ALUMINUM AND ITS EXTRACTION ON A COMMERCIAL BASIS.

By F. J. SEYMOUR.

THE metal aluminum has such peculiar and desirable qualities, especially in its use as an alloy with other metals, that the writer, in the year 1878, made some practical experiments looking to its production, which consisted mainly in the attempt to separate the metal from commercial zinc, having found that the Missouri and Illinois product carried aluminum in a small percentage; and for this purpose he constructed a furnace by which the metals of greater or lesser specific gravity could be separated while in a molten state, relying upon the difference in their specific gravity, also upon the degree of heat at which each metal under treatment began to crystallize. From this period of time (the first recognition of natural affinity between the metal aluminum and zinc) would sooner or later develop the economical process for their reduction. First experiments were made under the belief that the two metals could be reached together by distillation with appliances analogous to the distillation of zinc ores, and that the two ores, by treating together with carbon and other fluxes, could be cast down as an alloy in a metallic condition. Partial success was reached in these experiments, but it became apparent that the conditions for successful treatment should include an arrangement so complete that the very ethereal vapors distilled from the ores must be held under more rigid conditions than were needed for the distillation of zinc ores alone; and after repeated careful experiment on a practical basis, he finally determined that the economical process for obtaining the metal aluminum would be found by a process of vaporization and condensation, and under such condition as would hold under proper control the vapors liberated and almost entirely excluded from contact with the atmosphere; also subject to such conditions as would allow the introduction of hydrocarbon and other gases at any time needed to make perfect reduction and concentration of the silica and impurities, thereby making such concentration as would deliver the mineral contained in the ores in the condition of their oxides at one point, and the impurities to be delivered at another, and to be done by such an arrangement of appliances as would include cheap labor and the handling of large numbers of furnaces and large quantities of material.

Early effort to obtain this metal may be said to have commenced about the year 1855, since which time Messrs. Bell & Co., Wurtz & Co., De Ville, Wohler, and later James Webster and Freishmuth, of our own country, have each made success in obtaining the metal, but at such cost as to exclude its use for common purposes, and thereby it has been out of reach for those purposes for which its inherent qualities render the metal peculiarly adapted.

My process for obtaining aluminum is substantially as follows, and consists in taking the natural earths carrying the metal and treating them with calamine or carbonate zinc ore and other fluxes.

The formula is substantially as follows: Carbonate zinc ore 100 parts, kaolin 100 parts, carbon, either as anthracite coal or its equivalent in hydrocarbon gas, 125 parts, pearlash or its equivalent 15 parts, chloride sodium or its equivalent 10 parts, and may be varied somewhat, all these parts (except hydrocarbon gas when used) to be intimately mixed together by grinding under heavy rollers.

It has been found that the earths or ores peculiar to America carrying aluminum are mainly composed of silica and alumina in about equal proportion, viz., an average 40 per cent. alumina and 45 per cent. silica, the balance of parts being moisture and impurities. The union of the alumina and silica as found in the natural earths is to a certain extent a mechanical, not a chemical one, and it has also been found that all attempts to cast down the metal from the natural earths directly or by any process analogous to the general method of metallurgical operation, or to the method generally in use for the distillation of zinc ores, have failed, for the reason that alumina in its natural condition, as found in the various earths, is so very highly sublimated, also is so very light in its specific gravity when reduced into a metallic condition, that all the common methods of treating it by heat, either in an open crucible or by distillation, will fail to cast it down in any way analogous to the common methods of treating ores.

The method herein described consists mainly in the use of zinc ore of the calamine or carbonate order, with kaolin or earths carrying alumina, for the reason that the one metal has such chemical affinity for the other, and the one such greater gravity than the other, that when mixed in proper proportions and subjected to heat under conditions as hereinafter explained, the one will act as a flux and assist in liberating the oxides to be taken down together, either as the oxides of the two metals, or in a metallic condition.

The deposit of alumina in all the rocks and earths is found in such sublimated condition as to approach more closely than most other deposits of mineral to what may be stated as nearer the density of the atmosphere, and under a moderate degree of heat is expelled in such rarefied vapor as to escape observation.

A quantity of kaolin placed under heat in open crucible (showing 40 per cent. alumina by critical analysis) will vaporize before the silica is calcined and reduced, and will have entirely disappeared, so that no trace is found by the same analysis as the one preceding its being placed under heat.

Many inquiries have been made to determine from what source the great deposit of alumina is projected. Geologists determine that one-eighth per cent. of the entire crust of the earth is an aluminous deposit. There are certain localities and special formations of the earth's surface that show in excess the deposit of this mineral, notably the drift clays in America. The valley of the Connecticut river shows a drift clay of ancient origin, yet the deposit is still progressing, resulting mainly from the abrasion of granite and feldspar rocks carried down by the current and left as sediment, accumulating since the early history of this notable river.

Extensive deposits of kaolin are found in the State of Georgia almost white and free from iron. This kaolin will show 40 per cent. aluminum, 47 per cent. silica, the balance moisture and impurities.

An immense deposit of kaolin clay is found in Virginia, carrying 60 per cent. aluminum and 9 per

cent. silica, the balance moisture and impurities, with a trace of iron.

An abundant supply of clay adapted for the purposes of treatment by this process is found in the State of New York, notably in the vicinity of Syracuse. Large deposits are also found in some of the Western States and Territories, notably Colorado. Generally the kaolin of all the deposits mentioned, except that noticed in Virginia, shows about equal proportions of aluminum and silica.

The process herein described proposes to treat kaolin in its natural condition direct by heat, and includes making use of such fluxes as may be used to advantage in its reduction and concentration, and delivering it in the condition of oxide, and by subsequent treatment into an alloy of the two metals.

