The order for manganese bronze was accordingly countermanded, and aluminium brass adopted in its stead.

It is difficult to speak of these alloys without appearing to be guilty of extravagance; their quality is so uniformly excellent, their appearance so fine, their uses so many. But hundreds and hundreds of tests, similar to those above given, have been made, both officially and in private, and the results obtained have invariably substantiated all that was claimed for them. The chemical process at Birmingham also has a wide future before it. It can hardly be said to have more than started as yet, and the introduction of its "silver from clay" will naturally require time. Much is owing to chemistry for what it has done in the extraction of this elusive metal. But it cannot be denied that the value of aluminium in the arts will be chiefly in its alloys, and that the greater debt of gratitude is due to that protean and subtle form of motion known as electricity.

ALUMINIUM.

By HANFORD HENDERSON, Professor of Chemistry and Physics, Philadelphia Manual Training School.

[*A lecture delivered before the FRANKLIN INSTITUTE, Monday, January 9, 1888.*]

Prof. HENDERSON was introduced by Dr. PERSIFOR FRAZER, Professor of Chemistry in the INSTITUTE, and spoke as follows:

LADIES AND GENTLEMEN:

It is my purpose, this evening, to speak to you for a few moments on the subject of aluminium, an element whose name is to-day in almost everybody's mouth. You may have observed that in different mouths it has taken different forms. From some we hear of it as aluminum, while others are always careful to say aluminium. On grounds of both euphony and historic usage the longer name has, I

think, decidedly the preference. The substance of the element, unfortunately, has not attained so common a currency as its name. It has been called, and not without propriety, "the metal of the future." There is a dual significance locked upon in this designation. The metal is so almost noble in its qualities, so useful in its application to the arts, and in all respects so much to be desired, that as we wish all good things for the future, so we wish for it, aluminium. Had it been known in Sir Thomas More's time, it would undoubtedly have been the only metal used by the Utopians. But it is also the metal of the future in another and much less desirable sense. So persistently has it resisted the best skill of our metallurgic art, that it has taken some faith to believe that the metal would not always belong to the future and never to the present. However, ours is a progressive age, and the metallurgy of aluminium, though somewhat sluggish, does advance perceptibly. Our knowledge of the problem is to-day a little greater than it was yesterday. To-morrow, we may reasonably hope, will find our store of still better dimensions. The work of the past few years has been particularly encouraging. In calling your attention to this promising though somewhat elusive metal, therefore, I do so from a belief that the subject is one of growing importance, and will in time merit the share of interest you may bestow upon it.

You are acquainted, I doubt not, with the story of Tantalus. The position of the chemist in quest of aluminium is almost as unfortunate. The metal he seeks is all around him. He can scarcely move without treading on some of its compounds. Yet it eludes his eager pursuit, like some metallurgical will-o'-the-wisp. It recedes from his touch with almost the same persistence as the water and the fruit from the unhappy King of Phrygia.

Iron is the symbol of our present material civilization. It is among the most abundant of metals. It is, indeed, everywhere, for it is the great pigment of nature. It paints our sandstones brown; our bricks, red; and our clays, yellow. You can scarcely get out of the sight of it. But this comparatively new metal, aluminium, is even more abundant.

We do not know of what the centre of our great whirling earth is made. As the globe, taken as a whole, is between five and six times as heavy as water, while the rocks open to our study are only about two and a half to three times as heavy as that standard, we may not unreasonably suppose the core to be composed of the heavier metals, iron, lead, zinc, perhaps silver, gold and platinum. Of the composition of the surface of the earth, however, we have more definite information. Oxygen, the gas upon which life itself depends, makes up about one-half of these rocks; silicon, the basis of ordinary sand, about one-fourth, while aluminium stands third quantitatively in our recognized list of seventy odd elements. You see how relatively abundant this metal is in combination with other elements. And not only is there a great deal of it in absolute quantity, but the forms in which it occurs in nature are also correspondingly numerous.

Mineralogists have described and named nearly a thousand different minerals. In more than two hundred of these, aluminium occurs as an essential constituent. With many of its more beautiful forms you are doubtless familiar. It does not paint with the generous hand of iron, but it is a far more subtle colorist. There is scarcely a gem mineral, outside of the diamond and the rock crystal, that does not contain aluminium. The brilliant sapphire is an oxide of the metal. Of similar composition are the oriental ruby, the oriental topaz and the commoner form, corundum. Add a little iron to this and we have the valuable abrading material known as emery. The real ruby and the much prized gem, alexandrite, are compound oxides of the metal. Among the silicates it occurs in nearly all the known varieties, from the common clays and other rock-forming aggregates to such royal gems as the emerald, the garnet, the lapis-lazuli, the party-colored tourmalines, and the topaz. As a hydrous phosphate, it gives us the turquoise, one of the most beautiful among the mineral blues.

