Discussion.

Sir BENJAMIN BAKER, K.C.M.G., President, said he was sorry that neither the Author nor any one representing him was present. The Paper had unavoidably been delayed for some time owing to the building operations, and had been in the hands of the Institution nearly twelve months. It contained a great deal about the Pittsburgh Reduction Company, and the members must have been struck with the great advantages that that company enjoyed. In one of their works on the banks of Niagara they were within half a mile of one of the greatest and cheapest sources of power in the world, which he believed was equivalent to the consumption of 200,000 tons of coal a day in power; and in the other case, on the banks of the Alleghany, they had the exceptional advantage of being able to get steam-coal slack at 2*s.* 8*d.* per ton, with automatic delivery and mechanical feeding. There was another branch of the Paper, which would perhaps have been fresher twelve months ago, relating to the wonderful works at Niagara. They had heard a great deal about them in popular magazines during the past year. Many engineers of all nationalities were invited to assist in the work, and he was glad to say that one of them, a member of the Institution and an honoured representative —Prof. Unwin—was present that evening, and the members would be glad to hear some remarks from him. He begged to propose a vote of thanks to the Author of the Paper. Sir Benjamin Baker.

Prof. W. C. UNWIN thought that in much of the criticism of the Niagara works, the fact was overlooked that the problem there was in many respects unique. In the first place, if the works at Niagara were to succeed it must be mainly as a source of supply of power, not as a source of supply of electric light. Then it was unique because at that place one consideration which always governed ordinary hydraulic installations was absent. In ordinary hydraulic installations the water-supply was usually barely sufficient for the requirements; and economy of water, especially in times when the water-supply was scanty, was an absolute governing consideration in the design. At Niagara the water-supply was extraordinarily constant, and at all times enormously in excess of any possible requirements. The problem was again unique on account of the enormous scale on which the works had to be carried out. On a smaller scale, Prof. Unwin.

Prof. Unwin. those works would necessarily fail. It was only on the condition that they could be carried out on a very large scale, with the utilization of about 100,000 HP., that they could be a great commercial and financial success. These, however, were not the only points in which the problem was different from that with which engineers in connection with such matters had ordinarily to deal. Having to utilize something like 100,000 HP., it was necessarily a condition that the units of power should be very large. Before those works were established he did not think there was any turbine in the world which delivered more than about 1,000 HP. The single unit at the Niagara works was 5,000 HP., which meant the adoption of a turbine of quite exceptional dimensions. Looking at the drawings of the turbine, members would be somewhat surprised at the fact that the entire 5,000-HP. turbine with its regulating sluices was really a piece of pipe no larger than the supply-pipe of the turbine itself. The compactness of the turbines was extraordinary. He thought that no one who had not really tried to design a turbine using 25,000 cubic feet of water per minute could properly appreciate how extraordinarily compact those turbines were. He had tried the problem, and had failed to approach such compactness with other types of turbine. He was not particularly favourable to the type of turbine adopted, but so far it had perfectly answered its purpose. He had seen many designs made for those conditions, only one of which, that arrived at, after two or three trials, by one of the best makers in Europe, seemed to approach a successful solution. It was an axial-flow turbine of twin type. One peculiarity of the installation at Niagara was that instead of having a wheel-pit for each turbine, as would seem natural, there was a long wheel-pit in the earth 180 feet deep and as long as might be necessary for twenty turbines. It was not, however, yet complete. When the Commission for examining the project had sat in London it was much questioned whether the dynamos should be placed as they were above ground or in underground chambers. At first sight it would seem that excavation would be a great deal economised by placing dynamos and turbines in an underground chamber and merely taking the supply-pipes down to them. There were many objections to underground chambers—inaccessibility, damp, and various difficulties of that kind. Even if that plan of underground chambers were adopted, there would not be much excavation saved. It should be remembered that water had to be carried down to the turbine, and, calculating the area of the pits to take the water down, it would be found that whether there was a wheel-slot or a separate pit for each supply-pipe there was not much difference in the amount of excavation. The wheel-slot was excavated with greater facility than a number of separate pits. Having necessarily placed the turbines at the bottom of the fall and having decided to place the dynamos at the top of the fall, the wheel-slot was almost a necessity. Dealing with units of that size, what perhaps at first sight was not obvious, proved to be true, that no method could be adopted of transmission from the turbine to the dynamo, except that by a direct shaft; no form of belting, wire-ropes or gearing used for smaller turbines could possibly be used when dealing with the unit of 5000 HP. at such speeds as were possible with dynamos of that size. Having a dynamo at the top of the slot and the turbine at the bottom with a great shaft between, what was to be done with the enormous weight on the footstep? That difficulty had been overcome by simply utilizing part of the water-pressure in the turbine to support nearly the whole of the weight of the vertical shaft and the weight of the field-magnets of the dynamo. In the Paper the over-balance of pressure was given as 3,500 lbs., but he believed that in most conditions it was less than that. There was only a small surplus of unbalanced force which had to be carried by a thrust-block near the dynamos. In many of the designs of turbines submitted for the Niagara installation, although balancing more or less of that kind was adopted, there was in many of them the defect that in the regulation of the turbine the amount of the balancing force was altered. That was the fatal defect in some of the designs for turbines. There were some designs which would work perfectly well if the balancing was quite perfect when the turbine was running at a full load, in which all the balancing effect of the water was altered when the turbine was running at light load. There was one other peculiarity in the installation. The dynamos required a constancy of speed greater than any turbine maker had hitherto had to deal with on a large scale. That had been overcome by the adoption of a remarkably ingenious form of relay-governor, in which there was an extremely sensitive governor with nothing more to do than to send a message to the relay to move the sluices a certain amount. When the sluices had been accordingly moved the relay waited to know whether the governor said, "go on" or "go back." In that way all possible hunting was prevented. He believed that the governor had been erected under a guarantee that if half the load was suddenly thrown off, the variation of the speed would not reach 2 per cent. So far the works had been started quite Prof. Unwin.

