THE ELECTRO-METALLURGY OF ALUMINIUM.*

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Metallurgy is the art of extracting metals from their ores, and of refining them to the purity required for their use in the metal industries.

Electro-metallurgy is that branch or division of the metallurgic art which concerns the use of electricity as an adjunct to, or a substitute for, the ordinary methods of extracting metals from their ores or refining crude metal. Electrical methods may enter into metallurgical operations in three stages, viz.:

(A) Electrical refining of crude metal which has been produced from the ore by non-electric methods.

(B) Electrical reduction or production of crude metal from the ore, which is afterwards refined by non-electric methods.

(C) Electrical reduction and refining, or the entire substitution of electric for non-electric methods. The operations of reduction and refining may take place together, in one operation, or be effected consecutively, independently of each other.

The electrical methods used in metallurgy may be classed, as to their character, under three heads, viz.:

I. Electrolysis of aqueous solutions.

II. Electrolysis of fused electrolytes.

III. Electric smelting, or electro-thermal operations.

Considering these operations in order, I will enumerate the kind of metallurgical operation for which each is capable of being used.

I. Electrolysis of aqueous solutions may be used for:

(1) Refining crude metal, using it as soluble anodes in the solution of a salt of the same metal.

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(2) Extracting metals *directly* from their ores by using the ores themselves in the form of soluble anodes, in the solution of a salt of the same metal.

(3) Extracting metals *indirectly* from their ores by

a. Producing from the ore by some other means, chemical or electrical, a compound which can be used as a soluble anode, as in the former division. This method is especially applicable when the ore itself is unfit for use as a soluble anode.

b. Treating the ore chemically so as to convert it into a soluble salt; dissolving this in water, and precipitating the metal by electrolysis, using either insoluble anodes, or soluble anodes of a cheaper metal placed within porous cells.

II. Electrolysis of fused compounds may be applied to :

(1) Refining crude metal, using a fused salt of the same metal. This method is of very limited application.

(2) Extracting metals *directly* from their ores. This is applicable only when the ore itself is an easily fusible compound, in which case it is melted and electrolysed, using either an insoluble anode, or one which will combine with the non-metallic ingredient of the ore and form an inert compound.

(3) Extracting metals *indirectly* from their ores by :

a. Converting the ore into some suitable fusible compound, and then electrolysing this, as above.

b. Dissolving the ore in some fused salt which acts as a solvent for the ore, and which requires a higher electromotive force to decompose it, in which case a current of properly regulated potential will decompose the ore without affecting the fused salt which acts as its solvent. Either soluble or insoluble anodes may be used, as in (2).

III. Electric smelting or electro-thermal methods are those in which the apparatus is arranged so as to convert the electric energy as largely as possible into heat, the heat thus developed being utilised to effect chemical reactions or reductions. The ore, in contact with the substance or substances necessary to reduce it, is so placed in the appa-

ratus as to be subjected to the electrical heating, and is thereby reduced. Frequently the carbon used in the apparatus to convey the electric current serves as the reducing agent, as in reducing ores containing oxygen.

Electric smelting may be applied to:

(1) Extracting metals in a crude state *directly* from their ores.

(2) Extracting metals in a pure state from the purified ore, or from a pure compound of the metal prepared from the ore.

It is sometimes difficult to draw the line precisely between Classes II and III, because of the fact that, during the electrolysis of a fused salt, there is necessarily developed by the electric current an amount of heat proportioned to the conduction-resistance of the fused salt; and when the amount of current used for electrolysis is very large in relation to the size of the bath, the development of resistance heat may become so large as to keep the bath fused without the application of heat from an external source, and the process would then seem to have passed into the class of electric smelting processes. Such, however, I should not consider to be the case, because the electric heating, rendering the apparatus independent of external heating, is, in this case, only an incident to the process; the principle of the method does not depend on it at all. The electrical decomposition of fused salts is, therefore, to be distinguished by the low resistance of the bath, the low potential required to operate it, and the presence of those arrangements necessary for economical electrolysis. The temperatures attained in electric smelting furnaces are generally very high, reaching to nearly $4,000^{\circ}\text{C}$. ($7,000^{\circ}\text{F}$.), and under such conditions chemical reactions are effected which are impossible in any other form of furnace.