I had in my possession at one time a very interesting ring. The band was made of aluminium, and displayed a fine oriental ruby, thus illustrating to excellent advantage the appearance of both the metal and its oxide.

These treasures, however, constitute a very inconsiderable part of the earth's surface. It is made up, for the most part, of much commoner stuff, and it is with this that the metallurgist has to deal. Of the many forms of mineral compounds in which aluminium occurs, there are but four which are at present made the subject of his skill. These may properly be termed ores of aluminium. They are: corundum, the common oxide, which occurs in some plenty in the mountains of western North Carolina; cryolite, the double fluoride of aluminium and sodium, which is brought to Philadelphia by the shipload from Arksut Fiord, in Greenland; beauxite, the hydrated oxide of aluminium and iron, which occurs abundantly in Southern France, and kaolinite, or common clay, the silicate of the metal, which is found almost everywhere.

In nearly all of the older rocks we find an appreciable amount of gold. In the soils derived from the disintegration of these masses, the same precious metal is to be found. Some one has taken the trouble to calculate that the clay underlying Philadelphia contains at least \$15,000,000 worth of gold. But as it would take many times this sum to effect its extraction, the metal is likely to remain where it is. No one, I believe, has had the courage to calculate the value of the aluminium contained in the same clay beds. I shall not tax you with such a calculation, but I will ask your patience with a few figures that I have used for a less extended computation. I believe that they will do more than anything else I can say to impress you with the commercial value of the metal, and the present state of our chemical knowledge concerning its extraction. I am going to ask your attention, not to the vast amount of clay underlying our city, but to a single cubic yard of that material. I give the calculation in detail, believing that some of you who are not familiar with such processes may not find it uninteresting.

A cubic foot of water weighs approximately sixty-two pounds; consequently a cubic yard of that fluid will weigh 1,674 pounds. The specific gravity of clay may be taken at 2.5. The weight of a cubic yard of clay therefore would be

two and a half times the weight of the same volume of water, or 4,185 pounds. There is about forty per cent. oxide of aluminium in ordinary clay and about fifty-six per cent. of metal in the oxide, so that a cubic yard of clay contains about 937 pounds of metallic aluminium. At \$12 a pound, an average price, this is worth over \$11,000.

This result is rather surprising. Let me repeat it. One cubic yard of ordinarily pure clay contains an amount of aluminium for which society is willing to pay over \$11,000.

Nature is full of challenges to our inventive skill, and our powers of observation and reasoning. Not an apple falls to the ground in any quiet country orchard that does not challenge us to find out why it falls. The youngest school-child will tell you very glibly that it is the force of gravitation. But press him a little further, and ask him what is the force of gravitation, and he will be silent. He cannot answer your question. Neither can his masters. We do not know. These every-day, unexplained facts of nature seem to me like so many giant interrogation points constantly staring us in the face.* Even the clay, you tread under foot, is, you see, in an humbler, though more practical way, another of nature's challenges.

Aluminium has indeed been called "Silver from Clay," a name referring to its appearance and origin. But you must not be under the impression that because this clay silver costs about as much as the real silver, no efforts have been made to accomplish its easier extraction. I presume that there is not a single chemist the broad land over who has not, at some time—more probably, perhaps, when he was young—given serious thought to the problem. And to-day, I think I may say without exaggeration, that there are hundreds of earnest workers seeking its practical solution. Nor have their joint results been insignificant. There was a time when the metal in this same cubic yard of clay would have been worth twenty-two, or forty-four or even sixty-six thou-

* Although in these days it requires more courage to declare a thing impossible, than possible, Prof. Helmholtz has recently expressed the opinion that gravitation is incomprehensible, and Mr. Herbert Spencer has long regarded it as belonging to the Unknowable.

sand dollars. There was a time before that when it could have been obtained for no price, however fabulous; and a still earlier time when the very existence of a metal such as this was unsuspected.

To present the outlines of this progressive history, and to familiarize you in some slight degree with the appearance and properties of a metal in whose rising fortune I have so great a confidence, are the full measure of the evening's ambition. So far as I am aware there is absolutely nothing original in what I shall have to say. My "interest" in the metallurgy of aluminium, is the same in kind, as your own. It has no market value.