Prof. Unwin. successfully. The tunnel was an extraordinarily large work of its kind for power installation. He thought it would be better made with a much flatter slope so as to be treated as a pipe discharging under water than as an open channel. The slope was, on his recommendation, somewhat lowered, but it appeared to him that the tunnel ought to be treated as a submerged pipe. He saw no objection to that except the difficulty of access, which might be overcome by proper arrangements. Something of the fall in that case would be saved. There was, however, such a surplus of power at Niagara, that that was not a governing consideration, and there was only a very small loss on the whole of the work. It might be known to some members of the Institution that there was a probability of works quite as large, under the same direction as the works on the American side being begun on the Canadian side. At any rate, it was very probable that in the course of a year or two works would be started on both sides of the Niagara Falls.

Mr. Parker. Mr. THOMAS PARKER observed that the Author had stated that a large continuous electric current was passed through the molten mass with a small difference of potential, and that the process was carried on in carbon-lined iron pots, placed in series, the anodes being of carbon and dipping into the bath. It was further stated that the voltage was about 2·8, and that the losses were very small. He should be glad if the Author would state the number of vessels used in which the solution was electrolysed, and the total voltage between the terminals of the series of cells, the ampere-meter readings, and weight of metal obtained in a given time. It was stated that the theoretical quantity of power used was 5 HP. per lb. of aluminium per hour. He should be glad to know the exact quantity of energy used. The density of the current, too, as it entered the bath from the carbon anodes was very important. If those quantities were correctly given the amount of energy used per lb. of aluminium obtained could be found, and it would assist in electrolysing the molten salts of various other metals. The figures given in the Paper as to the production of aluminium were not in accordance with his own experience. Aluminium was, no doubt, delivered to the kathode, and did not need to sink through the electrolyte in a finely divided condition. The theoretical quantity of carbon anodes necessary for the decomposition of the aluminium was given in the Paper as $\frac{2}{3}$ lb. of carbon per 1 lb. of aluminium. He thought, however, it could scarcely be stated. If the Author could obtain anodes which were not attacked, that quantity would be negligible.

Dr. SAMUEL RIDEAL, after examination of samples of aluminium produced by the different processes, considered the statement that, by the Hall process, metal had been obtained containing 99·93 per cent. of the metal, a very sanguine estimate of the purity of commercial aluminium. In fact, the aluminium produced by the present processes contained a variety of elements, some of which, no doubt, had a very deleterious influence upon its mechanical and physical properties. It would seem desirable that the influence of those minute quantities of foreign metals should be more carefully studied. Amongst those impurities, silicon, carbon, iron, copper, and traces of titanium would seem to be unavoidably present in all the processes now used; but with regard to such metals as sodium, and those of the alkaline earths like calcium, which might be produced when calcium fluoride was present in the molten bath, they might certainly be removed by some further improvements in the process. It was exceedingly difficult at present when using cryolite to ensure the entire absence of metallic sodium from the metal. With regard to the bauxites used, it was not generally known that the colour of bauxite was not measured necessarily by the amount of oxide of iron present. It was well known that many high-coloured bauxites contained practically no oxide of iron.[1] Dr. Rideal.

Mr. G. L. ADDENBROOKE remarked, with reference to the arrangement of the field-magnets of the dynamos outside the armature, so that the magnetic force between them tended to counteract the centrifugal force which caused the wheel to fly to pieces, that the attraction between the magnets and the armature amounted to about 30 lbs. to the square inch. The field-magnets revolved with a peripheral speed of 9,000 feet per minute, and the centrifugal stress amounted to about 15 tons to the square inch, so that the back pull of the armature approaching was, in comparison with it, infinitesimal. He believed the maximum magnetic attraction between the two surfaces in absolute contact was only about 150 lbs. per square inch; and as there was about $\frac{1}{4}$ inch clearance between the two he thought that it amounted to about 30 lbs. per square inch. Mr. Addenbrooke.

Aluminium had hitherto been chiefly manufactured at Neuhausen in Germany, at Pittsburgh in the United States, and at Froges in France. The power required for the extraction of the metal had been given[2] as 16 HP. hours to 1 lb. of aluminium, and he

[1] "Aluminium," by Mr. J. W. Richards, 2nd edition, pp. 48, 49.

[2] "Aluminium," by Mr. J. W. Richards. Sampson Low, Marston & Co., 1896, p. 393.

Mr. Addenbrooke. believed that was the figure which had been worked upon at Neuhausen for some time past, but he had good authority for believing that the power had been considerably reduced. It was stated in the Paper to be about 5 HP., not including the amount required for heating of the bath, which depended on the radiation from it. It had been suggested that the baths might be heated by a coal-fire or otherwise, so that the electric current would only supply the heat required for the decomposition of the aluminium, but he did not think that had hitherto been put into practice. One of the great requisites was the purity of the alumina. At present nearly all the alumina of the requisite purity was made in Germany, and he understood that the Pittsburgh Reduction Company at one time imported it from that country, but probably they were now making it for themselves. The cost of the alumina was about 2½*d.* per lb., and nearly 50 per cent. of aluminium could be extracted from it, so that the cost of aluminium in the ore amounted to about 5*d.* per lb. It appeared from the Paper that 1 lb. of carbon was required, with various other things, and beyond that the only question was the electric current, which, he thought, should not amount to a very large figure; probably at Niagara it would be less than 2*d.* per lb. If the power required was taken as 12 or 14 HP.-hours, it would seem that if there was no great loss in the process, which the Author had not mentioned, supposing the aluminium to be manufactured on such a scale as at Pittsburgh, it ought to be produced and sold at less than 1*s.* per lb. As copper was 3·3 times as heavy as aluminium, 1*s.* per lb. about equalled the cost of copper for any purposes for which it might be required. The electrical conductivity was about 56 per cent. that of copper, and as it was only one-third of the weight, it was a better conductor than copper by weight in the ratio of 100 to 180. If its price fell to 1*s.* per lb. it might be useful for overhead conductors.