A furnace proper for this work may be described as follows, and would include capacity for reducing two tons of the ore of alumina and zinc in twenty-four hours. The use of fuel in form of gas is very desirable, as it may be obtained of such purity as to be driven directly upon the ores without crucibles. Its use as fuel also enables making the process continuous, and the necessity of stopping for cleaning and gathering the product a question of days, at the option of the operator.

The furnace for the reduction of ores may also be so constructed as to admit of crucible work to be used in the reduction of the oxide into metal alone, and the production of alloys of aluminum with all the metals for which it has any affinity.

The burners used in this furnace are constructed upon the blowpipe principle. Each burner has six pipes for gas and thirteen pipes for air. The gas is delivered through the burner and into the furnace under a pressure of one and a half pounds; the air is delivered through the burner and into the furnace under about the same pressure; the gas and air first come into contact at the point where combustion first takes place. The force by which each is impelled carries the consuming gas and heat directly upon the ores under treatment. Both gas and air have their independent chamber and valve, and the proportions of each, as delivered into the furnace, is such as to make combustion perfect, and both under complete control of the operator. The result of this arrangement includes an intense heat exactly upon the points in the furnace desirable to reach. The reduction chamber of this furnace may be fourteen inches square and fifteen feet long, provided at its ends with adjustable openings for the purpose of raking out the debris after the mineral has been expelled; also, provided at intervals, extending along its entire length, at its side surface, with openings to admit the projection of the pipes or burners to the proper distance under the outer wall of the furnace. Each burner having its independent supply of gas and air, and once adjusted, will run continuously for an indefinite length of time without changing the degree of heat attained in the furnace chamber.

This furnace is also provided at its upper side or floor with openings, at intervals, for the admission of crucibles or ores for concentration; and, also, with appliances for lifting crucibles from the reduction chamber, when desired. Each of the openings, as before described, communicates directly with the reduction chamber, and is each provided with a separate flue, and all communicate with a common heating chamber lying above and parallel, and is a part of furnace construction, as described above. This heating chamber is 30 inches wide, 36 inches high, and 15 feet long, constructed so thoroughly as to be able to sustain as great heat as the reduction chamber below, and may be designated chamber No. 1.

The mineral vapors expelled from the ores are carried by the blast and natural draught into this heating chamber, and there become homogeneous and uniformly sublimated. This is desirable, as the ores are fed into the reduction chamber below at somewhat irregular intervals. This heating chamber is provided at the top and center with a single outlet which communicates, by means of a flue, with a brick chamber, No. 2, 15 feet in diameter and 8½ feet high. The result to be secured by this chamber is a reduction of the heat and mineral vapors; also allows the vapors carrying the oxides of the minerals to become more homogeneous and better fitted for treatment by the reagents for precipitation, which is to follow. This chamber is provided with outlets at intervals through its arched top, which becomes the floor of the chamber to which it communicates.

Chamber No. 3 is of brick and thoroughly built; is 15 feet diameter, 10½ feet high, and cone shaped. The heat and vapors coming from the chamber below, through the arched floor, are met in this chamber by a spray of a weak solution of carb. potash, forced into a spray by a pressure of the atmosphere driven by a pressure blower. This chamber is also provided at its extreme upper end with an outlet through which projects a pipe, which may serve two purposes, one for carrying the hydrates of ammonia into and among the heat and vapor with which it is constantly being supplied, and the other as a measure of safety in determining the pressure carried. This is done by means of a pressure gauge attached to the lower end of the pipe or outlet.

This cone-shaped chamber, No. 3, is provided with an outlet pipe, somewhat below the center of its altitude, 20 inches in diameter, and communicates with a series of copper cylinders 6 feet in diameter and 5 feet long. These copper cylinders are placed at intervals of about six feet, the one from the other, and communication with each made by a continuation of the 20 inch pipe. This pipe extends beyond the copper cylinders and into a chimney for the escape of sulphurous material, if desired. The outlet pipe near the chimney is provided with a damper, or means for shutting off or checking the escape of any material that would be desirable to save, thus enabling the product continually liberated from the reduction furnace to be treated throughout the system on the retort or distillation principle. The copper cylinders or condensers are each provided, at their extreme upper diameter, with inlet pipes, which project inside the cylinders, to which are attached a bulb or sprayer, for the purpose of filling the inside of the cylinders with water in a mist or spray carrying a reagent in order to make complete the precipitation of the mineral vapors coming from the reduction furnace.

This system of reduction and appliances enables the operator to bring the heat and sublimated oxides liber-

ated from the ores by the reduction furnace through a series of cooling and condensing chambers, and then down to nearly the normal temperature of the atmosphere, which includes the opportunity to have made complete precipitation of the mineral contained in the ores under treatment. The copper condensing cylinders are also provided, at the extreme point of their lower diameter, with outlet pipes through which are carried automatically the flow of water and condensed mineral down and into vaporizing and drying pans. These pans are 24 feet long, 5 feet wide, and 5 inches deep. The flow of water or fluid coming from the condensing cylinders is directly over and in contact with heat, and at such degree as will vaporize the water from the mineral coming from the condensing cylinders and chambers about as rapidly as will keep the vaporizing pans from overflow. This enables the operator to make his runs of the furnace of such length as to result in economy in gathering the mineral, and all from the reducing chamber through to the product of dry oxide, and may be made rapid or slow, according to the degree of heat applied at the reduction furnace, including the amount of cooling material and reagents through which the liberated mineral vapors are obliged to come into contact in their transmission through the various stages of cooling and precipitating. This process will deliver the oxides nearly chemically pure, and in such condition as to be readily absorbed by metals in a molten state, notably iron, steel, copper, tin, and zinc, making an alloy with these metals, and increasing greatly their good qualities.