The great French chemist, Lavoisier, seems to have been the first to suggest the existence of metallic bases in the soils and alkaline earths. Sir Humphrey Davy, of safety-lamp fame, attempted to verify the truth of the suggestion, but though he succeeded in isolating the alkaline metals, sodium and potassium, by means of electricity, he failed to separate aluminium. Oersted, in 1824, came very near to the solution of the problem. Indeed, it is an open question whether he did not isolate the metal, but as his method did not give satisfactory results in the hands of other experimenters, the fame of the discovery of aluminium is generally accorded to Wöhler, who, in 1827, decomposed the chloride of aluminium by means of metallic potassium. Here the matter was permitted to rest until 1845, when the German chemist resumed his investigations, and by allowing the vapor of the chloride to pass over potassium contained in platinum receptacles, obtained globules of the metal of sufficient size to enable him to determine its principal properties. It was, however, less fusible than cast iron, and had the disadvantage of decomposing water at ordinary temperatures, two qualities which gave little promise of the future usefulness of the metal, even should it ever be isolated in sufficient quantities to enter the markets. It has since been found that the infusibility of Wöhler's metal was due to the platinum with which it was alloyed; and the ease with which it decomposed water, to the probable presence of either potassium or the unchanged chloride of aluminium.

And now we come to the epoch of greatest moment in this metallic history. In 1854, the genius of Henri St. Claire Deville was attracted towards the possibilities offered by the new metal. It came about, as we express it, by accident. Deville was experimenting upon the salts of aluminium, and for purposes of the work in hand attempted to prepare the metal according to Wöhler's earlier method. He failed in the original purpose of his experiment, but succeeded in obtaining globules of very pure metallic aluminium, and in determining for the first time its true properties. He was thus led to admire the beauty of a metal with which his name has since been inseparably associated; and to devote his large knowledge to an attempt to make the metal available for human uses. It was Michael Angelo who said: "Genius is infinite patience," and its truth was beautifully illustrated in the case of Deville. He applied himself to his chosen task with uncommon persistence and with uncommon results. He did his work with such thoroughness that only the cheapening of electric energy has enabled us to increase the store of information which he bequeathed to succeeding metallurgists. His first step was to supplant potassium by the cheaper and less dangerous metal sodium. By improvements in the manufacture of this indispensable reagent, he reduced its cost to a mere tithe of what it had formerly been. In the production of the chloride of aluminium he also introduced better processes, and by carrying out Wöhler's reaction, thus modified, on a large scale, Deville placed aluminium on the list of commercial products. During the latter part of his work, he enjoyed the patronage of the Emperor Napoleon III, who was chiefly actuated, it is said, by the hope that the extreme lightness of the metal would make it valuable in naval warfare. At the Paris Exposition of 1855, it was first exhibited in public. A large bar of the metal was shown, bearing the title, already quoted: "Silver from Clay." The first article made of aluminium, of which I find any record, was a baby's rattle, for which the material, on account of its extreme sonorousness, was admirably adapted. It was intended for the Prince Imperial, the poor boy who afterwards lost his life in Zululand.

France has ever remained the home of the aluminium industry. Of recent years, it has also developed to an encouraging extent in England. It has gained but a limited hold among the activities of Germany, Switzerland and the United States.

The methods of preparing metallic aluminium in vogue at the present time do not differ essentially from those of the past. If they have any distinctive feature, it lies in the completeness and perfection with which the various details have been worked out. It is in this humble, though all-conquering way, that the successes of to-day have been achieved. If one were to seek out all the methods, proposed as well as provided, for the isolation of aluminium, the task would be much more difficult than the one I have undertaken. But as our purpose includes only the consideration of those processes by which the market is actually being supplied, I shall sufficiently tax your patience if I ask you to regard the three methods of reduction which now divide the attention of practical metallurgists. These are: (1) Deville's method in its modern form; (2) electric methods, which include both those in which the current is used simply as a source of intense heat, and those in which the selective action of electrolysis is utilized, and (3) that indefinite though promising class of methods, which may be summed up under the general name of projects.

At the present time nearly all the metallic aluminium produced is made according to Deville's method. It is the sole source of the metal in France and in England, and, indeed, it has recently been so greatly improved that unless some exceedingly advantageous method of reduction is proposed, it promises to remain so. The study of the metallurgy of aluminium is therefore largely covered by the study of this one method. There are three distinct operations involved in the process:

- (1) The preparation of the double chloride of aluminium and sodium.
- (2) The preparation of metallic sodium.
- (3) The production of metallic aluminium by the reaction between the double chloride and the sodium.

The manufacture of the two necessary reagents is the most tedious, as well as the most expensive part of the entire process. The effort of inventors has therefore been chiefly directed towards the improvement of these preliminary operations.