It was a pity that the Author had not stated the cost of producing the power at Pittsburgh, although he had given some data which enabled it to be inferred. In England coal could be procured in some colliery districts at the price mentioned by the Author, at 2*s.* 6*d* per ton. delivered to the boilers. If 1 electrical HP.-hour could be produced for 3 lbs. of coal, which he thought was practicable with large compound or triple-expansion engines working under the best conditions, 750 electrical HP.-hours would be obtained for 2*s.* 6*d.*, or 25 HP.-hours for 1*d.* Not more than 12 HP.-hours were required for manufacturing 1 lb. of aluminium, therefore the cost of the current produced from coal in the best possible manner would not amount to more than $\frac{1}{2}d.$ per lb. for the coal used. The cost of stoking the boilers would not add more than $\frac{1}{2}d.$ to the price per lb. of aluminium. For the manufacture of aluminium or the supply of electrical power for any other purpose in the coal districts, as was done at Niagara, the works could be placed on a site of comparatively small area in a centre of population where power could be readily supplied for other purposes, and the great outlay in works, such as was occasioned at Niagara, would not be required. There would not be so much capital lying idle, although the actual generating expenses might be greater. Therefore, when the cost of electrical HP. was so small, the fact of being in the centre of a population with railways, near large towns and so on, would outweigh the advantages which could be obtained from water-derived power in some cases, and it would be quite possible for engineers in future to install large power stations in coal districts, with small difference in the expense. Mr. Addenbrooke.

Mr. Bertram Blount remarked, as to the lower oxide of aluminium, which the Author stated had been produced, that although iron—the chemical congener of aluminium—formed ferrous oxide, FeO, aluminium, in spite of being similar in most respects to iron, had hitherto not yielded a corresponding oxide. The only oxide of which thoroughly reliable evidence had been obtained was the sesquioxide, Al_2O_3. The carbon anode when acted upon by the alumina forming a constituent of the bath subjected to electrolysis was undoubtedly burnt away, and the product formed was carbon monoxide. On such considerations, the amount of carbon mentioned by the Author, $\frac{2}{3}$ lb. per pound of aluminium produced, was doubtless reckoned. Some of the speakers, especially Mr. Parker, had demurred somewhat to that view, and seemed to think that it was possible to obtain greater economy of carbon, which was a matter of some importance, because of the high cost of electrode carbon. It might be thought that carbon could be saved by carrying its oxidation to a higher point, viz., to the formation of carbon dioxide, but this appeared to him scarcely practicable. Another matter might be mentioned in which greater explicitness of statement was desirable. It was known that in the different processes known as the Minet, Hall and Heroult, which were very intimately blended, success was only attained when the electrolyte was kept in fusion, not by externally applied heat, but by the heat generated by the passage of the current through the electrolyte. In the bath, *Fig. 1*, p. 213, no arrangement was shown for heating it externally, and the presumption was that the contents were kept Mr. Blount.

Mr. Blount. in a state of liquidity by the passage of the current. It would be interesting to have exact information on this point, because Dr. Borchers, a German technologist of high reputation and large experience in these matters, had shown from theoretical considerations, and indeed by actual experiment, that great difficulties would always be encountered by any process seeking to reduce alumina in which the zone of greatest temperature did not lie in the centre of the bath. The quality of commercial aluminium was undoubtedly largely governed by the impurities it contained. There were few commercial metals with which he was acquainted that were not under a similar disability. It had also been recently shown by Mr. Moissan that a predominating influence on the quality of aluminium was exercised by sodium, a hitherto unsuspected impurity. That metal, although electro-positive to aluminium, and therefore unlikely to be reduced in the electrolytic bath in which aluminium was being deposited, yet under the influence of the high current-density which was habitually and necessarily employed in the electrolysis of alumina dissolved in cryolite or some similar substance, made its appearance and contaminated the finished article. When sodium was present, the aluminium contained a metal which was electro-positive to it, and capable of being corroded more readily than the aluminium itself; there was no evidence at present to show that such impurity was not segregated in the mass, and might form active centres of corrosion. In the experience which had been obtained in several countries on the possibility of using aluminium for light military utensils, etc., where weight was of much more importance than cost, experiment had gone to show that local corrosion was one objection to their being taken into regular employment. The probable cause of that local corrosion was the segregated sodium, and until some means were found to prevent the occurrence of sodium in the finished material, corrosion of that kind would be liable to occur. Not only was the sodium itself liable to attack, but, in contact with any aqueous liquid, it yielded a solution of caustic soda, which in turn acted on the aluminium. There was thus a secondary reaction of a comparatively violent kind which carried on the process of destruction unlimitedly, and therefore a small impurity might be of serious importance. It behoved those interested in the wide use of aluminium to study the question closely, and to make sure that the production of the metal which they proposed to supply for all purposes where it would come into contact with corroding agencies might be so carried out as to free it from that defect. Although aluminium had a lower specific gravity than the salts which formed the electrolytic bath when both were in the solid state, yet curiously enough in the molten state the conditions were precisely reversed. This fortunate circumstance had this practical bearing, that whereas, had aluminium a lower specific gravity than that of the molten electrolyte, the manufacturer would be confronted with the difficulty of aluminium collecting towards the anode and burning as fast as it was produced; yet under the actual conditions which obtained, it sank quietly to the bottom and could be run off and utilized. Mr. Blount.

Mr. THOMAS PARKER observed that he meant that the carbon took no active part in the reduction; it was simply attacked by the oxygen liberated in the process, and gave heat to the bath. He quite agreed that the sodium was reduced in consequence of the excessive current-density at the anodes. Mr. Parker.

Mr. CRAWFORD BARLOW had visited the works of the Niagara Falls Power Company in the summer of 1895, and had been impressed with the immense amount of water that was pouring down through the turbine-pit. The placing of the dynamos at the bottom would, therefore, be out of the question, as the damp would have prevented their working efficiently. Reference was made in the Paper to the effect of the difference of levels, caused in the Lakes and the Falls by the abstraction of this water, and also of the water of other power-works proposed to be erected on the Canadian side. It was estimated that the Chicago Canal would lower the level of Lake Michigan about 0·3 foot, and taking into consideration the results of all the abstractions of water for the other power-works, the total was estimated to be about 1 foot. He had good authority for stating that the annual variation of the Lakes between winter and summer was between $1\frac{1}{4}$ foot and 2 feet, and there was, in addition, a very large variation produced by natural causes—periodic variations, varying in period between five years and ten years. The amount of that variation was 5 feet, and the result arrived at was that the abstraction of water by the Canal—and it might also be said, with regard to these power-works—was practically *nil* as compared to the very great variations produced by natural causes. Mr. Barlow.