With this introduction, let us consider

THE ELECTRO-METALLURGY OF ALUMINIUM.

The native minerals which may be considered as the available ores of aluminium are as follows:

Bauxite.—Impure hydrated oxide of aluminium, carrying

usually some ferric oxide, silica and titanio oxide. It is insoluble in water, easily soluble in strong acids after being calcined; infusible, except in the electric furnace, and then practically a non-conductor of electricity. Soluble in certain fused fluoride salts, particularly the double fluorides of aluminium and the alkali metals. The resulting bath is a good electrolyte.

Cryolite.—Double fluoride of aluminium and sodium, usually impregnated with some silica. Insoluble in water, easily fusible at a bright-red heat, and then a good conductor of electricity, which liberates aluminium and fluorine (very irritating fumes).

Native Alums.—Included under this general head are the native sulphate of aluminium, or double sulphates of aluminium and the alkalis. Soluble in water; the acid of the aluminium sulphate driven off by gentle heating, leaving either an infusible residue of alumina or a pasty mixture of alumina and alkaline sulphate, from which the latter can be removed by washing.

Kaolin.—The pure, white china clay. A hydrated silicate of aluminium. Is found in immense quantity and very pure. Insoluble in water, infusible, except in the electric furnace; unattacked by acids, except sulphuric acid, which dissolves out the alumina and leaves the silica; and by hydrofluoric acid, which removes the silica and leaves aluminium fluoride.

The chemical compounds of aluminium which may be considered available for use in electric processes, and which may be formed by chemical processes from the ores and then used as the intermediate products mentioned in our classification, are briefly as follows :

Aluminium Chloride.—Formed by an expensive operation from alumina. Attracts moisture strongly from the air, easily soluble in water (the aqueous solution may be made by dissolving alumina in acids). Fusible easily, but fumes in the air and volatilises at a temperature close to that of its melting point. The fused salt conducts electricity very poorly.

Aluminium Chloride with Alkaline Chloride.—Formed in the

same manner as the simple chloride, alkaline chloride being added in the process. Easily soluble in water, only slightly deliquescent, easily fusible, and the fused salt a good electrolyte. Much easier to work with and handle than the simple chloride.

Aluminium Fluoride.—Can be made cheaply from the ores. Nearly insoluble in water, infusible, volatilises at a high temperature, soluble in many fused salts, and the resulting bath a good electrolyte.

Aluminium Fluoride with Alkaline or Alkaline-Earth Fluorides.—Insoluble in water, easily fusible salts, good conductors of electricity, dissolve alumina freely, and allow of its electrolysis without being themselves decomposed.

Alkaline Aluminates.—Soluble compounds of alumina and potassa or soda. Fusible with difficulty and decomposed by the current into alkali metal, aluminium and oxygen. Electrolysis unsatisfactory. Made by heating together alumina and the alkali; or, in solution, by dissolving alumina in solution of caustic alkali.

Metallic Aluminates.—Difficultly fusible compounds, troublesome to make and mostly insoluble in water; scarcely available in any electric method, excepting, possibly, in the electric furnace.

Aluminium Phosphate.—Insoluble in water, nearly infusible and very difficult to decompose.

Aluminium Borate.—Difficultly soluble in water, easily fusible, and when fused, a good electrolyte. Made by dissolving alumina in boric acid or borax. The current, however, liberates boron also.

Aluminium Nitrate and Acetate.—Soluble salts formed by dissolving alumina in the corresponding acids. Decomposed by gentle heating, leaving alumina.

Aluminium Sulphide.—A difficultly-fusible compound; attracts moisture, reacts on water, setting free hydrogen sulphide and leaving alumina. Made only with difficulty, by passing carbon bisulphide vapor over red-hot alumina. Hardly suitable for any electrical process.

Aluminium Sulphide with Alkaline Sulphides.—Easily fusible salts, made with comparative ease by melting together

alumina, carbon, sulphur and an alkali. Stable in the air, insoluble in water, and when fused, good conductors and easily decomposed by the current into aluminium and sulphur.

Before taking up in detail the different kinds of electric processes, allow me to make a few remarks on the properties of aluminium itself.

