent he also uses oxides to color his light.

In 1878 an English patent, No. 4,650, was issued to Clarke and Smith for producing ammonia by passing a mixture of nitrogen and hydrogen through sufficiently prolonged white heat produced by the electric arc.

The next electric furnace was that described in the celebrated English patent, No. 2,110, of May 27th, 1879, to C.W. Siemens. This may be said to inaugurate the era of electric furnaces proper, and to be the first real, hearty, and systematic attempt to make practical use of heating by the current.

As described in the patent with all its attendants of water cooled electrodes and regulating devices it is a formidable and elaborate piece of apparatus, but divested of its accessories its real operating parts become simply a crucible provided with two electrodes, arranged either vertically (Fig. 2) or horizontally (Fig. 3), through which the current passes.

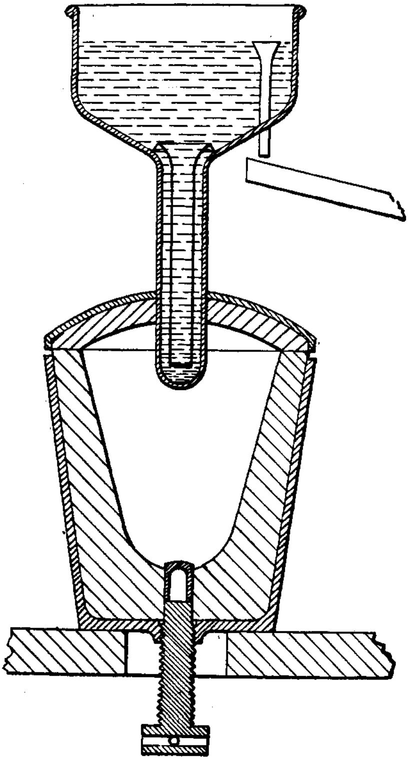
Fig. 2. Siemens' Furnace.

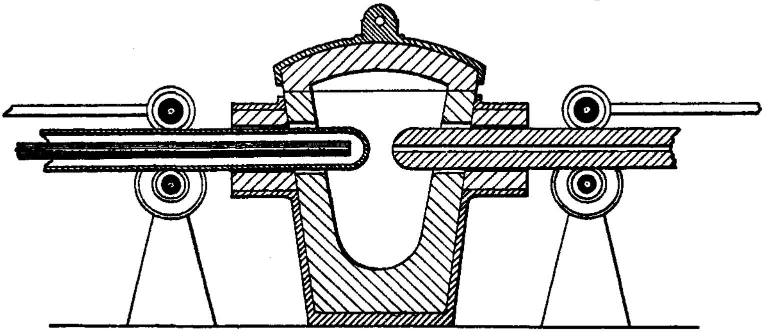
Fig. 3. Siemens' Furnace.

This apparatus was described and exhibited in actual operation before the Society of Telegraph Engineers[1] and the British Association[2]. The descriptions and exhibitions were confined for the most part to simple melting operations, although some attempts to saturate iron with carbon are described. It does not appear that Siemens ever used his furnace for the reduction of metals, although the article in Iron suggests that it might be so used. The death of Siemens undoubtedly cut off work in that direction with this apparatus.

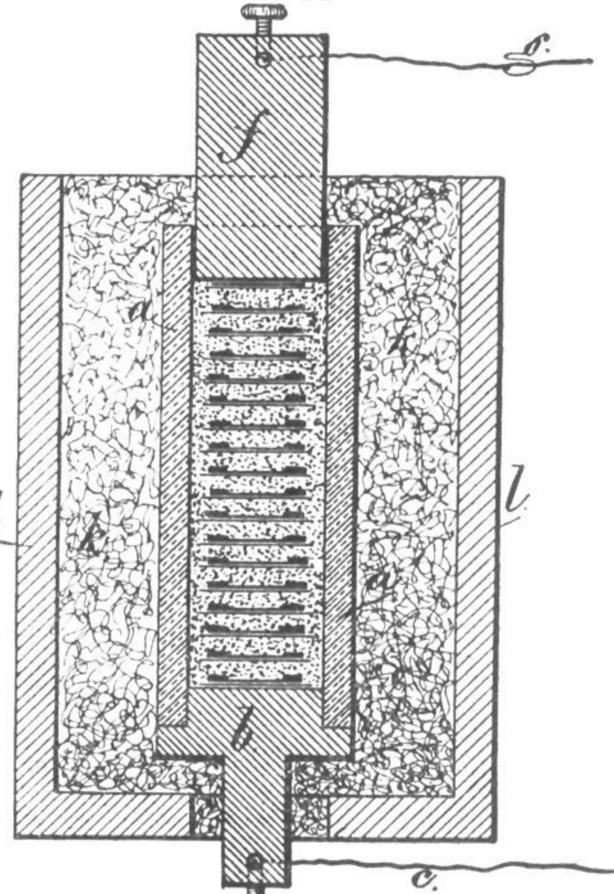

Fig. 4. Ball and Guest's Furnace.