At the great French establishment at Salindres, the crude material employed is the mineral *beauxite*, the hydrated oxide of aluminium and iron. It is finely pulverized and then thoroughly mixed with sodium carbonate. The mixture is strongly calcined in a reverberatory furnace, by which the aluminium is converted into a soluble aluminate of soda, while the iron remains as the insoluble sesqui-oxide. By washing with warm water, the two are easily separated. The aqueous solution of the aluminate is then treated with carbon dioxide gas, which precipitates the aluminium as a hydrated oxide, and regenerates sodium carbonate. A second filtration and washing separates the two. To convert alumina thus prepared into the double chloride of aluminium and sodium, it is mixed with carbon and common salt, chloride of sodium. The mixture is made as homogeneous as possible, and formed into balls as large as a good-sized orange. These are thoroughly dried at a temperature of about $150^{\circ}\text{C}.$, and are then packed into earthenware retorts, where they are calcined at a red heat. Meanwhile chlorine gas is introduced into the bottom of the retorts. The double chloride of aluminium and sodium is thus formed, and volatilizing, passes over into earthen pots, where it condenses and may be stored away for future use. The simple chloride of aluminium was employed in the early days of the industry, but as it is deliquescent, that is absorbs moisture from the atmosphere, it is difficult to preserve, and has been almost if not entirely superseded by the more convenient double chloride. The formula of this salt is $\text{Al}_2\text{Cl}_6 \cdot 2\text{NaCl}$.

A somewhat different method is in use at the English aluminium works at Birmingham. Alum is there employed as the crude material for the production of the double chloride. It is mixed with coal pitch, and calcined at a low temperature. Water is driven off, and sulphur, potash and

alumina remains. After subjecting the residue to the action of steam and air, at a low red heat, it is placed in a vat of hot water. The potash is thus dissolved out, and the insoluble alumina collected and dried. It is then converted into the double chloride by the usual process.

The second operation in Deville's method is the preparation of metallic sodium. As commonly carried out, the operation presents no great difficulties, but it is wasteful and therefore expensive. I give it in some detail, because I want you to fully appreciate the cleverness of an improved method devised by one of our compatriots, which promises to radically change the conditions of the aluminium industry in Europe. The older process, then, consists in reducing sodium carbonate by means of charcoal. As the carbonate is easily fusible, were the two simply heated together, the result would be that the carbon would float on top of the liquid mass, and, consequently, fail to accomplish its work of reduction. It is, therefore, necessary to add about fifteen per cent. of lime, in order that the mixture shall remain infusible and the carbon and soda be kept in contact with each other. The three reagents are mixed as intimately as possible, and subjected to a preliminary calcination at a red heat. This makes the mass more compact, and removes a considerable amount of carbon dioxide. It is afterwards placed in small wrought-iron cylinders and heated to a temperature of perhaps $1,400^{\circ}$ C. At this heat the reaction between the soda and charcoal takes place; the alkali is reduced and distils over into suitable condensers. Only about two-fifths of the metal contained in the charge is recovered. The greatest waste, however, is in the labor, the wear and tear of the "plant," and the fuel required to attain so high a heat. All of these causes combined have made sodium an expensive metal. It has been selling in this country for \$1.50 a pound, and it has been calculated by a competent English chemist that on the other side of the water it costs four shillings per pound to produce. As it takes something over three pounds of sodium to make one pound of aluminium, it will be seen that this item alone is largely responsible for the high price of the metal. Cheap sodium means comparatively cheap aluminium.

The improved process, to which I have alluded, is that invented by Mr. H. Y. Castner, of New York City. It has not been the result of chance, but of elaborate and systematic experimentation. Mr. Castner, I understand, was attracted to the aluminium problem, while he was yet a student at Columbia College. After an examination into the conditions of its metallurgy, and the possible directions for improvements, he came to the conclusion that the most probable field for better things lay in the cheaper production of sodium, and accordingly he devoted himself to that. I think he worked on the problem for a couple of years. The result of his work has been the production of a process so admirable that the only fault I have to find with it is that I did not invent it myself. Others have felt the same towards the process and from both sides of the Atlantic warm praise has been bestowed upon it and upon its inventor.

The germ of Mr. Castner's improvement is simplicity itself. Instead of making use of an infusible mixture, so that the carbon and sodium compound should be kept in contact, he has obtained the same result by a much more rational device. The little particles of carbon are weighted by means of particles of iron, and so, instead of floating uselessly on the surface of the sodium salt, mix through the whole mass and accomplish their work of reduction under much less wasteful conditions. The improvement you see belongs to the domain of physics and consists of so simple an expedient as increasing the specific gravity of the reducing agent until it equals or somewhat exceeds that of the fused salt. The process is not in use in America at the present time, but has been warmly welcomed in England. Large works are being erected at Birmingham, where both sodium and aluminium will be final products.