Aluminium melts at 625°C .—a dull-red heat. It volatilises slowly at the temperature of the electric furnace. In mass, it is very slightly affected by air or water, but when finely divided, burns rapidly in air and oxidises rapidly in water. Easily soluble in solutions of caustic alkalies and in hydrochloric acid; very slowly attacked by sulphuric, nitric or hydrofluoric acid. Conductivity for heat and electricity about one-half that of silver. Specific gravity, 2.7; when melted, 2.5, causing some difficulty in working fused baths. Rapidly attacked by melted silicates, borates or any salts which it can decompose. Its atomic weight is 27, its chemical equivalent 9. Its electro-chemical equivalent, therefore, is 0.00009315; that is, an electric current of 1 ampère will set free by electrolysis, from any aluminium compound capable of electrolysis, 0.00009315 grams of aluminium per second, or slightly over one-third gram per hour, or 8 grams ($=\frac{1}{4}$ ounce) per twenty-four hours.

The minimum voltage necessary to decompose the aluminium compounds, whose heats of formation are known, is as follows:

	<i>Volts.</i>
Aluminium fluoride	4.0
“ oxide	2.8
“ chloride	2.3
“ bromide	1.7
“ iodide	1.0
“ sulphide	0.9

We will now proceed to consider the electric processes according to the preceding classification.

I. Electrolysis of Aqueous Solutions.

(1) Refining of crude metal.

The question of thus refining impure aluminium to a high standard of purity is one to which very little attention

has thus far been given. Since the solution of metal at the anode balances the deposition of metal at the cathode, no voltage is absorbed in electric decomposition; potential is needed only to overcome the conduction-resistance of the electrolyte, and the water need not, therefore, be decomposed. The difficulty is to deposit the molecules of aluminium upon the cathode more rapidly than such finely divided particles can be oxidised by the water, otherwise the deposit is entirely changed to alumina. This difficulty is met by using a current of large quantity per unit of depositing surface. I give below the results of an experiment made by myself several years ago :

Solution.—A strong solution of aluminium chloride *plus* 10 per cent. of sodium acetate.

Voltage.—0·9 volts across the electrodes.

Resistance.—Of battery and wires 0·7 ohms.
Of solution 1·55 “
Specific resistance of the solution 20’ “

Current.—0·4 ampères, giving a current density of 290 ampères per square meter of cathode.

Results.—A liberal evolution of gas at the cathode, apparent attack of the anode (impure aluminium) and, in fifteen minutes, a bright metallic deposit of aluminium on the cathode.

I have quoted this experiment simply to prove the possibility of thus refining impure aluminium, and it is within the range of possibility that at some future time we may see impure aluminium being refined on these lines, just as copper is now treated.

To a Philadelphia audience the chief interest in this part of my subject will probably be concerned with the aluminium plating on the tower of the Public Buildings. This plating is deposited from aqueous solution, using soluble aluminium electrodes, but it is important to state that the bath used contains a tin salt as well as an aluminium salt. The deposit is, therefore, a mixture, or possibly an alloy, of aluminium and tin, which is much easier to deposit than pure aluminium, as the tin protects the particles of aluminium from oxidation during deposition. This method of procedure, therefore, is not applicable to the metallurgical purpose of obtaining *pure* aluminium from crude metal.

(2) Imagine an ore of aluminium in place of the soluble aluminium anodes, in the case I (1), and we have case I (2). No successful process has yet been developed on these lines, but it is not out of the range of possibility. The ores of aluminium are all non-conductors, but imagine them mixed in with the substance of a carbon anode, let us say, so that the composite anode, on being attacked by the liberated acid ingredient of the electrolyte, reforms the aluminium salt which was decomposed, and thus regenerates the solution. The voltage required for decomposition, in this case, would be practically that required to decompose the aluminium compound in the anode, and, if this compound were an oxygen compound of aluminium, would require 2·8 volts, thus entailing the simultaneous decomposition of the water (which requires 1·49 volts), and corresponding loss of power. While such processes would be very difficult to manage practically, they are, nevertheless, theoretically possible.

(3a) The previous case would be much simplified, if instead of the ore we could find some aluminium compound made from the ores which would be a good conductor of electricity, and could, therefore, act alone as an anode; and, particularly, if we could find one such requiring less than 1·49 volts to decompose it. I am not prepared to name such a compound, for I do not know of one; perhaps the double alkaline sulphides come the nearest of any with which we are at present acquainted. The voltage required for such salts is only 0·9, and they may possibly be conductors to some extent and stable in water. Our information on the properties of these salts is, I regret to say, very meager.