Mr. H. C. JENKINS remarked that further information as to the aluminous compound, to which the Author had early in the Paper referred, would be interesting. It was well known that Mr. H. St. Claire Deville many years ago sought long, but vainly, to find a series of aluminous compounds which at that time he thought existed; and reasoning from the analogy that aluminium Mr. Jenkins.

Mr. Jenkins. presents, in its chemical behaviour, to iron, he had thought there would be an easy way to reduce aluminium to a metallic state if he could start with an aluminous compound. He had been thrown back, however, upon the compounds in the higher state of oxidation, and those had been in use ever since.

He would ask the Author whether, in his later experience, he found the process absolutely quantitative, whether it was a true electrolytic one, as it was generally assumed to be. It appeared at first sight a perfect analogue of the reduction of sulphate of copper in a bath of water and sulphuric acid. There was a mixed bath of fluoride; alumina was dissolved in it, being added from time to time, and this was broken up and the aluminium obtained at the kathode and the oxygen at the anode. The statement had been made somewhat freely in the past that this was not quite the case, and that the full tale of aluminium which could have been expected was not obtained. The return was given by Fontaine as only between 50 per cent. and 80 per cent. with a very similar process, but probably with more experience of the process much higher figures had been obtained. Yet there was a doubt. Then, too, the oxygen was supposed to be given off at the anode in the form of carbon monoxide. Why should that be? If the oxygen were given off only in a nascent condition as from a true electrolytic process, why did it not on an elevation of the temperature of the bath give, as might be expected, CO_2? That would considerably reduce the consumption of carbon, and ought to do no harm. He thought that the working apartment, into which the Author allowed carbonic acid to escape in considerable quantities, would need efficient ventilation. The composition of the bath was stated in the Paper to be triple fluoride of aluminium, sodium, or potassium, and of calcium, but the proportions were not given. In making experiments some time ago he had found a triple fluoride of aluminium, sodium, and calcium, where each base had an equal number of molecules of fluoride, to be a very fluid bath indeed, satisfying some of the conditions required; and it was less dense than aluminium, so that the aluminium as it was reduced sank through it freely. It was quite mobile and easily melted. The exact composition of the mixture used by the Author was not stated, but Fontaine, in describing the whole process, gave, in addition to the proportions of cryolite and fluor-spar—the two minerals that made up the bath—about an equal amount of aluminium-fluoride, so that the bath described by Fontaine contained very much more aluminium-fluoride than the proportions just stated, and was, therefore, less likely to become clogged during work. He had endeavoured to reduce the somewhat rare metal, glucinium, in the bath. Glucinium was a metal very similar to aluminium, and although it was reduced, he could not collect it readily. The glucinium had a density of only 2·07, and consequently floated up to the surface and was burned as fast as it formed. He was able subsequently, with the aid of the bath, to separate glucinium from alumina after the reduction of glucinia had been effected by heating it with metallic aluminium. It was important to remember a fact that the Author had pointed out, namely, that many other metals could be reduced in the same way as aluminium if it was profitable to do so. Mr. Jenkins.

The current-density was a most important factor to know when carrying on the process. The scale of his operations had not, however, been stated by the Author. It was almost suggested that the greater part of the 15,000 HP. was employed by the Pittsburgh Reduction Company, and there were varying statements as to the amount of power actually taken. In one report [1] it was stated to be 6,500 HP., in another [2] it was given as 2,000 HP., which appeared to be the more likely. It was also stated [2] that at the Pittsburgh Reduction Works a difference of potential at the constant-current dynamos of 160 volts was used. That value was, however, omitted from the Paper. It was known that the potential on the alternating low-potential main was 115 volts, but that of the continuous-current main was not given. He would assume that somewhat more than 2,000 HP. was taken, and that a continuous current of about 10,000 amperes at 160 volts was used. From the Paper it appeared that 1 cubic foot of the solvent employed would produce 1 lb. of aluminium per hour. It also appeared that 1,333 ampere-hours were required to produce it, assuming that the reduction was perfect and quantitative. All the baths were in series, so that 7½ cubic feet was the volume for each bath, and the dimensions about 1 foot 3 inches wide by 1 foot 3 inches deep and a little more than 5 feet long. The current-density on this data would be about 460 amperes per square foot at the kathode, but it was much greater at the anode—ten or fifteen times as great. That would produce 7½ lbs. per hour, or 180 lbs. per day. The difference of potentials of the bath was scarcely indicated. It must, however, be more than 2·8 volts, which was the difference of potentials necessary to break up alumina under those conditions. It was probably a difference of about 4 volts,

[1] "Mineral Industry," vol. ii. 1893, p. 7.
[2] *Cassier's Magazine*, Niagara Number, vol. viii. p. 336.

Mr. Jenkins. and about that which would break up the solvent itself. In describing the process, Mr. H. Fontaine[1] had given it as between 7 volts and 8 volts. Assuming that there were forty baths in the series, with a difference of potentials of 4 volts each, there would be a daily production of 7,200 lbs. from the whole plant, which agreed well with the estimates which had been given[2] as the proposed output. It also gave the production of a pound of aluminium with the expenditure of 6·6 E.HP.-hours. If the Author used more electrical energy than was assumed to be the case—more than 2,000 HP.—the calculation would give a greater density of the current in the bath. If it was assumed that he used 15,000 HP. when the bath was drawn to scale, the density would be about 800 amperes per square foot. But perhaps the Author would give the exact figures.