In 1881 a United States patent, No. 236,478, was issued to Ball and Guest for an electrical carbonizing apparatus (Fig. 4) to produce carbons for the electric light. The articles to be carbonized are placed in a pile within a case and are surrounded by pulverized carbon. The case is then brought into the circuit and the contents thereby heated. A portion of the current passes through the carbon packing.

In 1881 an English patent, No. 304, was issued to Werderman for preparing carbon from sugar, which was then subjected in a mold to a white heat by the passage of the current, for use in electric lamps. In the same year silicon was to be heated by the current to prepare it for use in electric lamps, French patent, No. 144,317.

The Belgian patent, No. 144,387, of Aug. 13, 1881, described a special form of furnace with one or more pairs of electrodes to be forced forward by springs. The furnace was calcined magnesia mixed with metallic oxides.

In the English patent, No. 3,757, of 1882, Werderman pro-

---

[1] *J. Soc. Tel. Eng.*, **9**, 285.
[2] *Chem. News*, **46**, 163; see also *Iron* Supplement, 1880, p. 424.

posed to heat silicon under pressure by the passage of the current.

At the Washington meeting of the American Institute of Mining Engineers, in February, 1882, in discussing the paper of Mr. Keith on the application of electricity to mining and

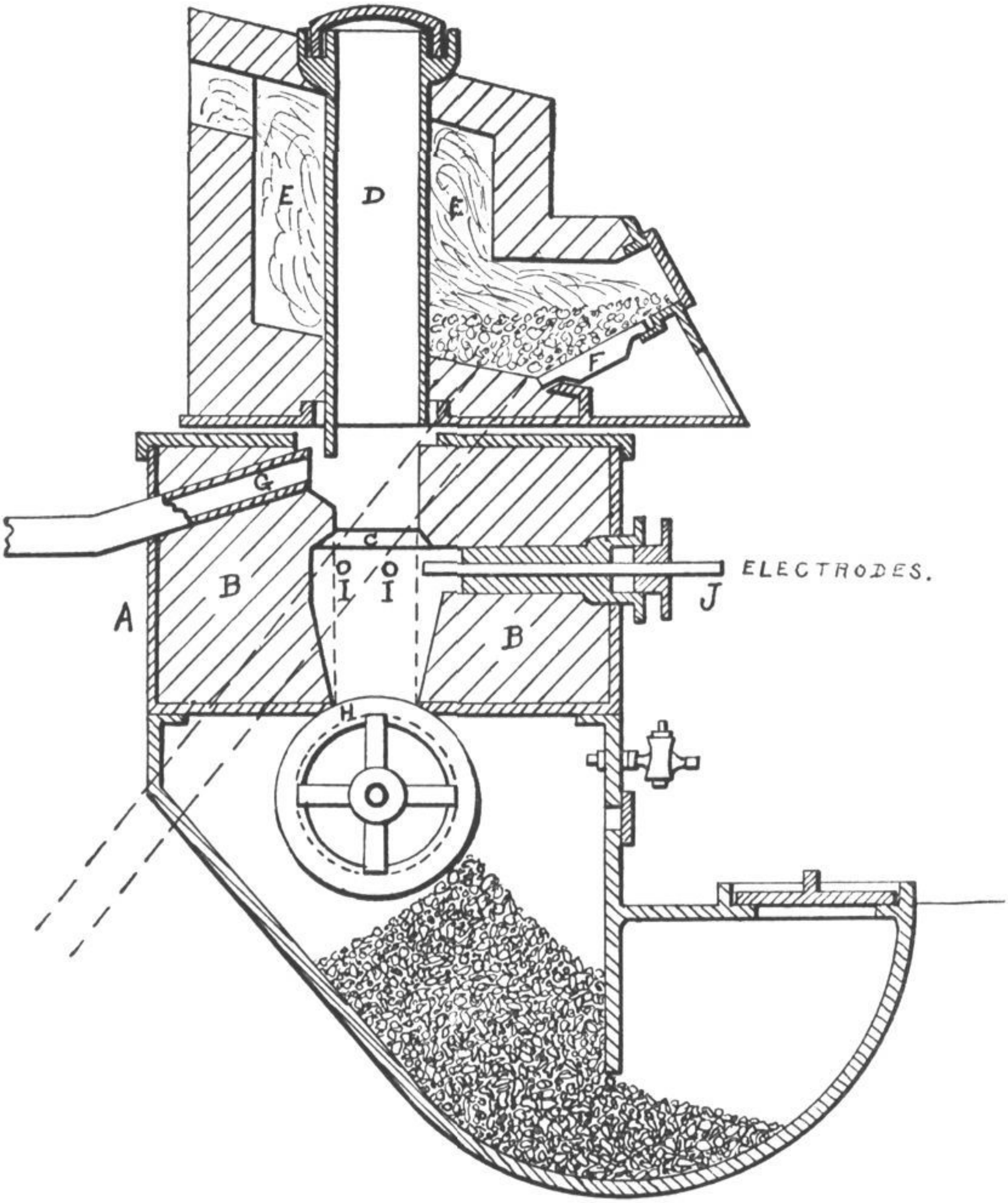

Fig. 5. Faure's Furnace.

metallurgy, Mr. H. M. Howe[1] briefly outlined a process which should have been developed into a successful commercial process. He said:

---

[1] Trans. Am. Inst. Min. Eng., 10, 317.

"The aluminous compound is placed in a carbon crucible, which is connected as the cathode of an electric current of great intensity. A voltaic arc is then thrown across from another electrode against this carbon crucible, the current thus first melting and then decomposing the aluminous compound, and metallic aluminum being deposited on the sides of the crucible."

In 1880–82–83–84 a series of patents[1] was issued to M. C. A. Faure, which has attracted considerable attention; more perhaps from their suggestiveness than from their actual contents. As described in the English patent, No. 6,058, of 1882, the process was designed for the reduction of sodium, and the furnace (Fig. 5) consisted of a tube in which the charge was first heated by an external fire. It was then passed into a chamber provided with electrodes for the passage of the current where it was intensely heated. Below was an automatic discharge for the refuse. There were also suitable condensing arrangements.

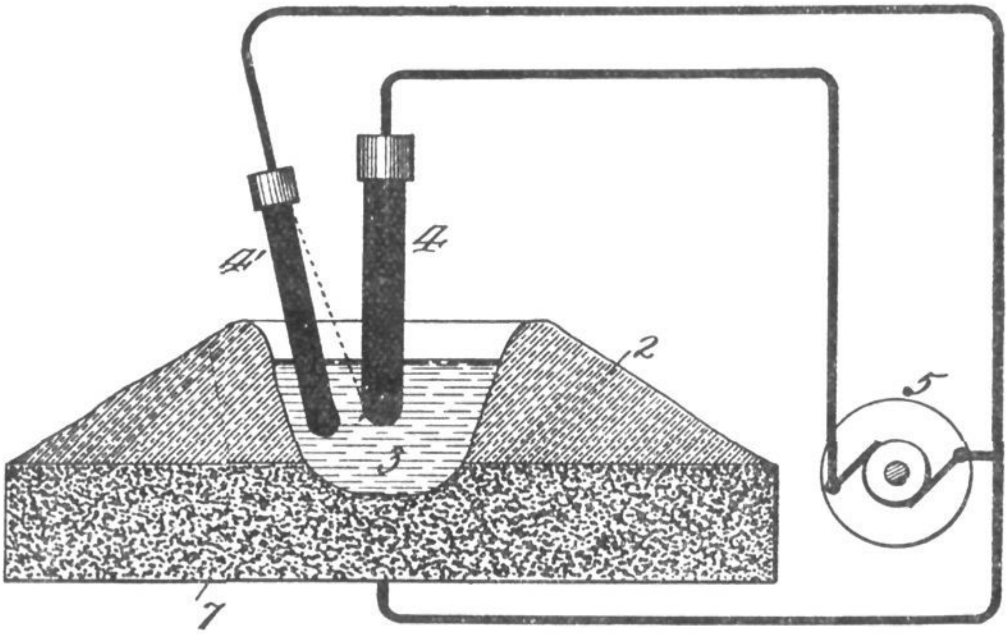

Fig. 6. Bradley's Furnace.