This product of alloys, including aluminum, bronze, nickel and tin alloys, aluminized iron and steel, is crucible work, and may be done in what is here described as the reduction furnace, and as follows. The metal to be alloyed is first placed in the crucible and under heat, and after being brought to a melted condition of ebullition, the fluxes, which include the oxides, are added, and then the crucible covered, and should be subjected to high heat for forty-five minutes, or until the fluxes have been almost disintegrated and absorbed by heat. Copper and nickel alloys with aluminum are greatly improved in quality by being recast, and do not lose their durable qualities by this being repeated many times. The reduction of the oxides aluminum and zinc into their alloys consists in packing a quantity of the oxides in crucibles, first having been thoroughly and intimately mixed with carbon and proper fluxes, and subjecting to a proper degree of heat. The character of the treatment of the two ores has led them into such intimate and such close relationship that under heat as above a considerable portion of the metals contained in the oxide is liberated, and the heavy metal will carry the lighter down into an alloy, and the percentage of each will correspond nearly to the percentage of each ore submitted for treatment in the reduction furnace.

The separation of the aluminum from the zinc, as found in the alloys obtained as described above, may be accomplished by two methods. One by heat and nearly complete volatilization of the zinc, leaving the aluminum behind. Metallic zinc volatilizes easily and is easily expelled from the alloy. Aluminum does not volatilize easily after once in a metallic condition. This may be done and separations made under conditions in which the vaporized zinc may be saved.

Another method is accomplished by the difference in their specific gravity, which under moderate heat, and separating by agitation, the lighter metal may be taken from the surface almost chemically pure, and the heavier metal from the bottom. It is desirable that by this process of separation the volume of metal under treatment should be of such quantity that fresh alloy may be added from time to time without changing materially the temperature of the volume under heat, thereby making the process continuous and the two metals zinc and aluminum obtained in commercial form and useful for any purpose for which the two metals may be adapted.

ALUMINUM.*

By Sir HENRY ROSCOE, M.P., D.C.L., LL.D., V.P.R.S.

CHEMISTS of many lands have contributed to our knowledge of the metal aluminum. Davy, in 1807, tried in vain to reduce alumina by means of the electric current. Oerstedt, the Dane, in 1824 pointed out that the metal could be obtained by treating the chloride with an alkali metal; this was accomplished in Germany by Wohler in 1827, and more completely in 1845, while in 1854, Bunsen showed how the metal can be obtained by electrolysis. But it is to France, by the hands of Henri Ste.-Claire Deville, in the same year, that the honor belongs of having first prepared aluminum in a state of purity and of obtaining it on a scale which enables its valuable properties to be recognized and made available, and the bar of "silver-white metal from clay" was one of the chemical wonders in the first Paris exhibition of 1855. Now England and America step in, and I have this evening to relate the important changes which further investigation has effected in the metallurgy of aluminum. The process suggested by Oerstedt, carried out by Wohler, and modified by Deville, remains in principle unchanged. The metal is prepared, as before, by a reduction of the double chloride of aluminum and sodium, by means of metallic sodium in presence of cryolite; and it is therefore not so much a description of a new reaction as of improvements of old ones of which I have to speak.

I may perhaps be allowed to remind my hearers that more than 33 years ago, Mr. Barlow, then secretary to the Institution, delivered a discourse in the presence of M. Deville on the properties and mode of preparation of aluminum, then a novelty. He stated that the metal was then sold at the rate of £3 per ounce, and the exhibition of a small ingot, cast in the laboratory by M. Deville, was considered remarkable. As indicating the progress since made, I may remark that the metal is now sold at 20s. per lb., and manufactured by the ton, by the Aluminum Company, at their works at Oldbury, near Birmingham. The improvements which have been made in this manufacture by the zeal and energy of Mr. Castner, an American metallurgist, are of so important a character that the process may properly be termed the Deville-Castner process.

The production of aluminum previous to 1887 prob-

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ably did not exceed 10,000 lb. per annum, while the price at that time was very high. To attain even this production required that at least 100,000 lb. of double chloride and 40,000 lb. of sodium should be manufactured annually. From these figures an idea of the magnitude of the undertaking assumed by the Aluminum Company may be estimated, when we learn that they erected works having an annual producing capacity of 100,000 lb. of aluminum. To accomplish this required not only that at least 400,000 lb. of sodium, 800,000 lb. of chlorine, and 1,000,000 lb. of double chloride should be annually manufactured, but in addition that each of these materials should be produced at a very low cost, in order to enable the metal to be sold at 20s. per lb.

The works now cover a space of nearly five acres. They are divided into five separate departments, viz., 1st, sodium; 2d, chlorine; 3d, chloride; 4th, aluminum; and 5th, foundry, rolling, wire mills, etc.

In each department an accurate account is kept of the production each day, the amount of material used, the different furnaces and apparatus in operation, etc. In this manner it has been found possible to ascertain each day exactly how the different processes are progressing, and what effect any modification has, either on cost, quantity, or quality of product. By this means a complicated chemical process is reduced to a series of very simple operations, so that while the processes are apparently complicated and difficult to carry out successfully, this is not the case now that the details connected with the manufacture have been perfected, and each operation carried on quite independently until the final materials are brought together for the production of the aluminum.

MANUFACTURE OF SODIUM.