Mr. Head. Mr. JEREMIAH HEAD had visited the works of the Pittsburgh Reduction Company, and had seen the processes described. The results achieved seemed superior to any that had been previously obtained. The most striking point was the enormous power required to supply the current necessary for a comparatively small production, and also the fact that the material, the alumina, actually being decomposed, was apparently very pure and must have undergone certain preliminary processes before it could be brought into that state from natural products. It also appeared that the heat of the electric arc did not seem to be sufficient for its reduction without the addition of fluxes, the effect of which must be to render it reducible at a lower temperature than otherwise would be the case. The name of Sir Lowthian Bell ought to be mentioned in that discussion, seeing that there was no one in England who had devoted more time, attention and expense to obtaining the metal aluminium from its oxide than he had done, although he was not in the end successful, because of the great amount of material he found he had to treat in order to obtain a very small quantity of this metal. The superiority of the present process was at once shown by the cheapening of the product from about 6*s*. per lb. to less than 2*s*. per lb. He had visited the power-house at Niagara City, and had been impressed by the completeness of the arrangements, and the gigantic nature of the enterprise. The new works commenced by making the tunnel, the mouth of which was a little above the Niagara River, driving it inland a distance of between 1 and 2 miles, so as to be able to turn

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[1] "Electrolyse," by Mr. H. Fontaine, Paris, 1892, p. 346.
[2] "Mineral Industry," vol. ii. 1893, p. 7.

into a "tail race," so to speak, whatever water was diverted at the top level from the rapids above Niagara, and make it operate turbines in its descent. Along the top of the cliff and not far from the mouth of the tunnel, were arranged a number of corn-mills and other old-fashioned factories, which equally used water diverted from the Rapids above the falls, which, after turning the water-wheels, or turbines, or whatever was used for obtaining power, was taken out through the cliff at a comparatively short distance below the upper surface. A number of these tail-races could be seen pouring out at 50 feet or 100 feet only, below the surface. That was all the power they took, although there was still a considerable distance down to the bottom that might have been utilized. It showed how wastefully water-power was applied in those times compared with the present, when works of the kind are scientifically considered and worked out. The planting of a factory for the production of aluminium at Niagara City was an enormous step in advance, inasmuch as the power was obtained from falling water, of which there was there an almost unlimited store. It was obtained cheaply compared to what would be the case if it had to be derived from a steam-engine or otherwise; not only was there this great factory, but there were others building which would be worked in the same way. The whole of the Niagara City power-house and everything connected with it was therefore a matter of extreme interest to engineers as being the pioneer, possibly, of many other manufacturing cities which might spring up in the future, and where manufacturing operations might be conducted. There was probably no place in the world where there was such an unlimited store of water-power as Niagara, but there were many other places where there was sufficient store to establish large factories, and perhaps even big manufacturing cities, so that the progress of these factories founded on water-power was of the greatest interest. In Norway and Sweden, where he had lately travelled a good deal, he had been impressed by the enormous quantity of water going to waste everywhere, and with the idea that much benefit might be obtained from those waterfalls if they could be only applied to useful purposes. Arising from these considerations was the very interesting one of the conveyance of this electrical power for great distances without undue loss. At Niagara it was not as yet contemplated to convey the power more than about 20 miles, but by means of alternating currents he supposed it could be carried to a very much greater distance. It would require to be conveyed between 500 miles and 1,000 miles if any of the principal waterfalls of Norway or Sweden were to be utilized in England. The inhabitants of those Mr. Head.

Mr. Head. countries were exceedingly anxious that their power should be conveyed to England for manufacturing purposes, and, in fact, many of them distinctly believed it was only a question of time as to when it would be done, and since the installation of Niagara had been erected, it was said the waterfalls in Norway and Sweden had distinctly risen in value. He indulged the hope that, in the progress of electrical science, it might be possible to carry power to much greater distances for useful purposes than had as yet ever been contemplated.

Mr. De Segundo. Mr. E. C. DE SEGUNDO remarked that no figures as to the cost of the production of aluminium were given in the Paper, although, to engineers, such data were of the highest importance. A great deal had been promised; in fact, when he had visited the works, he had been told that the cost of production would be such as to enable aluminium to be sold at about 1*s.* per lb. That figure, he thought, had not been approached. He understood that aluminium could be obtained in this country at 1*s.* 7*d.* per lb. In regard to the cost of the electrical energy at Niagara, which must be a large factor in the production of aluminium, he believed that it would be possible to sell one Board of Trade unit, one kilowatt-hour, for about $\frac{1}{4}d.$ and make a considerable profit. If that could be achieved and the power could be transmitted to the Pittsburgh Reduction Company's factory at an efficient rate, no doubt a reduction in the price of 1*s.* 7*d.* per lb. in aluminium would eventually be arrived at. It was significant that the Pittsburgh Reduction Company found it advantageous to erect a plant at Niagara, although good coal was so cheap at Pittsburgh. The scheme of bringing electrical energy, or energy in any form, from Norway under the sea, which Mr. Head referred to as having been seriously mooted, was not an impossible one in itself, but he feared that directly any scheme of the kind was broached, the owners of the waterfalls began to think the waterfalls were very valuable, and a correspondingly high rent was demanded. After all, the cost at which water-power could be obtained was not the only factor in the total cost of the supply of energy. It was thought, for instance, with regard to electric generating-stations, that when coal was cheap the cost of electrical engines must decrease accordingly. It did nothing of the kind, because the cost of coal was by no means the only factor in the total cost of production of electrical energy. And similarly the cost of water-power was not the whole cost; not only the production of electricity but the price at which the electrical energy could be sold at the spot at which it was going to be consumed must be taken into account. One

Board of Trade unit might cost a quarter of a cent at Niagara, but if it cost a quarter of a dollar at New York, it might be better to produce it on the spot with coal. Mr. De Segundo.

Mr. A. WOLLHEIM had looked in vain in the Paper for the actual cost of energy per horse-power at Niagara, and the cost of horse-power per annum under contract. There was a more serious aspect to the question of water-power in Sweden and Norway. As far as he knew, all the waterfalls had been engaged in 1895 by American and German speculators. There was no necessity for laying cables across the sea to England. These Norwegian and Swedish waterfalls were very peculiarly situated, being only a few miles from the sea. The freight to England would be very low, so that these Norwegian falls were on an entirely different basis to the Niagara Falls, which could not possibly have a bearing on the productions of the world on account of the great freights. As to the cost of the works at the turbines, he had been investigating this question for some time, and had found the Neuhausen works cost £2 10*s.* per horse-power per annum, or about 2*d.* per horse-power per twenty-four hours. At the Niagara works the cost was stated to be about 1¼*d.* per horse-power for twenty-four hours. He could not compare steam-power with that last figure, and he did not think steam-power could be developed for less than £7 10*s.* per horse-power per annum, *i.e.*, 6*d.* per horse-power per twenty-four hours. Mr. Wollheim.