Caustic soda is used in preference to the sodium carbonate. The reaction is represented with sufficient accuracy by the following equation:

The carbide of iron here symbolized is replaced in

the practical working by a specially prepared mechanical mixture, which is found to act as a perfect equivalent. The so-called "carbide" is prepared by mixing together definite amounts of finely-divided iron and melted pitch. When the mixture cools, it is broken in pieces and coked in suitable retorts. This finely ground metallic coke is the reducing agent which has solved the problem of cheap sodium. The reduction is carried out in capacious cast-iron crucibles. The charge consists of caustic soda of the highest obtainable strength and the proportion of so-called "carbide" needed to satisfy the formula given.

The charged crucibles are placed in a small furnace where they are moderately heated for about thirty minutes. The mass fuses, and for a time boils with considerable violence, owing to the plentiful escape of hydrogen. At the end of the preliminary heating, the fusion becomes quiet and the crucibles are transferred to the distilling furnace. Here each crucible is placed upon a small elevator platform and is raised into position. The covers of the crucibles are stationary, and are made with convex edges. The crucibles themselves have grooved edges in which a little powdered lime is placed. By simply raising them into the furnace they are effectually sealed during the process of distillation, and may readily be detached when that process is completed and a freshly charged crucible is wanted. Tubes project from the stationary covers and lead to the condensers where the distilled sodium again solidifies. The hydrogen escapes from a small opening in the opposite end of the condenser, and is generally lighted in order to show how the distillation progresses. The operation lasts about an hour and a half and is carried out at a temperature of about 825° C. instead of $1,400^{\circ}$ as in the older method. The residues consist mainly of carbonate of soda and metallic iron, both of which are again utilized in future distillations, the one in the form of caustic soda, the other in the reducing "carbide." The whole process is extremely simple and ingenious. It will produce metallic sodium at a cost of less than one shilling a pound. The English company, which is now putting the process into commercial

operation promises to place aluminium on the market in a few months at a price not greater than \$5 a pound. If this can be done successfully, the uses to which the metal is put will be greatly increased, for it is making its way in certain fields at more than double that price.

I have dwelt upon Mr. Castner's invention with particular pleasure, both because it comes from a thinking rather than a so-called "practical" man, and because it is so neat a solution of a difficulty of somewhat long standing that it should encourage others to attack similar problems in the faith that equally simple solutions are to be found, if one will but look with sufficient persistence.

We have now come to the third operation in Deville's method, the utilization of these expensively won reagents in the final reaction by which metallic aluminium is produced. A difficulty which beset the early metallurgists was the provision of a flux sufficiently light to permit the reduced metal to sink to the bottom of the reducing hearth, and so unite into an available mass. This is now met by the use of cryolite, which serves the purpose to excellent advantage.

The furnace in which the reaction is carried out is a small affair, built after the reverberatory pattern. It is securely bound together by iron tie-rods, for the interior of the furnace during the operation is the scene of pretty severe cannonading. When the double chloride of aluminium and sodium is brought into contact with metallic sodium in the heat, the sodium, by virtue of its greater affinity for chlorine, displaces the aluminium, setting it free in the desired form of a metal, while the chloride of sodium so formed unites with the cryolite and forms a very light and fusible slag. The reduced metal is run off into moulds and at once cast into marketable ingots. A portion of the slag contains enough aluminium in the form of scattered shots of metal to make its re-working profitable.

In these days when the electric methods are promising so freely and so much, it is common to regard Deville's method as rather a thing of the past, but as it has produced, and is still producing, the bulk of all the aluminium in the

markets, I think it not unwise to go on the principle that "a bird in the hand is worth two in the bush," and familiarize oneself with what is actually being accomplished before devoting one's attention to those achievements that are expressible only in the future tense. This is my excuse for having considered at such length an "old-fashioned" but constantly improving method.

In the employment of electricity in the reduction of aluminium there is, at the present time, an atmosphere of hope rather than of realization. Of its ultimate success one can hardly doubt, who has watched its course in other fields. It presents to us a power that furnishes at once an intense heat, or an ability to control chemical action, that is almost irresistible. The Cowles process depends upon the first of these functions, while all electrolytic methods, as their name implies, depend upon the latter.