The first improvement occurs in the manufacture of sodium by what is known as the "Castner process." The successful working of this process marks an era in the production of sodium, as it not only has greatly cheapened the metal, but has enabled the manufacture to be carried out upon a very large scale with little or no danger. Practically, the process consists in heating fused caustic soda in contact with carbon while the former substance is in a perfectly liquid condition. By the process in vogue before the introduction of this method, it was always deemed necessary that special means should be taken to guard against actual fusion of the mixed charges, which, if it were to take place, would to a large extent allow the alkali and reducing material to separate. Thus, having an infusible charge to heat, requiring the employment of a very high temperature for its decomposition, the iron vessels must be of small circumference to allow the penetration of the heat to the center of the charge without actually melting the vessel in which the materials are heated. By the new process, owing to the alkali being in a fused or perfectly liquid condition in contact directly with carbon, the necessity of this is avoided, and consequently, the reduction can be carried on in large vessels at a comparatively low temperature. The reaction taking place may be expressed as follows:

The vessels in which the charges of alkali and reducing material are heated are of egg-shaped pattern, about 18 inches in width at their widest part and about 3 feet high, and are made in two portions, the lower one being actually in the form of a crucible, while the upper one is provided with an upright stem and a protruding hollow arm. This part of the apparatus is known as the cover. In commencing the operation, these covers are raised in the heated furnace through apertures provided in the floor of the heated chamber, and are then fastened in their place by an attachment adjusted to the stem; the hollow arm extends outside the furnace. Directly below each aperture in the bottom of the furnace are situated the hydraulic lifts, attached to the top of which are the platforms upon which are placed the crucibles to be raised into the furnace. Attached to the hydraulic lifts are the usual reversing valves for lowering or raising, and the platform is of such a size as, when raised, completely to fill the bottom aperture of the furnace. The charged crucible, being placed upon the platform, is raised into its position, the edges meeting those of the cover, forming an air-tight joint which prevents the escape of gas and vapor from the vessel during reduction, except by the hollow arm provided for this purpose. The natural expansion of the iron vessels is accommodated by the water pressure in the hydraulic lifts, so that the joint of the cover and crucible are not disturbed until it is intended to lower the lift for the purpose of removing the crucible.

The length of time required for the first operation of reduction and distillation is about two hours. At the end of this time the crucibles are lowered, taken from the platforms by a large pair of tongs on wheels, carried to a dumping pit, and thrown on their side. The residue is cleaned out, and the hot pot, being again gripped by the tongs, is taken back to the furnace. On its way, the charge of alkali and reducing material is thrown in. It is again placed on the lift and raised in position against the edges of the cover. The time consumed in making the change is one and a half minutes, and it only requires about seven minutes to draw, empty, recharge, and replace the five crucibles in each furnace. In this manner the crucibles retain the greater amount of their heat, so that the operation of reduction and distillation now only requires one hour and ten minutes. Each of the four furnaces, of five crucibles each, when in operation, is drawn alternately, so that the process is carried on night and day.

Attached to the protruding hollow arm from the cover are the condensers, which are of a peculiar pattern specially adapted to this process, being quite different from those formerly used. They are about 5 inches in diameter, and nearly 3 feet long, and have a small opening in the bottom about 20 inches from the nozzle. The bottom of these condensers is so inclined that the metal condensed from the vapor issuing from the crucible during reduction flows down and out into a small pot placed directly below this opening. The uncondensed gases escape from the condenser at the further end, and burn with the characteristic sodium flame. The condensers are also provided with a small hinged door at the further end, by means of which the workmen from time to time may look into observe how

the distillation is progressing. Previous to drawing the crucibles from the furnace for the purpose of emptying and recharging, the small pots each containing the distilled metal are removed, and empty ones substituted. Those removed each contain on an average about 6 lb. of metal, and are taken directly to the sodium casting shop, where it is melted and cast, either into large bars ready to be used for making aluminum, or in smaller sticks to be sold.

Special care is taken to keep the temperature of the furnaces at about 1,000° C., and the gas and air valves are carefully regulated, so as to maintain as even a temperature as possible. The covers remain in the furnace from Sunday night to Saturday afternoon, and the crucibles are kept in use until they are worn out, when new ones are substituted without interrupting the general running of the furnace. A furnace in operation requires 250 lb. of caustic soda every one hour and ten minutes, and yields in the same time 30 lb. of sodium and about 240 lb. of crude carbonate of soda. With the four furnaces at work 120 lb. of sodium can be made every seventy minutes, or over a ton in the twenty-four hours. The residual carbonate, on treatment with lime in the usual manner, yields two-thirds of the original amount of caustic operated upon. The sodium, after being cast, is saturated with kerosene oil, and stored in large tanks holding several tons, placed in rooms specially designed both for security against either fire or water.

CHLORINE MANUFACTURE.

This part of the works is connected with the adjacent works of Messrs. Chance Bros. by a large gutter percha pipe, by means of which from time to time hydrochloric acid is supplied direct into the large storage cisterns, from which it is used as desired for making the chlorine. For the preparation of the chlorine gas needed in making the chloride, the usual method is employed; that is, hydrochloric acid and manganese dioxide are heated together, when chlorine gas is evolved with effervescence, and is led away by earthenware and lead pipes to large lead-lined gasometers, where it is stored.

The materials for the generation of the chlorine are brought together in large tanks, or stills, built up out of great sandstone slabs, having rubber joints, and the heating is effected by the injection of steam. The evolution of gas, at first rapid, becomes gradually slower, and at last stops; the hydrochloric acid and manganese dioxide being converted into chlorine and manganous chloride. This last compound remains dissolved in the "spent still liquor," and is reconverted into manganese dioxide, to be used over again, by Weldon's manganese recovery process. Owing to the difficulty of keeping up a regular supply of chlorine under a constant pressure directly from the stills, in order that the quantity passed into the sixty different retorts in which the double chloride is made can be regulated and fed as desired, four large gasometers were erected. Each of these is capable of holding 1,000 cubic feet of gas, and is completely lined with lead, as are all the connecting mains, etc., this being the only available metal which withstands the corrosive action of chlorine. The gasometers are filled in turn from the stills, the chlorine consumed being taken direct from a gasometer under a regular pressure until it is exhausted; the valves being changed, the supply is taken from another holder, the emptied one being refilled from the still.