Mr. HUNT, in reply to the discussion, stated that the voltage of any given series of pots varied with their size and with the amount of electrolyte required to be traversed by the current; usually between 5 volts and 10 volts were required per pot. The problem of obtaining anodes which would not be corroded in the electrolytic operation, had been in the manufacture of aluminium, as in other similar electro-metallurgical or electro-chemical operations, a vexatious one. Iron, copper, or nickel anodes had been employed advantageously instead of carbon anodes when alloys with these metals had been desired; but their use was obviously precluded when pure aluminium was required. The common impurities in aluminium as made electrically in modern apparatus, were a small amount of iron and silicon in the ordinary combined form, as they existed usually in pig-iron, and a graphitoidal allotropic modification as carbon similarly existed in pig-iron. Attention had recently been called by Mr. Henri Moissan,[1] to the presence of Mr. Hunt.

[1] Comptes Rendus, vol. cxix. p. 12, and vol. cxxi. pp. 794 and 851, and *post*, pp. 519 and 520.

Mr. Hunt. carbon and sodium in commercial aluminium. Mr. Hunt had given special attention to the precautions necessary to preclude the presence of these impurities, as well as to the occurrence of occluded nitrogen in the metal. The chief points to be attained were that the metal was not heated much beyond its melting-point in the presence of carbon, to prevent the contamination with carbon and nitrogen, and, in the case of sodium, that the most advantageous mixtures of the fluoride salts were used, and that the supply of alumina should be so uniformly fed into the bath as to prevent the electromotive-force rising and thereby causing the reduction of the alkali metals from their fluoride salts. He had called attention in the Paper to the fact that the electrical resistance greatly increased when the proper supply of alumina dissolved in the bath was diminished. It was at this point that skilful working of the process was especially required. Improperly electrically-made aluminium containing sodium seggregated in the metal had given especially poor results in many cases, and had been the cause of many failures of the metal to withstand corrosion. Copper and nickel were impurities in much of the metal made by re-melting scrap, occasioned by the fact that they were intentionally used as hardeners in many instances. The presence of these impurities, as of titanium, tungsten, chromium, and similar metals, was not inherent to the process, however, but was due to such metals having been added as hardeners in previous operations. With the exception referred to, together with occluded gases, there were no other impurities in commercial aluminium as at present manufactured. The metal was being regularly made in commercial practice with over 99 per cent. of purity.

Much of the corrosion of aluminium, to which attention had been called, had been occasioned by galvanic action. Aluminium standing so high in the series of electro-positive metals, it was necessary to insulate it from the more common metals with which it would be most likely to come into contact in ordinary forms of construction, when wet or immersed, otherwise the corrosion, largely at the expense of the most electro-positive metal, the aluminium, took place.

He was not aware of the occurrence of many high-coloured bauxites containing practically no iron, referred to by Dr. Rideal. The deep red-coloured bauxites were all continually classed as containing high percentages of the sesqui-oxide of iron, the red bauxite of the Var, containing some 18 per cent. of oxide of iron, being a good illustration of the class. Organic matter gave considerable variegated colouring to some bauxites, but this had always been in connection with the colouring of a considerable amount of oxide of iron, in all the varieties that had come within his experience. There were some bauxites occurring in the States of Georgia and Alabama, which contained considerable amounts of manganese and vanadium, which in their oxidized forms had changed the colour of the bauxites, but these ores as well carried much oxide of iron. Both silica and titanic acid (two of the most troublesome impurities) did not change the natural white or grey colour of the mineral. He therefore agreed that colour was not a true measure of the purity of a bauxite. Mr. Hunt.

If the entire energy of the electric current could be used in producing its electrolytic effect, larger outputs per unit of power expended would be produced. The trouble had hitherto been in the use of external heat with the process that pot or furnace-linings, which were heated on both sides, were rapidly burned or worn away, and made to leak the very permeating molten fluoride which they were required to retain. Again, in all the operations hitherto conducted on a large scale, the heat evolved by the current traversing the electrolyte had been amply sufficient for the metallurgical operations; and cooling, rather than heat-retaining devices, often had been resorted to. While externally-heated pots had been successfully used—especially in operations on a small scale, where the relative surface for radiation had been very large—they were not used in the commercial practice at Niagara.

The costs of anhydrous alumina, quoted at $2\frac{1}{2}d.$ per pound, were excessive. It had been selling at somewhat less than $1\frac{3}{4}d.$ per pound in the European markets for the same time, and it was being made at a considerably lower price in both the United States and in Germany for the manufacture of aluminium. As to the costs of manufacture of aluminium, the following estimate had been given by Prof. Roberts-Austen.[1]

	d.
Energy	1·1
Alumina	6·0
Labour and superintendence	1·5
Interest, repairs and maintenance	2·0
Chemical stores	1·0
Carbon electrodes	2·0
	13·6

Each of these items had been considerably decreased by all the manufacturers of aluminium during the past two years, especially

[1] Report of Committee on Utilization of Water-Power at Periyar Works. Selections from the Records of the Government of India, Public Works Department, No. ccxv., Enclosure No. 1, p. 20.

Mr. Hunt. the cost of the alumina, as was evident from the rapidly lowering selling price of aluminium within the same period. He agreed that factors of freight and conditions for economical manufacture would, in many cases, outweigh the advantages of the more economical water-powers. The results of the Pittsburgh Reduction Company as to the consumption of coal and natural gas at the Kensington Works, had been practically confirmed by experiments made by the National Transit Company of Pittsburgh.[1] Various quantities between 20 cubic feet were given for the equivalent of natural gas for 1 lb. of coal; the average being about 12 cubic feet in most of the tests made with pure natural gas unmixed with air.

Further data had been published regarding the lower oxide of aluminium,[2] considered to have been the formula of Al O. The specific gravity of solid aluminium was, as Mr. Blount had stated, less than that of the solid fluoride salt mixtures generally used, and the reverse condition, when the aluminium became relatively heavier, happily only occurred when the materials assumed the molten condition. As to the output of aluminium per pound of alumina added as an ore, in the regular practice of the Pittsburgh Reduction Company, where the monthly totals of weights of ore used and of metal produced were regularly compared, the output was always within 1 per cent. of the theoretical amount of aluminium added as alumina. Considering the small losses in dust, etc., inherent in the handling of the powdered alumina ore, the operation on a large scale was a practically quantitative one. There were no losses of aluminium, as in ordinary metallurgical operations, in the form of slag or by volatilization.