Chronologically considered, the United States patents to C. S. Bradley may be considered here, since the fundamental application was filed in February, 1883, although the patents were not issued for about nine years.[2] In these three patents (Fig. 6) the claims are drawn to cover three points. Using an unfused portion of the charge itself to enclose and contain the bath of fused material. Using the current for the double purpose of

---

[1] French patent No. 139,188. English patent No. 6,058, of 1882, and 5,489, of 1883, and Belgian patent No. 63,385.

[2] United States patents, No. 464,933, of Dec. 8, 1891; No. 468,141, of Feb. 2, 1892, and No. 473,866, of 1892.

fusing and decomposing the charge. Using a downwardly projecting blowpipe, or other flame, to supply a portion of the heat.

A United States patent, No. 282,964 was issued to Delaplaine, Hendrickson, and Clamer, in 1883, for melting the tin off from tin scrap by the current.

When, in 1885–86, the simple and beautiful process of Messrs. E. H. and A. H. Cowles[1] was announced, both the scientific and practical worlds were surprised and intensely interested, and a revolution in high heat metallurgy seemed imminent, particularly in the metallurgy of aluminum, but later developments have not fulfilled the early promises in general metallurgy, and aluminum metallurgy has now passed out of the field of high heats.

This process consists in mixing the ore to be reduced with a so-called resistance material (which for practical reasons was carbon) and then passing the current through. The current generated a very high heat and difficultly reducible oxides were reduced to metal. In the case of aluminum the reaction went a step farther, and the reduced metal combined with the carbon and formed a carbide of aluminum.

The generation of the heat was attributed to the passage of the current through the resistance material. This was not altogether so, but the high heat was generated by the passage of the current from particles of the charge to other particles, in other words, by dividing up the current into innumerable small arcs, and the great advantage of the process lies in evenly distributing the heat of a large arc through a considerable space, through which the material to be acted upon is distributed.

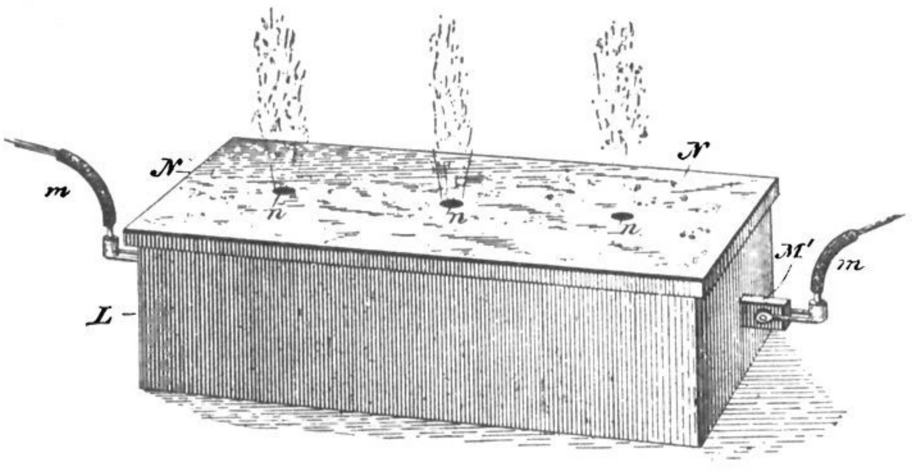

Fig. 7. Cowles' Furnace. (Outside.)

The furnace (Fig. 7) consisted of an outside case of brick

---

[1] United States patents Nos. 319,795; 319,945; 324,658, and others. Also foreign patents. The Cowles process was widely described. Proc. A. A. A. S., **24**, 136; Trans. A. I. M. E., **14**, 492; *J. Franklin Inst.*, **121**, 111, and **122**, 51 and 273; *J. Soc. Chem. Ind.*, **5**, 206; *Mont. Sci.*, *1885*, p. 1288, and *1886*, p. 1032, Industries, Vol. 8, p. 273, 294, and elsewhere.

work, lined on the inside with carbon, then the charge containing the ore and carbon was put into the centre in contact with the electrodes, the charge was covered with carbon and a perforated cover placed over all.

By this process silicon, potassium, sodium, magnesium, calcium, chromium, and titanium, as well as aluminum were produced, but on account of so much of the aluminum combining with carbon it became necessary to introduce an alloying metal into the charge. This was usually copper or iron. By this process the price of aluminum in alloys was very largely reduced, but no considerable amount of the pure metal was ever produced.