MANUFACTURE OF THE DOUBLE CHLORIDE.

Twelve large regenerative gas furnaces are used for heating, and in each of these are fixed five horizontal fire clay retorts about 10 feet in length, into which the mixture for making the double chloride is placed. These furnaces have been built in two rows, six on a side, the clear passageway down the center of the building, which is about 250 feet long, being 50 feet in width. Above this central passage is the staging, carrying the large lead mains for the supply of the chlorine coming from the gasometers. Opposite each retort and attached to the main are situated the regulating valves, connected with lead and earthenware pipes, for the regulation and passage of the chlorine to each retort. The valves are of peculiar design, and have been so constructed that the chlorine is made to pass through a certain depth of liquid, which not only, by opposing a certain pressure, allows a known quantity of gas to pass in a given time, but also prevents any return from the retort into the main, should an increase of pressure be suddenly developed in the retorts.

The mixture with which the retorts are charged is made by grinding together hydrate of alumina, salt, and charcoal. This mixture is then moistened with water, which partially dissolves the salt, and thrown into a pug mill of the usual type for making drain pipes, excepting that the mass is forced out into solid cylindrical lengths upon a platform alongside of which a workman is stationed with a large knife, by means of which the material is cut into lengths of about three inches each. These are then piled on top of the large furnaces to dry. In a few hours they have sufficiently hardened to allow of their being handled. They are then transferred to large wagons, and are ready to be used in charging the retorts.

The success of this process is in a great measure dependent, 1st, on the proportionate mixture of materials; 2d, on the temperature of the furnace; 3d, on the quantity of chlorine introduced in a given time, and 4th, on the actual construction of the retorts. I am, however, not at liberty to discuss the details of this part of the process, which have only a commercial interest. In carrying on the operation the furnaces or retorts, when at the proper temperature, are charged by throwing in the balls until they are quite full, the fronts are then sealed up, and the charge allowed to remain undisturbed for about four hours, during which time the water of the alumina hydrate is completely expelled. At the end of this time the valves on the chlorine main are opened, and the gas is allowed to pass into the charged retorts. In the rear of each retort, and connected therewith by means of an earthenware pipe, are the condenser boxes, which are built in brick. These boxes are provided with openings or doors, and also with earthenware pipes, connected with a small flue for carrying off the uncondensed vapors to the large chimney. At first the chlorine passed into each retort is all absorbed by the charge, and only carbonic oxide escapes into the open boxes, where it

burns. After a certain time, however, dense fumes are evolved, and the boxes are then closed, while the connecting pipe between the box and the small flue serves to carry off the uncondensed vapors to the chimney.

The reaction which takes place is as follows:

The chlorine is passed in for about seventy-two hours in varying quantity, the boxes at the back being opened from time to time by the workmen to ascertain the progress of the distillation. At the end of the time mentioned the chlorine valves are closed and the boxes at the back of the furnace are all thrown open. The crude double chloride, as distilled from the retorts, condenses in the connecting pipe and trickles down into the boxes, where it solidifies in large irregular masses. The yield from a bench of five retorts will average from 1,600 to 1,800 lb., which is not far from the theoretical quantity. After the removal of the crude chloride from the condenser boxes the retorts are opened at their charging end, and the residue, which consists of a small quantity of alumina, charcoal, and salt, is raked out and remixed in certain proportions with fresh material to be used over again. The furnace is immediately recharged and the same operations repeated, so that from each furnace upward of 3,500 lb. of chloride are obtained weekly. With ten of the twelve furnaces always at work the plant is easily capable of producing 30,000 lb. of chloride per week, or 1,500,000 lb. per annum.

Owing to the presence of iron, both in the materials used (viz., charcoal, alumina, etc.) and in the fire clay composing the retorts, the distilled chloride always contains a varying proportion of this metal in the form of ferrous and ferric chlorides. When it is remembered that it requires 10 lb. of this chloride to produce 1 lb. of aluminum by reduction, it will be quite apparent how materially a very small percentage of iron in the chloride will influence the quality of the resulting metal. I may say that, exercising the utmost care as to the purity of the alumina and the charcoal used, and after having the retorts made of special fire clay containing only a very small percentage of iron, it was found almost impossible to produce upon a large scale a chloride containing less than 0.3 per cent. of iron.

This crude double chloride, as it is now called at the works, is highly deliquescent, and varies in color from a light yellow to a dark red. The variation in color is not so much due to the varying percentage of iron contained as to the relative proportion of ferric or ferrous chlorides present, and although a sample may be either very dark or quite light, it may still contain only a small percentage of iron if it be present as ferric salt, or a very large percentage if it is in the ferrous condition.

Even when exercising all possible precautions, the average analysis of the crude double chloride shows about 0.4 per cent. of iron. The metal subsequently made from this chloride, therefore, never contained much less than about 5 per cent. of iron, and, as this quantity greatly injures the capacity of aluminum for drawing into wire, rolling, etc., the metal thus obtained required to be refined. This was successfully accomplished by Mr. Castner and his able assistant Mr. Cullen, and for some time all the metal made was refined, the iron being lowered to about 2 per cent.

The process, however, was difficult to carry out, and required careful manipulation, but as it then seemed the only remedy for effectively removing the iron, it was adopted and carried on for some time quite successfully, until another invention of Mr. Castner's rendered it totally unnecessary. This consisted in purifying the double chloride before reduction.