(3b) Aluminium ore can easily be converted into soluble salts, but it is practically out of the question to decompose such solutions with the use of *insoluble* anodes, for the reason that the voltage required for decomposition alone would, in any possible case, reach several volts, and metal could only be obtained by using very concentrated solutions, current of great density, and high voltage (and consequent great loss of power) in the process. However, using soluble anodes of another cheaper metal, placed in porous cells to

prevent their salts from mixing with the aluminium salt around the cathode, the case is changed. The voltage required for decomposition in this case is only the *difference* between that required to decompose the aluminium salt, and that which would be required to decompose the corresponding salt of the other metal, which latter voltage represents the counter-electromotive force obtained by the solution of the anode. This difference of voltage, representing the voltage necessary for decomposition, would have the following values when the soluble anodes were the metals designated:

	<i>Volts.</i>
Zinc	0.22
Iron	0.55
Tin	0.58
Lead	0.54

If, therefore, the refining of impure aluminium in aqueous solution could be effected satisfactorily, it would apparently not be a very difficult step to extract the aluminium directly from a solution of its salt, using zinc or possibly iron for the soluble anode, and keeping the zinc or iron salt apart from the aluminium salt by a porous partition. Theory indicates such a process as being within the range of possibility.

II. Electrolysis of Fused Compounds.

(1) Refining of crude metal.

It is quite conceivable that by the use of some of the good-conducting double chlorides or double fluorides of aluminium and the alkaline metals, which melt below the fusing point of aluminium, the refining of crude aluminium, using it as the anodes, might be practised successfully; but I do not know that such an experiment has ever been made. This direction appears to me to offer great inducements for experimental work, since, by the present methods of extraction, impure aluminium can be produced direct from the ores at nearly 10 cents per pound less than pure metal. With so large a margin for profit, therefore, a suitable refining process should find a place in the industry.

(2) The only fusible ore of aluminium available for direct electrolysis is *cryolite*. If melted and electrolysed with an insoluble anode, aluminium is separated and fluorine set free (which acts on the carbon anode, forming carbon fluoride, a very disagreeable gas), while the composition of the bath is gradually changed by the elimination of aluminium fluoride, leaving it relatively richer in sodium fluoride, until at last sodium is set free and the bath practically stops working. This method of working cannot be practised commercially for several very evident reasons. Dr. Kleiner, of Zurich, tried, in 1887, to keep the bath constant by lining the decomposing vessel with bauxite, hoping that the evolved fluorine would attack and thus re-form aluminium fluoride. The regeneration, however, was very imperfect. No substance is known which, when used as an anode in electrolysing cryolite, will unite with the liberated fluorine and render it inert. This class of processes, based on the direct decomposition of cryolite, may be said to be practically inoperative, and to offer very little, if any, inducement to the investigator.

(3a) Converting the ore into some suitable fusible compound, and then electrolysing. This heading brings us at once to the original process by which Deville and Bunsen, in 1854, first made aluminium *en masse*. Wöhler had isolated aluminium in 1827, by decomposing aluminium chloride with metallic potassium. Bunsen had isolated magnesium by electrolysing fused magnesium chloride, and shortly after, both Deville and Bunsen, independently of each other, treated aluminium-sodium double chloride in the same way, and obtained the aluminium in considerable quantity. This salt, which melts at about 185°C. , was contained in a glazed porcelain crucible, and electrolysed by the current of a primary battery, with a cathode of sheet platinum and an anode of carbon, two Bunsen cells in series (giving 3.6 volts) being found capable of decomposing the bath. As the bath is decomposed, fresh salt is fed in, and chlorine is continually evolved, while sodium chloride accumulates in the bath and finally stops the operation. Had Deville had dynamos at his command, even this imperfect process might

have been developed by him into a cheaper method than his sodium process.

Quite recently, the idea has been advanced of converting the ore into the fusible double sulphide of aluminium and an alkali metal, and electrolysing this compound. The great advantages of this salt over the double chloride are, that it is much more cheaply prepared, is very stable in the air and requires less than 1 volt to decompose it. The journals have reported that the process has been worked at the Rhine Falls, Switzerland, but I can obtain no authoritative confirmation of that statement.