It is quite within limits, I think, to say that the Cowles process is the most important among all the electric methods. It does not, at the present time, produce pure aluminium, but simply alloys of the metal with copper. These, however, are of such high value that they deserve all of the attention that they are now receiving. The ore used in this process is preferably the corundum obtained from the Southern States. The furnace in which the reduction is carried out is, in its simplest form, a rectangular box of fire-clay, lined with powdered charcoal. The electric terminals are huge arc-light carbons projecting from each end of the furnace. The space between the ends of the terminals is filled with a mixture of ore, granulated copper and coarsely pulverized carbon. When the current passes the resistance offered by the carbon causes so intense a heat that the oxide of aluminium is reduced, and the metal formed unites with the now molten copper. It will be observed that the passage of the current is continuous, and that its only function is to produce a heat far more intense than that obtainable by ordinary processes of combustion. The result of this electric smelting is an alloy containing anywhere from a few per cent. of aluminium up to forty or more. It is cast into ingots, analyzed and re-melted with

sufficient copper to form an aluminium bronze of the desired proportions. The electric furnace has been of late much improved and many refinements introduced into the process. These have made it a commercial as well as a scientific success. As power is the great desideratum, the Cowles Company has located its new works at Lockport, N. Y., where it has available water pressure to the amount of 1200 horsepower. To those who are sensible of the wonderful beauty of the correlation of forces, there is something highly instructive in this quiet transformation of the power stored in a water-fall into mechanical motion, into electricity, into heat, until it finally loses itself in the work of chemical dissociation. I understand that at the present time it costs by this method something less than forty cents per pound to produce the metallic aluminium in the alloys now on the market. They are sold, the company informs me, at the rate of three dollars per pound, with the copper at the market rates. As one of the chief uses of the metal is in the aluminium bronze thus produced, the Messrs. Cowles have solved a very important problem in the metallurgy of aluminium. The process having been so successful in the production of alloys of the metal, it has not unnaturally aroused the hope that it might become a source of the pure metal itself. The function of the copper is to collect and preserve the aluminium as it is reduced. Were it absent, difficulties would arise in the collection of the metal and also from the fact that it would unite with the carbon to form a yellow, crystalline carbide of aluminium, which would require subsequent treatment. It is believed that the copper and aluminium form a true chemical compound, for their union is attended with the disengagement of heat. It is improbable, therefore, that they can be readily separated by any liquation process. There are other metals, however, with which this would be possible. Tin is one of these. When this metal takes the place of copper in the electric smelting, an alloy of tin and aluminium is produced, which, on being subsequently melted with the proper proportions of lead, yields a metallic bath consisting of an alloy of tin and lead beneath and a layer of pure aluminium above. The perfecting of

this process promises an abundance of the pure metal at a very low price. It is not yet carried out on the commercial scale, but I understand is at present the subject of very careful and persistent study. That it may meet with the most ample success, is the wish of all chemical spectators—except those who have rival processes in mind.

Still another modification of the Cowles process has been brought into vogue by the requirements of the Mitis castings in wrought iron. It consists in the substitution of iron for copper, and the consequent production of alloys of aluminium and iron. Only a few years ago the expression "wrought-iron castings" would have been received with incredulity if not ridicule. The high temperature at which wrought iron melts and the difficulty of keeping it sufficiently fluid to cast with any success have limited the working of the material almost entirely to forge processes. Mr. Peter Ostberg, a Swedish engineer, has, however, so far conquered these conditions that the Mitis castings are now to be found in the regular metal market. He has won this victory by means of aluminium. An alloy always melts at a much lower temperature than the average fusing point of its constituent metals. Wrought iron melts approximately at $4,000^{\circ}\text{F.}$, but if even a fraction of one per cent. of aluminium be added, the needed temperature is reduced by at least 500° . It is on this principle that the Mitis castings are made. To fluid wrought iron, a small amount of metallic aluminium is added, whereby the fusing point is reduced to about $3,500^{\circ}\text{F.}$ But the temperature of the resultant alloy is little below $4,000^{\circ}$. The thermal difference, or degree of super-heating, permits therefore a leisurely and accurate casting before the metal approaches its point of solidification. The presence of the aluminium is stated to have no disadvantageous effect upon the metal, but rather to increase its tenacity. Although such small quantities are used, the present costliness of aluminium would be a serious disadvantage to the process, but as an alloy of iron and aluminium serves the purpose equally well, the Cowles product is utilized and the two processes become mutually helpful.