I cannot now explain this process, but I am able to show some of the product. This purified chloride, or pure double chloride, is, as you see, quite white, and is far less deliquescent than the crude, so that it is quite reasonable to infer that this most undesirable property is greatly due to the former presence of iron chlorides. I have seen large quantities containing upward of 1½ per cent. of iron, or 150 lb. to 10,000 of the chloride, completely purified from iron in a few minutes, so that, while the substance before treatment was wholly unfit for the preparation of aluminum, owing to the presence of iron, the result was, like the sample exhibited, a mass containing only 1 lb. of iron in 10,000, or 0.01 per cent. The process is extremely simple, and adds little or no appreciable cost to the final product. After treatment, this pure chloride is melted in large iron pots and run into drums similar to those used for storing caustic soda. As far as I am aware it was generally believed to be an impossibility to remove the iron from anhydrous double chloride of aluminum and sodium, and few, if any, chemists have ever seen a pure white double chloride.

ALUMINUM MANUFACTURE.

I now come to the final stage of the process, viz., the reduction of the pure double chloride by sodium. This is effected, not in a tube of Bohemian glass, as shown in Mr. Barlow's lecture in 1856, but in a large reverberatory furnace, having an inclined hearth about six feet square, the inclination being toward the front of the furnace, through which are several openings at different heights. The pure chloride is ground together with cryolite in about the proportions of two to one, and is then carried to a staging erected above the reducing furnace. The sodium, in large slabs or blocks, is run through a machine similar to an ordinary tobacco cutting machine, where it is cut into small, thin slices; it is then also transferred to the staging above the reducing furnace.

Both materials are now thrown into a large revolving drum, when they become thoroughly mixed. The drum being opened and partially turned, the contents drop out into a car on a tramway directly below. The furnace having been raised to the desired temperature, the dampers of the furnace are all closed to prevent the access of air, the heating gas also being shut off. The car is then moved out on the roof of the furnace until it stands directly over the center of the hearth. The furnace roof is provided with large hoppers, and through these openings the charge is introduced as quickly as possible. The reaction takes place almost immediately, and the whole charge quickly liquefies. At the end of a certain time the heating gas is again introduced and the charge kept at a moderate temperature for about two hours. At the end of this period the furnace is tapped by driving a bar through the lower

opening, which has previously been stopped with a fire clay plug, and the liquid metal run out in a silver stream into moulds placed below the opening. When the metal has all been drawn off, the slag is allowed to run out into small iron wagons and removed. The openings being again plugged up, the furnace is ready for another charge. From each charge, composed of about 1,200 lb. of pure chloride, 600 lb. of cryolite, and 350 lb. of sodium, about 115 to 120 lb. of aluminum is obtained.

The purity of the metal entirely depends upon the purity of the chloride used, and without exercising more than ordinary care the metal tests usually indicate a purity of metal above 99 per cent. On the table is the metal run from a single charge, its weight is 116 lb., and its composition, as shown by analysis, is 99.2 aluminum, 0.3 silicon, and 0.5 iron. This I believe to be the largest and the purest mass of metal ever made in one operation.

The results of eight or nine charges are laid on one side, and then melted down in the furnace to make a uniform quality, the liquid metal, after a good stirring, being drawn off into moulds. These large ingots, weighing about 60 lb. each, are sent to the casting shop, there to be melted and cast into the ordinary pigs, or other shapes, as may be required for the making of tubes, sheets, or wire, or else used directly for making alloys of either copper or iron.

The following table shows approximately the quantity of each material used in the production of one ton of aluminum:

Metallic sodium.....	6,300 lb.
Double chloride.....	22,400 lb.
Cryolite.....	8,000 lb.
Coal.....	8 tons.

To produce 6,300 lb. of sodium is required:

Caustic soda.....	44,000 lb.
Carbide made from pitch, 12,000 lb., and iron turnings, 1,000 lb.	7,000 lb.
Crucible castings.....	2½ tons.
Coal.....	75 tons.

For the production of 22,400 lb. double chloride is required:

Common salt.....	8,000 lb.
Alumina hydrate ..	11,000 lb.
Chlorine gas.....	15,000 lb.
Coal.....	180 tons.

For the production of 15,000 lb. of chlorine gas is required:

Hydrochloric acid	180,000 lb.
Limestone dust.....	45,000 lb.
Lime.....	30,000 lb.
Loss of manganese	1,000 lb.

(These figures were rendered more evident by the aid of small blocks, each cut a given size so as to represent the relative weights of the different materials used to produce one unit of aluminum.)

It might seem, on looking over the above numbers, as if an extraordinary amount of waste occurred, and as if the production is far below that which ought to be obtained, but a study of the figures will show that this is not the case. I would wish to call attention to one item in particular, viz., fuel, it having been remarked that the consumption of coal must prevent cheap production. I think when it is remembered that coal, such as used at the works, costs only 4s. per ton, while the product is worth £2,240 per ton, the cost of coal is not an item of consequence in the cost of production. The total cost of the coal to produce one ton of metal being £50, the actual cost for fuel is less than sixpence for every pound of aluminum produced. The ratio of cost of fuel to value of product is indeed less than is the case in making either iron or steel. In concluding my remarks as to the method of manufacture and the process in general, I may add that I do not think it is too much to expect, in view of the rapid strides already made, that in the future further improvements and modifications will enable aluminum to be produced and sold even at a lower price than appears at present possible.

PROPERTIES OF ALUMINUM.

In its physical properties aluminum widely differs from all the other metals. Its color is a beautiful white, with a slight blue tint. The intensity of this color becomes more apparent when the metal has been worked, or when it contains silicon or iron. The surface may be made to take a very high polish, when the blue tint of the metal becomes manifest, or it may be treated with caustic soda and then nitric acid, which will leave the metal quite white. The extensibility or malleability of aluminum is very high, ranking with gold and silver if the metal be of good quality. It may be beaten out into thin leaf quite as easily as either gold or silver, although it requires more careful annealing.