As to the atmosphere of the working-room in which the electrolytic operation was conducted being oppressive or poisonous on account of excess of carbonic acid or presence of carbonic oxide or of fluorine, when the operation was being conducted normally and regularly, absolutely no trouble was experienced by the workmen. The buildings should be constructed high on posts and good ventilation arrangements should be provided, and with skilful work no trouble on this account should be experienced. But with lack of regular and skilful working, the surrounding atmosphere would be found to have the property of etching everything with

[1] *American Manufacturer*, November 30th, 1894.

[2] The Berliner Berichte of the German Chemical Society, 1890, p. 772; also 'Aluminium,' by J. W. Richards, 3rd edition, pp. 229, 230. Dr. Clemens Winkler was the first to publish data regarding the separation of this interesting lower oxide of aluminium.

which it came into contact, including glass, as well as the mucous membranes of every person within range. Grass grew luxuriously and green around the aluminium plants of the Pittsburgh Reduction Company. On the other hand, when the fluoride salts, rather than entirely oxide of aluminium were electrolyzed, an aluminium plant was a healthy place to keep away from. Mr. Hunt.

As to the exact composition of the bath, a solution that had been used extensively was composed of 677 parts of aluminium fluoride, 251 parts of sodium fluoride, and 234 parts of calcium fluoride. He had been much interested in the account of Mr. Jenkins's operations in the electrolysis of glucinium. Similar efforts had been made, with lack of success, under the Author's supervision. The greatest trouble had been to obtain a glucinium salt without too great an expense that was free enough from silica for successful operations.

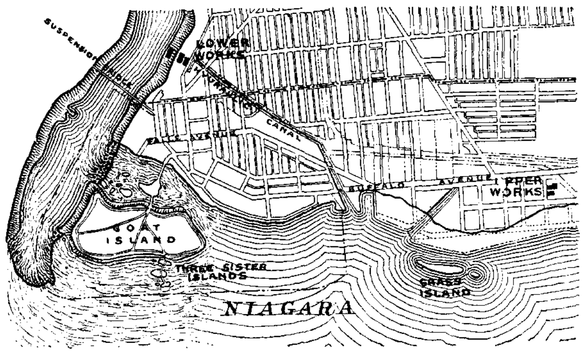
He was glad to add his tribute to that given by Mr. Jeremiah Head to Sir I. Lowthian Bell, who, with his brother, was certainly a pioneer in the production of commercial aluminium, not only in Great Britain, but in the world. Next in chronological order, after the works established in 1856, and finally moved to Salindres, near Paris, by Mr. H. St. Claire Deville, came the works in Battersea, near London, erected by Mr. C. H. Gerhart, in 1859, and in 1860 the works at Washington, near Newcastle-on-Tyne, were erected by Sir I. Lowthian Bell. At his works much of the aluminium of commerce had been produced from which the study of its properties had been made. Referring to the long-distance transmission of electrical power to which Mr. Head had called attention, the problem now seemed to depend upon the proper form of insulation of the conductors for the high-voltage currents that would require to be transmitted. The experiments at Niagara had shown that even the best forms of porcelain petticoat insulators were insufficient, under some conditions, to insulate a current at 50,000 volts pressure.

The cost of large quantities of power at Niagara was about the same as at Neuhausen, between £2 5*s.* and £2 10*s.* per horse-power per annum. His experience showed that steam-power could be produced at between £5 and £7 per horse-power per annum, under favourable conditions, in large quantities.

Since the Paper had been written the Pittsburgh Reduction Company had increased the size of their Upper Niagara Works, and the amount of power first taken had been more than doubled, each of the rotary converters having been enlarged from 400 kilowatts to 600 kilowatts capacity, additional machines being also used. A

Mr. Hunt. still larger block of power had been taken from the Niagara Falls Power and Manufacturing Company, who worked the surface canal, which directed a portion of the water of the upper Niagara River from its natural channel around the falls through the centre of the City of Niagara Falls, New York, to a basin on the high bank of the lower river, a short distance below the State reservation, *Fig. 7*. This canal was 4,400 feet long. Ground had first been broken in 1853, but it was not completed until 1861, the canal being about 36 feet wide and about 8 feet deep. Only about 7,000 horse-power was utilized from this canal, as only 50 feet or 60 feet of head had been attempted until within the past few years. In 1892 the Niagara Falls Hydraulic Power and Manufacturing Company commenced an enlargement of its canal. The plan adopted

Fig. 7.



Scale, 4,000 feet = 1 inch.

was to widen the original channel to 70 feet, and make the new portion 14 feet deep. The canal was cut through solid rock below the water-line. The power for driving the drills in this work had been obtained from an air-compressor driven by water-power from the station at the end of the canal, the air being conveyed along the line of the canal in pipes. Here was presented the curious spectacle of the canal furnishing power to dig itself deeper, a condition of affairs that would undoubtedly receive further application in the rock-cutting for the new wheel-pits soon to be placed by the Niagara Falls Power Company. The availability of large amounts of cheap power, the fruit of previous operations, would prove of great advantage and economy in future engineering work at Niagara. The enlargement of the canal had been excavated by dredges, and the flow of water through it was not interfered with.

This improvement was now completed, and the canal had a capacity of 5,200 cubic feet per second, giving a surplus of 70,000 HP. after supplying the old lessees with about 7,000 HP. Mr. Hunt.