In the electrolytic methods, Germany and Switzerland have particularly exercised their ingenuity, although there have not been wanting inventors in the United States who have worked in the same direction. There are any number of methods, distinctive at least in their name, if in nothing else. Sir Humphrey Davy, in the early part of the century, attempted to isolate aluminium by means of electricity, and failed. Both Deville in France and Bunsen in Germany, as early as 1854, electrolyzed the fused double chloride of aluminium and sodium. Since their time the cheapening of the electric current has made the method more practicable. At the present time, however, I know of no aluminium made in this way. The experiments of Dr. Kleiner, of Zurich, have attracted favorable comment and may give rise to an industrial operation. He subjects a bath of fused cryolite to electrolytic action. In Germany the process of Richard Grätzel appears to be the most promising. I have seen beautiful specimens of the metal made by that process, but I am informed by the New York agent of the company operating it, that at present all work is experimental. They hope soon to put their product on the market and will also supply magnesium in commercial quantities.

All of these methods differ from each other, if they differ at all, in the special form of apparatus used, which is supposed to effect a more economical utilization of the current. In principle they are the same, depending simply upon the dissociating action of electricity upon fused compounds of aluminium. The metal collects on the negative electrode. The electrolysis of aqueous solutions of aluminium salts is readily accomplished, but is far too expensive a source of the metal to be industrially available.

Of those various schemes which I have summed up under the name of projects, it is more difficult to speak, for their name is legion. The high prize which awaits the successful inventor of a cheap process for the reduction of aluminium has attracted a class of metallurgical adventurers. They have tried nearly everything that is possible, and have proposed nearly everything that is impossible. The regret which I would otherwise feel in my inability to present all

of these schemes to your attention, is therefore tempered by the consideration that such completeness would not be desirable. It is quite possible that with time some of these propositions will mature into industrial operations. In the absence of any prophetic indications to that effect, however, it will be best to limit our view to one or two processes which have a contemporary interest.

At the present speaking there is but one establishment in the United States where pure aluminium has been a regular commercial product. It is that of Colonel William Frishmuth, at Frankford. It is represented to-night by an admirable display of the metal in the form of ingots, bars, plates and wires. I am unable to state with any definiteness the manner in which the metal has been obtained, for Col. Frishmuth deems it wiser to withhold this information from the public. His older method consisted in a modification of Deville's. Metallic sodium and a volatile salt of aluminium are generated in separate retorts, and brought together while still in the state of vapors, in a third retort, where the reduction takes place, and metallic aluminium is precipitated. He tells me that his present method is a combined smelting and electric one, which promises an excellent and inexpensive product. I am not able to speak of it from personal inspection. This small American establishment has an historic interest from being the place where the aluminium cap of the Washington Monument was cast.

And now it remains for us to consider specifically the advantageous properties which warrant so expensive and so troublesome a metallurgy. I cannot do better perhaps than to refer you to the metal itself for answer. Like all good things, it is its own best advocate. But like them again, its entire merits only appear on very long acquaintance. It will, therefore, be well to enumerate them somewhat systematically.

Physically, then, aluminium possesses properties which distinguish it from all other members of the metallic family. When pure, it has a fine white color, a trifle blue when compared with silver. It is on the whole very pleasing, and

well adapted for ornamental usage. Unlike copper or other base metals, it has neither odor nor taste. It is sufficiently malleable and ductile to be beaten out into very thin foil or drawn into exceedingly fine wire. Of the sturdier properties, aluminium has its full share. It is elastic, exceedingly tenacious, and when hammered, quite as hard as iron. It possesses also a characteristic sonorousness, which leads to the expectation that it may sometime become an advantageous constituent of bell metal.

But the physical property upon which our hope for the future usefulness of aluminium chiefly rests, is its very small specific gravity. It is but 2.56 times as heavy as water. The significance of this levity will appear more strikingly when comparison is made with some of the more common metals. Thus aluminium is only about a third as heavy as iron, less than one-fourth as heavy as silver, and little more than an eighth as heavy as gold. You will have a still more feeling realization of this difference on handling these two slabs of metal which Col. Frishmuth has kindly had cast for me. They possess the same volume, but one is of lead and the other is of aluminium, and one is almost five times as heavy as the other. In considering the costliness of aluminium, its levity must be kept in mind. With both metals at a dollar an ounce, a cubic inch of silver would cost over four times as much as a cubic inch of aluminium.