I know of no other fusible aluminium salt available for this direct electrolysis, although it is within the range of

FREDERICK WÖHLER,
Discoverer of Aluminium,
1827.

H. ST. CLAIRE DEVILLE,
Founder of the Aluminium
Industry. 1854.

possibility, and even of probability, that others will be discovered and, perhaps, made available in the industry.

(3*b*) Dissolving the ore in a fused salt which acts as a solvent, and then electrolysing. This division of electro-metallurgic processes contains the only methods by which commercial aluminium is at present being produced. The application of this principle to the production of aluminium was made independently, in the year 1886, by Héroult, in Europe, and by Hall, in America. The latter worked out the idea in commercial shape more quickly than his European rival, and was the first to put aluminium made on this principle on the market. This was in 1888.

In the process as at present practised, the solvent bath is composed of the double fluorides of aluminium and sodium. This bath may be simply cryolite, but preferably cryolite to which has been added a further proportion of aluminium fluoride and a little calcium fluoride (fluorspar). Into this bath is stirred pure alumina, made from ore by a chemical process, and which is dissolved by the bath to the extent of one-fifth of its weight. The electric current is then sent through this mixture, using for anodes carbon rods dipping into the bath from above. The cathode is formed by the carbon lining of the vessel, on the bottom of which the melted aluminium collects. When the dissolved alumina has nearly all been removed, the resistance of the bath rises, and fluorine fumes, from the decomposition of the solvent, begin to appear; fresh alumina is then stirred in, and the operation thus proceeds continuously. *Fig. 1** is a view of the interior of one of the pot rooms of the Pittsburgh Reduction Company, which works the Hall process. The pot is of boiler iron, having a thick lining of hard-baked carbon. It is made the negative electrode. The heavy copper bar above conveys the positive current, heavy carbon cylinders dipping into the fused material serving as the immediate positive electrodes, being connected with the copper bar by copper rods and cast-iron screw clamps. The whole is set on bricks, to ensure circulation of air, and thus to prevent the bottom from getting overheated. The boxes against the wall contain delicate voltmeters, which, by showing an increased potential absorbed by the pot, indicate at once to the workman the necessity of stirring in a fresh supply of alumina. *Fig. 2* is a sketch (not drawn to scale) of a vertical longitudinal section of one of these pots, with its several attachments. The several parts may be distinguished as follows:

S, iron shell; *N*, negative conductor; *L*, carbon lining, negative electrode; *P*, positive conductor; *A*, Screw clamps; *D*, copper rods; *C*, carbon cylinders, positive electrode; *F*, fused bath; *E*, cover of carbon dust.

* For the use of *Figs. 1* and *3* the *Journal* is indebted to the courtesy of *Cassier's Magazine*.

FIG. 1.—THE HALL ELECTROLYTIC PROCESS FOR ALUMINIUM. VIEW OF THE INTERIOR OF ONE OF THE POT-ROOMS OF THE PITTSBURGH REDUCTION COMPANY.

The cavity containing the fused salt has a sump in which the molten metal collects, and from which it is removed by ladles.

The ingredients present in the bath and the relative potentials necessary to decompose them are as follows:

	<i>Volts.</i>
Alumina	2·8
Aluminium fluoride	4·0
Sodium fluoride	4·7

The action of the current, when not of too high a voltage, is to decompose only the alumina, as long as it is pres-

FIG. 2.—Vertical section of pot for operating the Hall process.

ent in the bath in sufficient amount. The oxygen simply combines with the carbon anodes and passes away as carbonic oxide.

We can calculate easily what the practical output is in such a process. Assuming that a pot absorbs on the average 6 volts, then we have a current of 1 ampère moved by a potential of 6 volts, equal to 6 watts of electrical work, capable, as we have before stated, of separating $\frac{1}{4}$ ounce of aluminium in twenty-four hours. But 746 watts constitute the electrical equivalent of an English

horse-power ; therefore, 1 horse-power should be capable of separating

$$\frac{1}{4} \times \frac{746}{6} = 31.5 \text{ ounces per 24 hours ;}$$

and, if we assume an efficiency of 80 per cent. in the operation, we should still obtain $1\frac{1}{2}$ pounds of aluminium per day per electrical horse-power used.

FIG. 3.—Interior of engine and dynamo room in the plant at New Kensington, Pa.