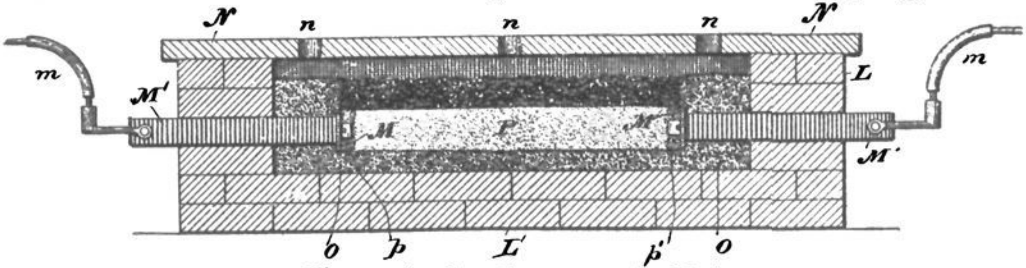

Fig. 7. Cowles' Furnace. (Inside.)

In 1886 a United States patent, No. 335,499 was issued to Bradley and Crocker, in which the current was used to heat the charge, and was divided into two portions, one part passed through the walls of the retort, and another passed through the charge.

In 1887–88 a series of patents[1] was granted to M. P. L. T. Heroult, in which alumina was melted by the passage of the current and then electrolyzed with molten copper, or iron, as the cathode with which the separated aluminum alloyed.

The furnace (Fig. 8) was a suitable containing vessel of carbon to which the negative wire was attached. The positive electrode was of carbon. In running the furnace copper or iron was first put in and melted by the current, then alumina was added, which was also melted, and then electrolyzed by the current. More alumina and copper, or iron, were added from time to time, and the resulting alloy was tapped out periodically.

This was a very promising high heat alloying process, but it, as well as the Cowles process, was superseded in the aluminum field by the Hall process of producing the pure metal, of which it is only necessary to say here that in this process the charge is both melted and electrolyzed by the current, but the fact is to be emphasized that only a comparatively low temperature is required.

---

[1] French patent No. 170,003. Belgian patent No. 77,100. English patent No. 7,426, of 1887. United States patent No. 387,876. See also Richards Aluminium, 2nd ed., p. 36 and 309. Trans. A. I. M. E., **18**, 666. Industries, Vol. V, p. 405.

From 1892 to March 15, 1895,[1] there has been much published regarding the work of M. Henri Moissan, who has done so much fine work in the field of high temperatures, and has accomplished such wonderful results.