It would be quite safe to leave to your imagination the manifold advantages possessed by a metal at once so light and so strong. Among the smaller articles which one is called upon from time to time to carry about with him, such as watch, compass, opera-glass, barometer, surveying instruments and the like, the difference between a light and a heavy material is often the difference between comfort and discomfort. The superiority of an aluminium barometer over one of brass weighing about three times as much will not appeal to you very forcibly on casually handling the two, but carry them on successive days over a rough trail, and your opinions will be more pronounced. In more mathematic surveying work, the weight of transit, level or theodolite, is no small tax upon the user. If the consideration be

carried to the more serious problems of portability, the importance of light constructive material looms into still greater prominence. In all of our systems of transportation, by land or water or air, the movement of such large masses of dead weight is an economical evil. The wagon is disproportionately heavy, compared to its burden of freight. A train of vestibuled Pullmans is almost as ponderous when empty as when full. The ocean greyhound carries thousands of tons on each transatlantic passage on which no freight is paid. And so one might follow the entire list of portables and observe the immense advantage that would result from the introduction of a metal as light as porcelain and as strong as steel. We might press the question still further, and speculate upon the greater speed at which so light a train might safely be run, since its diminished momentum would permit it the sooner to be brought to rest.

The metal does not, however, need to be in motion to display the merit of a small specific gravity. In our present structures of iron we have almost reached the limits in the way of possible dimensions. Any further increase in size would be followed by a collapse resulting from the mere weight of the material itself. Could this be reduced two-thirds, and the strength remain unimpaired, one can easily foresee the advantage. There is still another direction in which a small specific gravity means something. This is in the construction of delicate analytical balances. By making the cross-beams of aluminium they are almost perfectly rigid and unalterable, and the centre of gravity of the system is considerably lowered, with a resulting increase of delicacy. Messrs. Troemner & Co., of this city, now construct their finest balances in this fashion, and also employ aluminium for the smaller weights. It may be of interest to know that two such balances form a part of the equipment of the princely laboratory which Mr. Edison has recently erected on the Orange Mountain.

A word should also be said concerning the behavior of aluminium towards heat. At any ordinary temperature, it is absolutely fixed, becoming fluid at about 750° C. It is a

good conductor of heat, and consequently of electricity. It has a larger specific heat than any other of the useful metals; that is to say, it requires a longer time to become either heated or cooled. Deville has suggested that by virtue of this property a plate of aluminium would make a good chafing dish.

In its chemical properties, aluminium is not less remarkable. The most useful of these is its complete indifference to the action of either air or water, and its failure to unite with sulphur under ordinary conditions. A metal which will not rust possesses a manifest superiority over iron and copper or any of the so-called base metals. It was this property which determined the selection of aluminium for the apex of the Washington Monument. As the metallic oxides are poor conductors of electricity, it is important to have a metal for the tips of lightning rods which will not oxidize, and aluminium would be well adapted for the purpose. As a constructive material, a metal which may be freely exposed to the elements without suffering harm needs no praise. As a simple saver of labor it appeals to our philanthropic feelings. When one recalls the multitude of tired arms that daily struggle with the base affinities of brass and try to wring from it an evanescent glitter, the mere thought of a metal which would dispense with this frictional devotion brings a sensation akin to restfulness. In resisting the action of sulphur, aluminium possesses a merit much above silver, which, as you know, blackens on the slightest contact with that element. Spoons and dishes of aluminium are particularly suitable therefore for eggs and other foods containing sulphur. One more mention, and I will close, without however exhausting this catalogue of virtues. In its behavior towards the acids, the metal we are considering shows itself a base of weak affinities. It dissolves very readily in hydrochloric acid, but is almost untouched by nitric and sulphuric. As a substitute for platinum, therefore, in the Grove cell, it has been found to work very well. Towards the weaker acids, such as acetic, it manifests a like indifference, a neutrality which well adapts it for the construction of culinary vessels.

If I have succeeded, by this sketchy statement of the uses of aluminium, in persuading you that the metal is one well adapted to nearly all possible uses, either æsthetic or utilitarian, I have succeeded in making current an opinion which I entertain myself.

I have already spoken, I fear, beyond the proper chronometric limits. Yet I cannot conclude without first anticipating that criticism of incompleteness, which in view of this partial presentation of the subject would be quite justifiable. I am entirely conscious that I have given but a fragment. Into the heights and depths of aluminium, we have scarcely penetrated. In giving this superficial view, however, I have tried to present that side of the cube which most nearly touches the daily affairs of life. By way of caution, I should perhaps add that this view is more favorable than that held by many sober-minded scientists, I do not wish to impose my own enthusiasm upon your better judgment, but for myself, I have great confidence that before many years shall have passed, some chemist will arise among us who shall succeed in transforming by his subtler alchemy, aluminium, the metal of the future, into aluminium, the metal of the present.

NOTE.—The lecturer takes this opportunity of expressing his indebtedness to Messrs. Tiffany & Co.; to Mr. Peter Ostberg; to Col. Wm. Frishmuth; to Messrs. Queen & Co.; to Messrs. Troemner & Co. and others, for their kindness in furnishing specimens of aluminium for exhibition.