The plants now engaged in making aluminium on this principle are the following :

The Pittsburgh Reduction Company's plant at New Kensington, Pa., on the Allegheny River, near Pittsburgh. This plant is run by steam-power, the coal used costing only 65 cents per ton ; and, no doubt, is conducted as economically as any steam-power plant possibly could be, with our present means and knowledge.

Fig. 3 shows the interior of the engine and dynamo room, showing the new, six-pole, 600 horse-power Westinghouse

dynamos, and further off two dynamos of different type, driven by Westinghouse automatic engines.

The force employed at the Kensington plant is approximately 1,500 horse-power, and the output averages 2,000 pounds per day. At the same place the company has a rolling mill for making all sorts of plates, bars, beams and sheet,

FIG. 4.—Sketch of plan of plant at Niagara Falls.

and is at present installing a new set of rolls driven by a 1,500 horse-power engine, which will be capable of rolling aluminium plates and sheets up to 8 feet in width. The purified alumina used by this company is partly imported from Germany and partly of domestic manufacture. The company also practically owns the largest of the Georgia bauxite deposits.

This company has had in operation, since July, 1895, a reduction plant at Niagara Falls. It is on the land of the Niagara Falls Power Company, a quarter of a mile above the new power-house. The alternating electric current of 2,500 volts potential and 500 ampères quantity (1,700 electric horse-power) is carried to the reduction works through an underground conduit. It then passes through six static transformers, which transform the current from 2,500 to 115 volts, at the same time correspondingly increasing the ampères, the loss in transformation being about 3 per cent. The currents from each pair of these transformers are passed into rotary transformers, each of 500 horse-power, each of which receives the alternating current of 115 volts by 3,600 ampères from a pair of static transformers and converts it into a direct current of 160 volts by 2,500 ampères, with a loss of another 3 per cent. Three of these rotary transformers, run in parallel, give a current of 7,500 ampères, which is conducted, on heavy copper bars of 8 square inches section, to the pot room. Here the current is passed through a series of thirty pots, the total output being a little over 1 ton of aluminium per day.

Fig. 4 is a sketch of the arrangement of the plant, showing, at the upper corner, the transformer room with its four pairs of static transformers *S, S*, and four rotary transformers *R, R*. Three of the four sets are in continuous operation, the fourth being held in reserve. In the pot room, arranged in a double row, are thirty reducing pots, *P, P*, the current passing down one row and returning up the other. The proposed enlargement will consist in rebuilding each of the 500 horse-power rotary transformers to 800 horse-power each, and adding a fifth one of like capacity. This will double the power, and the unoccupied half of the pot room will then be stocked with a duplicate set of pots. The capacity of the enlarged plant will be $2\frac{1}{2}$ tons of aluminium per day.

The same company is also building a works on the land of the Hydraulic Power Company, of Niagara, close to the edge of the gorge, where it has contracted to take 4,500 horse-power. Six large dynamos of 750 horse-power each

are now being built for this plant by the Westinghouse Electric Company, and it is probable that they will be in operation at the close of this year.

Fig. 5 shows the type of dynamo which has been chosen for this new plant, and we may safely conclude that it represents the best modern type of machine for electrolytic work. In general outline it is very similar to the famous Oerlikon dynamos built at Zurich. At the new Niagara plant, these machines will be run directly coupled to the turbines.

FIG. 5.—Type of dynamos to be used at the new Niagara Falls plant.

The capacity of this plant will be nearly 5,000 pounds of aluminium per day. The output of the plants of the Pittsburgh Reduction Company, now running, is, therefore, about 4,000 pounds per day, while the capacity of the works at the close of the present year, when the enlargements are completed, will be 11,000 pounds daily, or 2,000 tons per year. The officials and managers of this company deserve to be highly commended for the vigorous manner in which they have developed the industry.