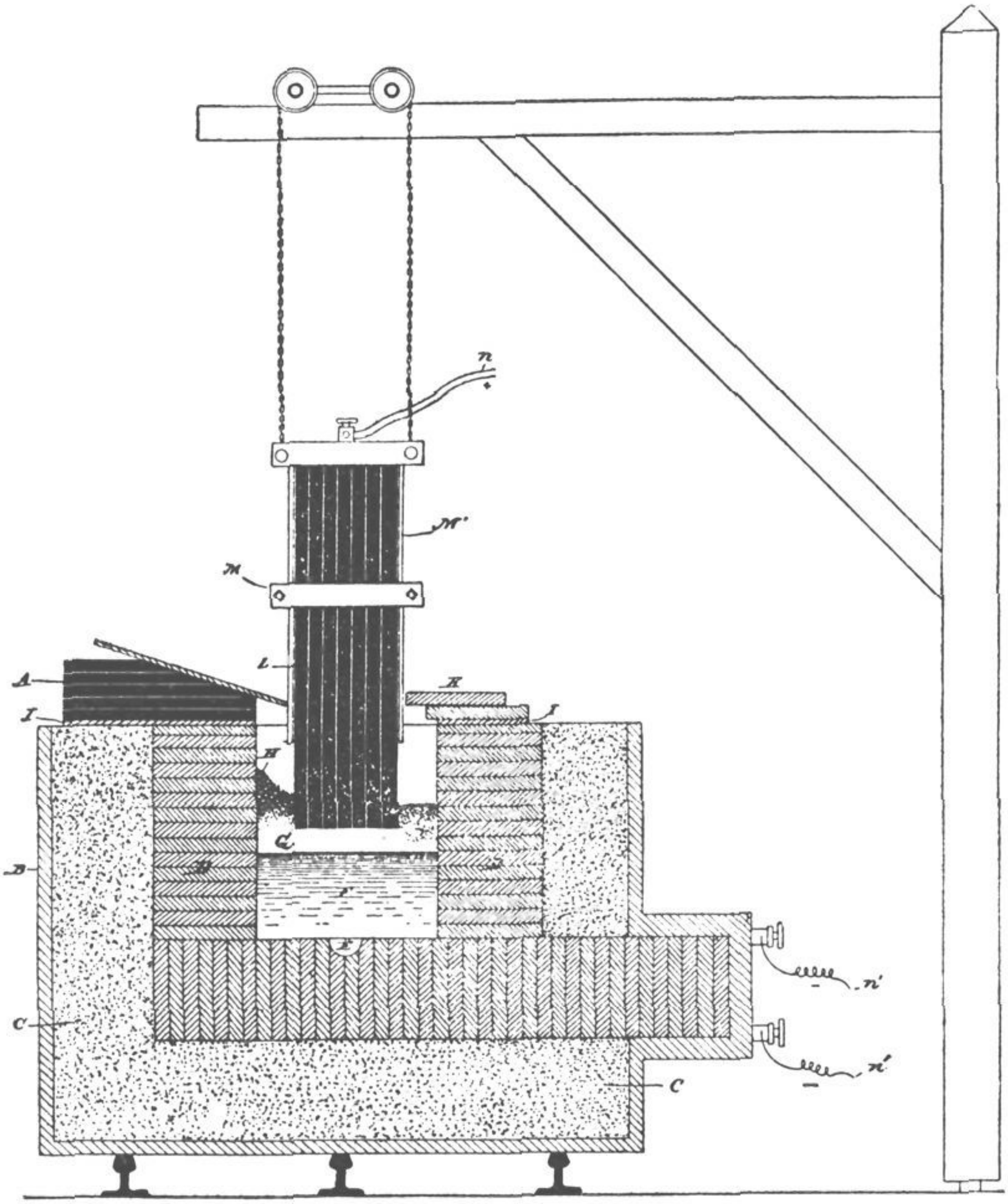

Fig. 8. Heroult's Furnace.

He employed various styles of furnaces and different amounts of current His early furnace (Fig. 9) consisted of a simple block of quicklime suitably bound, and provided with electrodes

---

[1] *Compt. rend.*, 115, 1031; 116, 549; 117, 679; 118, 116 and 501. La Nature, Vol. 21, pt. 1, *1893*, p. 225 and 275. *Ann. Chim. Phys.* [7], 4, 386.

and a cover. In this some very interesting results were obtained.

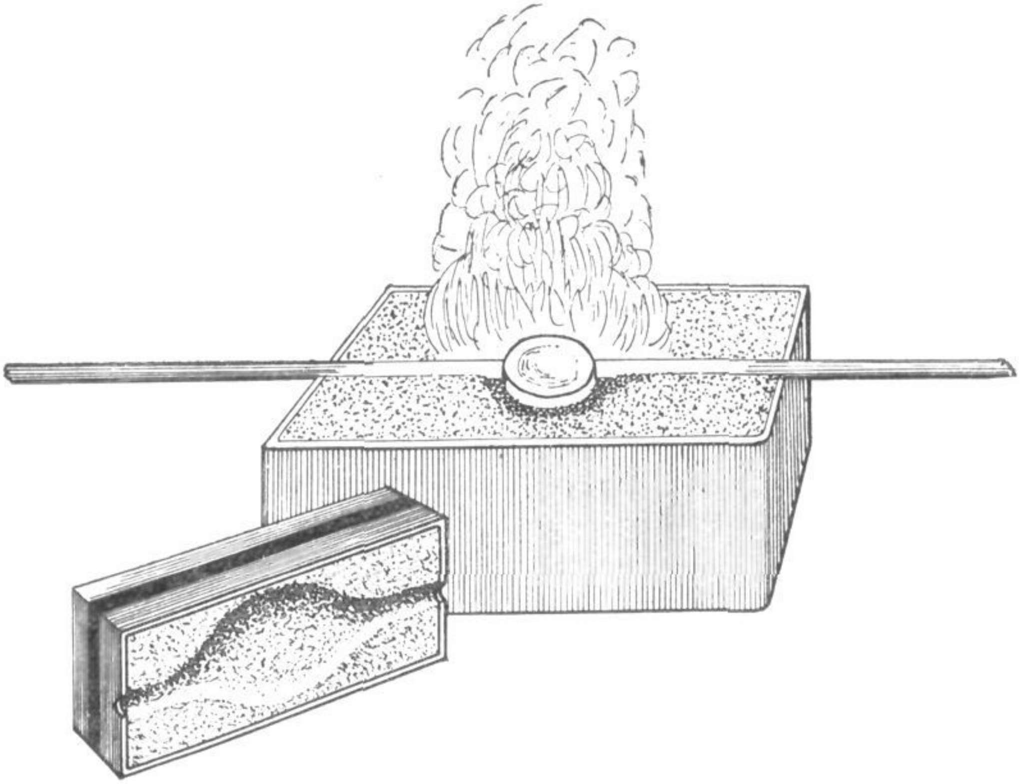

Fig. 9. Moissan's Early Furnace.