It is extremely ductile and may be easily drawn, especial care only being required in the annealing.

The excessive sonorousness of aluminum is best shown by example (large suspended bar being struck). Faraday has remarked, after experiments conducted in his laboratory, that the sound produced by an ingot of aluminum is not simple, and one may distinguish the two sounds by turning the vibrating ingot.

After being cast it has about the hardness of pure silver, but may be sensibly hardened by hammering.

Its tensile strength varies between 12 and 14 tons to the inch (test sample which was shown having been broken at 13 tons or 27,000 lb.), ordinary cast iron being about 8 tons. Comparing the strength of aluminum in relation to its weight, it is equal to steel of 38 tons tensile strength. The specific gravity of cast aluminum is 2.58, but after rolling or hammering this figure is increased to about 2.68.

The specific gravity of aluminum being 1, copper is 3.6, nickel 3.5, silver 4, lead 4.8, gold 7.7.

The fusibility of aluminum has been variously stated as being between that of zinc and silver, or between 630° and 1,000° C.

As no reliable information has ever been made public on this subject, my friend Professor Carnelley undertook to determine it. I was aware, from information gained at the works at Oldbury, that a small increase in the percentage of contained iron materially raised its point of fusion, and it has been undoubtedly due to this cause that such wide limits are given for the melt-

ing point. Under these circumstances two samples were forwarded for testing, of which No. 1, containing ½ per cent. of iron, had a melting point of 700° C.; whereas No. 2, containing 5 per cent. of iron, does not melt at 700°, and only softens somewhat above that temperature, but undergoes incipient fusion at 730°.

According to Faraday, aluminum ranks very high among metallic conductors of heat and electricity, and he found that it conducted heat better than either silver or copper. The specific heat is also very high, which accounts for length of time required for an ingot of the metal to either melt or get cold after being cast.

Chemically, its properties are well worthy of study.

Air, either wet or dry, has absolutely no effect on aluminum at the ordinary temperature, but this property is only possessed by a very pure quality of metal, and the pure metal in mass undergoes only slight oxidation even at the melting power of platinum.

Thin leaf, however, when heated in a current of oxygen, burns with a brilliant bluish white light. (Experiment shown.) If the metal be pure, water has no effect on it whatever, even at a red heat. Sulphur and its compounds also are without action on it, while under the same circumstances nearly all metals would be discolored with great rapidity. (Experiment shown using silver and aluminum under the same conditions.)

Dilute sulphuric acid and nitric acid, both diluted and concentrated, have no effect on it, although it may be dissolved in either hydrochloric acid or caustic alkali. Heated in an atmosphere of chlorine it burns with a vivid light, producing aluminum chloride. (Experiment shown.) In connection with the subject it may be of interest to state the true melting point of the double chloride of aluminum and sodium, which has always been given at 170° to 180° C., but which Mr. Baker, the chemist of the works, finds lies between 125° and 130° C.

USES OF ALUMINUM.

Its uses, unalloyed, have heretofore been greatly restricted. This is, I believe, alone owing to its former high price, for no metal possessing the properties of aluminum could help coming into larger use if its cost were moderate. Much has been said as to the impossibility of soldering it being against its popular use, but I believe that this difficulty will now soon be overcome. The following are a few of the purposes to which it is at present put: Telescope tubes, marine glasses, eye glasses, and sextants, especially on account of its lightness. Fine wire for the making of lace, embroidery, etc. Leaf, in the place of silver leaf, saber sheaths, sword handles, etc., statuettes and works of art, jewelry and delicate physical apparatus, culinary utensils, harness fittings, metallic parts of soldiers' uniforms, dental purposes, surgical instruments, reflectors (it not being tarnished by the products of combustion), photographic apparatus, aeronautical and engineering purposes, and especially for the making of alloys.

ALLOYS OF ALUMINUM.

The most important alloys of aluminum are those made with copper. These alloys were first prepared by Dr. Percy, in England, and now give promise of being largely used. The alloy produced by the addition of 10 per cent. of aluminum to copper, the maximum amount that can be used to produce a satisfactory alloy, is known as aluminum bronze. Bronzes, however, are made which contain smaller amounts of aluminum, possessing in a degree the valuable properties of the ten per cent. bronze. According to the percentage of aluminum up to 10 per cent., the color varies from red gold to pale yellow. The 10 per cent. alloy takes a fine polish, and has the color of jewelers' gold. The 5 per cent. alloy is not quite so hard, the color being very similar to that of pure gold. I am indebted to Prof. Roberts-Austen for a splendid specimen of crystallized gold, as also for a mould in which the gold at the Mint is usually cast, and in this I have prepared ingots of the 10 and 5 per cent. alloy, so that a comparison may be made of the color of these with a gold ingot cast in the same mould (for the loan of which I have to thank Messrs. Johnson, Matthey & Co.), all of which are before you.

I have also ingots of the same size, of pure aluminum, from which an idea of the relative weights of gold and aluminum may be obtained.

To arrive at perfection in the making of these alloys, not only is it required that the aluminum used should be of good quality, but also that the copper must be of the very best obtainable. For this purpose only the best brands of Lake Superior copper should be used. Inferior brands of copper or any impurities in the alloy give poor results. The alloys all possess a good color, polish well, keep their color far better than all other copper alloys, are extremely malleable and ductile, can be worked either hot or cold, easily engraved, the higher grades have an elasticity exceeding steel, are easily cast into complicated objects, do not lose in remelting, and are possessed of great strength, dependent, of course, on the purity and percentage of contained aluminum. The 10 per cent. alloy, when cast, has a tensile strength of between 70,000 and 80,000 lb. per square inch, but when hammered or worked, the test exceeds 100,000 lb. (A sample shown broke at 105,000 lb.)