In Switzerland, the works of the Aluminium Industrie

Actien-Gesellschaft, located at the Falls of the Rhine, have been in operation eight years, using the Héroult process. The company's present force is 4,000 horse-power, and its daily output 5,000 pounds of aluminium. For three years the company made only aluminium alloys with copper and iron, by Héroult's alloy process, which is described under the head of electric smelting. With the advent of cheap aluminium, the market for ready-made alloys almost disappeared, and the company, under the direction of the well-known electro-metallurgist, Dr. Martin Kiliani, began to make aluminium by Héroult's cryolite and alumina process. The principle of this process is practically identical with Hall's process. Hall says: "Melt cryolite, dissolve alumina in it, and electrolyse." Héroult says: "Flux alumina by melting cryolite with it, and then electrolyse." The processes are so similar that the United States Patent Office rejected Héroult's application, and issued the patent to Hall only. The practical operation of Héroult's process at Neuhausen is so similar to Hall's procedure, already described, that no further description of it is necessary. It may be mentioned here that the cost of all the items of raw material, labor and power is lower in Europe than in the United States, so that the present tariff of 10 cents per pound fairly represents only the difference in cost price here and abroad.

The Neuhausen Works are most picturesquely situated on the north bank of the Rhine, within a stone's throw of the famous Rhine Falls. The accompanying diagram, *Fig. 6*, shows the plan of the present works. The water has a fall of about 80 feet, and is delivered through two large pipes into a large main, from which it is distributed to the seven dynamos. The arrangement of these penstock tubes is not that which accords with the greatest economy of power, but the designers were hampered to a large extent by the situation of the plant, immediately beneath a bluff of rock. The diagram exhibits the old plant (shaded dark), which consists of a 300 horse-power turbine (third in the row), used since 1888; and two 600 horse-power turbines, in operation since 1891. The new plant (outlined) consists of four 600

horse-power turbines, used since 1893, and an extra one of the same power, since installed, which is held as a reserve. The large turbines are run by an upward current of water (Jonval type), the shaft being vertical (see *Fig. 7*).

The dynamos are on the floor above the turbines, and have as their shafts a continuation of the axle of the turbine. The armature is fixed to the shaft and revolves 150 turns per minute, while the field rings and poles are fixed. The brushes are accessible on the floor immediately above

FIG. 7.—Jonval turbines used at the Rhine Falls, Switzerland.

the turbine, while the field is on the floor above (*Fig. 8*). The whole construction passes through three floors or stages of the building.

Fig. 9 shows a nearer view of these admirable and neatly designed machines. Each generator gives a current of 7,500 ampères at a tension of 55 volts, and serves to operate a row of six pots. It appears that a greater voltage is used per pot than in our American practice. The cost of aluminium at these works is probably not over 25 cents per

pound. The market price of the Neuhausen metal in 1895 was 35 cents per pound.

The Neuhausen Company has in process of erection a 10,000 horse-power plant at Rheinfelden, near Basle, which will probably be in operation in 1897. It has also acquired a water right in Austria.

In France, the Société Electro-metallurgique Française worked the Héroult process from 1889 to 1893, at Froges (Isère), and has since removed to La Praz, on the Arc, in Savoy, where it has a plant with a daily capacity of 3,000

FIG. 8.—Showing the arrangement of dynamos above the Jonval turbines.

pounds of pure aluminium. The Société Industrielle de l'Aluminium was formed in 1895, to work the Hall process in France. The company has a large works at Saint-Michel, in the Savoy, where 4,000 horse-power are available, half of which is already being utilised, and the other half will be working during 1896.

In Great Britain, the British Aluminium Company has acquired an interest in the Irish bauxite mines and erected a works to make pure alumina at Larne Harbor, near Bel-

FIG. 6.—PLÅRLAND.

FIG. 6.—PLAN OF THE WORKS OF THE ALUMINIUM INDUSTRIE ACTIEN-GESELLSCHAFT, AT NEUHAUSEN, SWITZERLAND.

fast. The company has purchased water rights at the Falls of Foyers, in Scotland, where 4,000 horse-power will be available. It will operate by the Héroult process, and the capacity of the plant will be about 5,000 pounds per day.

FIG. 9.—The 600 horse-power Oerlikon dynamos used at the Rhine Falls. This plant is expected to get into operation during the present year.

In Norway, a syndicate of German and American capitalists has purchased water rights at the waterfall of Sarps-

fos, on the estate of Hafslund, between Christiania and Göteborg. There is estimated to be available 10,000 horse-power, and it is purposed to have an aluminium works in operation there by 1898.