Another furnace (Fig. 10) was especially designed for determining the temperature by the specific heat method. A piece of carbon was put on the end of one electrode, the current passed, and the carbon pushed off from the electrode, at the same time a slide was

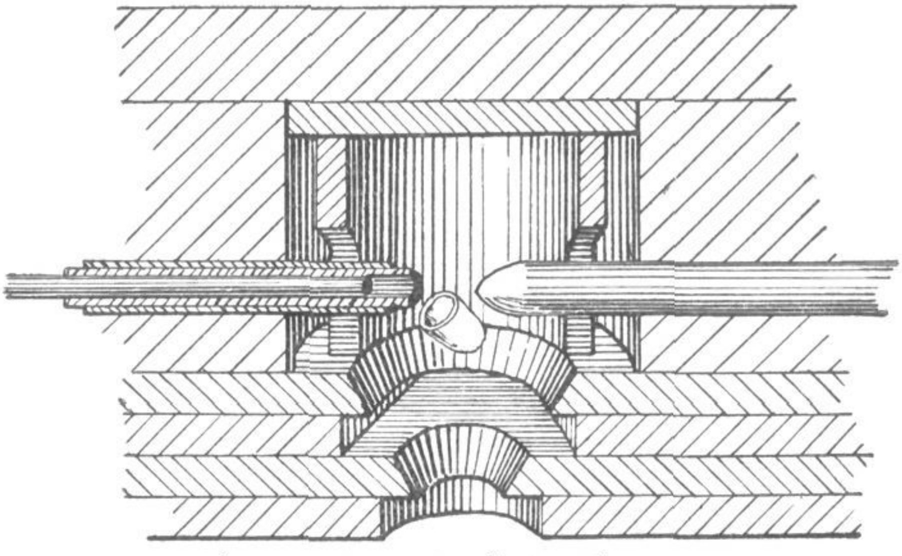

Fig. 10. Moissan's Specific Heat Furnace.

withdrawn from the bottom of the furnace and the hot carbon allowed to fall in the calorimeter below. A number of temperature determinations were made in connection with M. Violle. Another furnace (Fig. 11) was provided with tubes for the introduction of gases. In this pure and colorless carbide of silicon was formed from carbon and silicon vapors. This furnace also had various layers, beginning with lime on the outside, and followed by carbon and then magnesia on the inside, or vice versa. Another furnace (Fig. 12) had transparent ends of glass, or mica, so that the operations could be watched. It also had magnets to direct and control the arc.

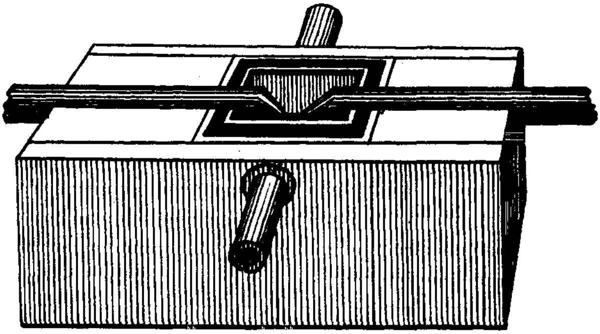

Fig. 11. Moissan's Furnace for Gas Reactions.

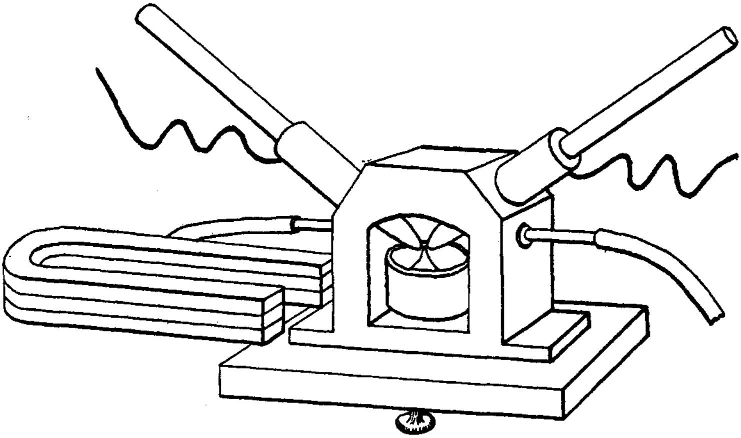

Fig. 12. Moissan's Furnace with Transparent Ends and Magnet.