An attempt to enumerate either the present uses or the possible future commercial value of these alloys is beyond my present purpose. I may, however, remark that they are not only adapted to take the place of bronze, brass, and steel, but they so far surpass all of those metals, both physically and chemically, as to make their extended use assured. (Sheets, rods, tubes, wire, and ingots shown.)

But even a more important use of aluminum seems to be its employment in the iron industry, of which it promises shortly to become a valuable factor, owing to certain effects which it produces when present, even in the most minute proportions. Experiments are now being carried on at numerous iron and steel works, in England, on the Continent, and in America. The results so far attained are greatly at variance, for while in the majority of cases the improvements made have encouraged the continuance of the trials, in others the results have not been satisfactory. On this point I would wish to say to those who may contemplate making use of aluminum in this direction, that it would be advisable before trying their experiments to ascertain whether the aluminum alloy they may purchase actually contains any aluminum at all, for some of the so-

called aluminum alloys contain little or no aluminum, and this may doubtless account for the negative results obtained. Again, others contain such varying proportions of carbon, silicon, and other impurities as to render their use highly objectionable.

It seems to be a prevailing idea with some people that because aluminum is so light compared with iron, they cannot be directly alloyed, and furthermore that for the same reason alloys made by the direct melting together of the two metals would not be equal to an alloy where both metals are reduced together. Now, of course, this is not the case, and the statement has been put forward by those who were only able to make the alloys in one way.

Aluminum added to molten iron and steel lowers their melting points, consequently increases the fluidity of the metal, and causes it to run easily into moulds, and set there, without entrapping air and other gases, which serve to form blow holes and similar imperfections. It is already used by a large number of steel foundries, and seems to render the production of sound steel castings more certain and easy than is otherwise possible.

One of the most remarkable applications of this property which aluminum possesses of lowering the melting point of iron has been made use of by Mr. Nordenfelt in the production of castings of wrought iron.

Aluminum forms alloys with most other metals, and although each possesses peculiar properties which in the future may be utilized, at present they are but little used.

In conclusion, I beg to call your attention to the wood models on the table, one being representative of aluminum, the other aluminum bronze. The originals of these models are now in the Paris exhibition, each weighing 1,000 lb. With regard to the aluminum bronze, I cannot speak positively, but the block of pure aluminum is undoubtedly the largest casting ever made in this most wonderful metal.

I have to thank the directors of the aluminum company, and especially Mr. Castner, for furnishing me with the interesting series of specimens of raw and manufactured metal for illustrating my discourse.

INDUSTRIAL APPLICATIONS OF THERMO-CHEMISTRY.

By SAMUEL RIDEAL, D.Sc., F.I.C.

THE study of the heat changes in chemical reactions during the last few years has thrown light on numerous problems of theoretical chemistry, and the labors of Julius Thomsen in Copenhagen, Berthelot in Paris, and many other investigators, have given us an accumulation of data which are now of value in several directions of applied chemistry. The fundamental principles upon which the value of thermo-chemical determinations depend are very simple. Some of the earlier work by Laplace, Lavoisier, Andrews, Favre, and Silbermann showed that the amount of heat evolved in the combination of two substances to form a new compound was equal to the amount of heat or other form of energy required to resolve the compound back into its constituents. This law, it will be seen, is in accord with the principle of the conservation of energy, and has been of value in determining the amount of work required to be done in effecting the decomposition of salts by electrolysis, and in many other directions. The second important theorem also seems to be universally true, and is in accord with the belief in the dissipation of energy. It may be called the law of maximum work, and be thus shortly stated: Every system of bodies tends to undergo that internal change that will develop the most heat. There are many familiar examples which may be cited in illustration of this principle. There are, for example, two oxides of hydrogen, water H₂O and hydrogen peroxide H₂O₂; also carbon forms the two oxides CO and CO₂. The heats of formation of these bodies from their elements have been known for some time, and they prove that the heat of formation of water is greater than that of hydrogen peroxide; but the heat of formation of carbonic acid is greater than that of carbon monoxide. Now, when hydrogen burns in air or oxygen, no hydrogen peroxide is produced, and when carbon burns no carbon monoxide is formed. Thus in these two cases the compound produced is the one which gives out the greatest amount of heat. The notation employed by chemists to denote the amount of heat change is easily understood. Thus the expression [H₂, O] = 68,400 is used to denote the heat of formation of water, and states that when 2 grammes of hydrogen are converted into water, an amount of heat equal to 68,400 gramme degrees, or sufficient to raise 68,400 grammes of water from 0° C. to 1° C., is evolved.

If we take the equation

and examine the heat changes involved in the reaction, we find that the amount of heat required to decompose a molecule of water is less than that evolved in the formation of two molecules of hydrochloric acid in solution in water. Thus

There is consequently, in such a change, an evolution of about 10,000 heat units, and we should therefore expect that chlorine and water would not be a stable mixture, which is known to be the case.

In many cases, the heat of formation of a body can only be indirectly determined. For example, marsh gas (CH₄) and ethylene (C₂H₄) cannot be produced synthetically from their elements. We can determine, however, the difference in the amount of heat evolved when marsh gas (CH₄) is burnt, and a mixture of carbon and hydrogen in the same proportion. The difference between the quantities of heat evolved in these two cases—since the products are the same in each—will be the amount of heat evolved in the production of marsh gas from its elements. The apparatus required for determining accurately the quantity of heat given out in any chemical change necessarily varies with the state and kind of materials employed. Julius Thomsen uses a silver calorimeter surrounded by an outer platinum vessel containing water constantly stirred by means of a small electromotor. By turning a stopcock, the two reacting liquids are allowed to