A tabular statement of the aluminium works now in operation, their power and daily capacity, is as follows :

	<i>Horse-Power.</i>	<i>Daily Capacity, Pounds.</i>
<i>United States :</i>		
New Kensington, Pa.	1,600	2,000
Niagara Falls, N. Y.	1,600	2,400
<i>Switzerland :</i>		
Rhine Falls	4,000	5,000
<i>France :</i>		
La Praz	2,500	3,000
Saint Michel	2,000	2,500
Total	11,700	14,900

This tabulation exhibits a present capacity of 2,500 tons per year; the production during 1895 was approximately 1,500 tons.

The enlargements and new plants at present projected—and which will probably be in operation in 1897, or by 1898 at the latest—are as follows :

	<i>Horse-Power.</i>	<i>Daily Capacity, Pounds.</i>
<i>United States :</i>		
Niagara Falls, N. Y.	5,500	7,000
<i>Switzerland :</i>		
Rheinfelden	6,000	8,000
<i>France :</i>		
Saint Michel	2,000	2,500
<i>Great Britain :</i>		
Falls of Foyers	3,000	4,000
<i>Norway :</i>		
Falls of Sarpsfos	5,000	6,500
Total capacity of projected plants . .	21,500	28,000
“ “ of plants in operation .	11,500	14,500
Total capacity in 1898	33,000	42,500
		<i>Tons.</i>
Annual capacity in 1898 (in short tons)		7,650

When this production has been attained, it is quite probable that the selling price of aluminium will be as low as 25 cents per pound, at which price there are, for practical purposes, only three cheaper metals—iron, lead and zinc.

III. Electro-Thermal Processes.

Following out my classification, I am brought to a decided anti-climax. The present successful methods of producing aluminium have all been described, and this chapter must be confined to a brief allusion to processes which have outlived their usefulness.

In these processes, the current is converted as largely as possible into heat, and, at the temperature obtained, alumina is readily reduced by carbon. The Cowles Brothers

FIG. 10.—Section of Cowles alloy furnace.

used horizontal electrodes, and placed between them the mixture of alumina and carbon, using copper or iron to catch the aluminium and prevent its volatilisation.

Pure aluminium cannot be made in this way, for there is large loss by volatilisation and oxidation, the quality of the metal is vitiated by absorbing carbon, nitrogen and other elements present, and the metal is only obtained in the form of shot, and by an interrupted, and not a continuous, process. *Fig. 10* shows a section of the Cowles furnace, such as was operated for several years at Lockport, N. Y., and at Milton, in England. *Fig. 11* shows the exterior of the battery of furnaces at Milton.

The Hérault alloy furnace was operated for several years in Switzerland and France, and experimentally in the United States, at Boonton, N. J. It is provided with a ver-

FIG. 11.—Battery of Cowles furnaces, at Milton, England.

FIG. 12.—Suite of five Héroult alloy furnaces, at Froges, France.

tical anode, dipping into a cavity in a carbon-lined box, the carbon lining being the cathode. In this cavity, copper or iron is first placed, then melted by the electric arc playing between the electrodes, after which pure alumina is fed in and similarly melted until it forms a liquid bath above the copper. The greater part of the alumina is then reduced by the carbon present. Alloys only can thus be formed. *Fig. 12* shows a battery of five such furnaces, at the works at Froges, France.

So high a voltage is required to conduct these operations, and the aluminium obtained is so impure, that they cannot compete economically with the gentler and yet much more efficient *electrolytic* processes—which have entirely displaced them. The only possible way in which I can imagine the electro-thermal methods being used again in producing aluminium is in the form of huge electrical furnaces, resembling blast furnaces, in which, with the use of suitable fluxes and reducing agents, and the intense heat obtained by the electric arc, raw bauxite would be reduced on a large scale to impure aluminium, which would then be refined by a chemical or electrolytic method.

STEREOSCOPIC RÖNTGEN SHADOW PICTURES.

BY ELIHU THOMSON

The ordinary single shadow picture, as produced by Röntgen's method, shows the position and dimensions of an object in a single plane only. The thickness, depth or relative positions of objects in a direction perpendicular to the plane of the sensitive plate are not shown or indicated in any way. Thus, in a shadow image of a hand, showing the bones with a faint covering of flesh, there would be no indication of a flexure of a finger or of its being directed upward or downward. Neither is there any indication of the actual position of the bones within the soft integuments, except in the direction of length or breadth. The third dimension is missing.