In this work Moissan designed to investigate and study the simple heating effect of the current separated as much as possible from any electrolytic effect. He speaks of and treats the arc as one would speak of an ordinary flame.

Moissan began with a very moderate current of thirty-five to forty amperes at fifty-five volts, and passed through various stages up to 1200–1600 amperes at 110 volts.

A few of the results obtained by Moissan may be mentioned. Magnesia was the only irreducible oxide found, it was melted and volatilized. Lime, strontia, and magnesia began to volatilize before melting. Lime was easily melted and the metal calcium reduced, but it immediately combined with the carbon vapor forming calcium carbide ($CaC_2$). Alumina and platinum were volatilized. Artificial diamonds were produced. Various temperatures from 2000° to about 3800° C. were measured. Carbon begins to volatilize at about 3500° C. Various quantities of the rarer metals were reduced, 200 to 300 grams of uranium; 100 grams of vanadium; ten kilos of chromium, as well as manganese.

As in practical flame work the amount of fuel burned determines the temperature of the furnace, so in this case the amount of current passed determines the temperature and the furnace must be designed to stand the current to be employed. While Moissan's small furnace will stand the temperature developed by small currents, yet with 1200 amperes at 110 volts the lime and magnesia melt down, volatilize rapidly, and in a few moments the furnace is spoiled at a temperature of about 3500° C.

For materials of construction it was found that lime was the best nonconductor for heat, but its fusibility and the ease of forming the carbide, prevent its use for the inside of the furnace at very high temperatures. Compared with lime, carbon is a good conductor of heat. Magnesia is also a better heat conductor than lime. It does not form carbide of magnesium, and therefore can be heated very hot in direct contact with carbon, while lime cannot. It, however, is volatile, and can be melted at very high temperature. Practically, therefore, the outside of the furnace is quicklime, while the interior is variously lined with carbon or magnesia, or both, and when carbon is in direct contact with the lime it must not get too hot at the point of contact.

In 1893 a United States patent, No. 492,767,[1] was issued to E. G. Acheson in which a mixture of silica, carbon, and salt was heated by the passage of the current and silicon carbide produced, which has found considerable application as an abrasive.

In the present early stage and activity of the calcium car-

---

[1] See also *J. Franklin Inst.*, 136, 194 and 229; 137, 401. Sci. Am., 70, 215. West. Elec. 17, 271. N. Y. Sun. Oct. 20, 1895. Cassiers Mag., 9, 387.

bide and barium carbide questions it might not be wise to go into the details of the work and the claims of the various workers (Borscher, Maquenne, Moissan, Travers, Willson, I arrange these names simply alphabetically) but I mention these various carbide processes to show the present condition of our subject, and to draw especial attention to a notable fact.

In reviewing our subject we find that in the early days the current was suggested, tried and used for various metallurgical operations, in which both the heating and decomposing actions of the current were utilized. Then in the principal, practical part of the field, that of the production of sodium and aluminum, the generation of intense temperatures became paramount. ·This activity culminated in the high heat processes of Cowles and Heroult, and they were very soon superseded by the low temperature process of Hall for the production of aluminum, which carried with it the greater part of the demand for the production of sodium.

At the present day, therefore, there is no practical production of metals by high electric heats, with the possible exception of the production of chromium. On the other hand, high electric heats are being employed to go a step beyond the reduction of the metals, and to form new compounds, as in the carbide processes mentioned. In these the metals are first reduced, and are then immediately recombined with carbon, and thus in the field of high heat our subject becomes the application of high electric heat to chemistry.

*Jan. 14, 1896.* FREDERIC P. DEWEY.

## NOTES.

*The Second International Congress of Applied Chemistry.*—The First International Congress of Applied Chemistry was held at Brussels, under the patronage of the Belgian Government, from August 4th to 11th, 1894. On the last day of the meeting it was voted to hold the next congress in Paris, in 1896. This approaching congress will be held in August of this year, the exact date to be hereafter published in this Journal, under the patronage of the French Government and pursuant to a plan of organization formulated by the Association of Chemists of the Sugar Industry and Distilling in France and the Colonies. M. Berthelot, the distinguished chemist, and now Minister of Foreign Affairs, is one of the Presidents of Honor. The congress will be held in ten sections, as follows ;