The water from the canal flowed into a hydraulic basin parallel to and about 300 feet back from the edge of the high bank of the Niagara river on the New York side, about 2,300 feet below the American Falls. For the Lower Niagara Works of the Pittsburgh Reduction Company the water would be taken in an open canal to a forebay 30 feet wide and 22 feet deep at the extreme edge of the high bank. From this forebay a penstock 240 feet in length and 8 feet in diameter, built of riveted steel plates, conducted the water vertically down about 135 feet to the top of the sloping bank, and thence down the slope to the power-house on the lower bank. The power-house, 180 feet long and 100 feet wide, was built upon a level ledge of Medina sandstone, which was cleared of surface debris consisting of broken and disintegrated rock which had fallen from the bank during past ages and covered the red rock to a depth of between 10 feet and 70 feet, by means of a "giant" nozzle, the water for this hydraulic mining being furnished under the pressure of the fall from the basin on the high bank. Owing to the contraction of the channel of the river below, there was an extreme fluctuation in the level of the river water at the site of the power-house of the Lower Niagara Works of the Pittsburgh Reduction Company of about 30 feet, and it was liable to sudden changes, especially due to the wind. On this account the first floor of the power-house on which the wheels were placed was set about 16 feet above the ordinary level of the water of the river, which was above the highest recorded rise, the remaining part of the head being obtained by the use of draft tubes. At the same level, and adjacent, on the up-river side was the wood-pulp grinding mill of the Cliff Paper Company, who used two Leffel wheels of about 1,250 horse-power each, revolving at a speed of 225 revolutions per minute. Each wheel was equipped on either side with a set of stones for grinding wood-pulp. This plant had been in successful operation since 1892.

The water was conveyed from the bottom of the vertical penstock through a horizontal pipe 10 feet in diameter suspended over the tail-race. This conduit had walls $\frac{15}{16}$ inch thick and supplied, through 60-inch valves and the bottom of the wheel cases, the turbines, which were three in number, and were situated directly over the supply-pipe. These turbines took the water from below and discharged it through draft tubes running down on either side of the supply-pipe. The wheels had horizontal axes, and each

Mr. Hunt. furnished 1,900 HP. under a head of 205 feet, and all parts were designed to stand the pressures due to a head of 220 feet without undue strain. The ordinary head would be 210 feet, which was the highest under which water had ever been used to develop power in the quantity to be used in this plant. The wheel-cases were each supported on 20-inch steel beams weighing 80 lbs. per foot and 21 feet 6 inches in length. The wheels were driven at a speed of 300 revolutions per minute, and were guaranteed to show a useful effect of not less than 78 per cent. at any point between full and three-quarters load of water under any head between 205 feet and 220 feet, and running at a constant speed of 300 revolutions per minute. This useful effect was guaranteed to be not less than 60 per cent., under the same conditions, from three-quarters to one-half load of water. To each end of the water-wheel shafts would be coupled, by means of flexible couplings, a direct-current generator capable of developing 560 kilowatts of electrical energy at 280 volts. These generators were eight-pole shunt-wound direct-current dynamos running at a speed of 250 revolutions per minute. The electrical current was to be conveyed upon suitably-designed brackets attached to the penstock, on aluminium conductors of 28 square inches cross-sectional area, equivalent copper conductors having an area of $17\frac{1}{2}$ square inches. The pure aluminium bars used as conductors had been proved by actual measurement to have 62 per cent. of conducting power as compared with pure copper. The Lower Niagara Pot-Room Plant of the Pittsburgh Reduction Company for manufacturing aluminium was situated on the high bank directly above the power-house and between the hydraulic basin and the edge of the cliff. In this way necessity for transforming the current was avoided, and simplicity of working was obtained. The plant would probably be in operation about the 1st of July, 1896, when it was expected that about 10,000 lbs. of aluminium would be manufactured per day.

The general design of the new power-house of the Pittsburgh Reduction Company was similar to that already in successful operation of the Cliff Paper Company in their wood-pulp grinding plant. The general arrangement of both these plants, taking the water over the bank at a velocity of about 6 feet or 7 feet per second into a larger trunk, diminishing the velocity to about 4 feet per second, and taking the water up into the bottom of the wheel-case so as to place the wheels, which had their bronze wheel-runners absolutely balanced, due to the equal discharge of water on each side, on the level of the floor of the station, was, in many respects, novel. The engineering work of both plants of the Cliff Paper Company and the Lower Niagara Works of the Pittsburgh Reduction Company had been entirely conducted by the chief engineer of the Niagara Falls Hydraulic and Manufacturing Company, Mr. W. C. Johnson, with the exception of a small amount of engineering work in connection with some of the details which had been carried out together with the supervision of the work by the Author, as the President and General Manager of the Pittsburgh Reduction Company. Mr. Hunt.

Correspondence.

Dr. Coleman Sellers remarked that during the month of August, 1895, a test had been made of the 5,000-HP. turbines which were described as erected by the Cataract Construction Company for the Niagara Falls Power Company, and the results showed an efficiency of more than 80 per cent., which, it might be noted, was 5 per cent. in excess of the efficiency guaranteed by the designers of the wheels, Messrs. Faesch and Piccard of Geneva, Switzerland. The test of the governing machinery had also come well within the specified guarantee, namely, to control the speed within 4 per cent. if one-fourth of the whole load should be suddenly either taken off or applied. The results of the tests of No. 2 turbine were shown in the following Table, from which it would be seen how the speed was affected by the varying loads. On the 30th September, 1895, the turbine had been put in operation without load, the speed being 250 revolutions per minute. An electrical Dr. Sellers.

Tests of Governors of No. 2, 5,000 HP., Turbine of Niagara Falls Power Company.

Load at Start.	Change of Load.		Speed at Start.	Greatest Alteration of Speed resulting from Change of Load.		Uniform Speed after Change of Load.		Duration of Perturbation.
HP.	HP.	Per Cent.	Revs. per Minute.	Revs. per Minute.	Change Per Cent.	Revs. per Minute.	Change Per Cent.	Secs.
5,000	−1,300	− 26·00	245	253	+ 3·27	246	+0·40	6
3,700	+1,300	+ 35·25	248	240	+ 3·23	245	−1·19	11
5,000	−1,500	− 30·00	245	255	+ 4·08	248	+1·20	8
3,500	+1,500	+ 43·00	248	235	− 5·24	245	−1·19	12
5,000	−2,000	− 40·00	246	257	+ 4·47	249	+1·21	11
3,000	+2,000	+ 67·00	248	234	− 5·64	245	−1·19	14
5,000	−2,500	− 50·00	245	262	+ 6·94	250	+2·00	11
2,500	+2,500	+100·00	249	230	− 7·63	245	−2·00	16
5,000	−3,000	− 60·00	245	270	+10·20	250	+2·44	14
2,000	+3,000	+150·00	250	225	−10·00	245	−2·00	18
5,000	−3,500	− 70·00	244	272	+11·47	252	+3·28	16
1,500	+3,500	+233·00	247	225	− 8·90	245	−0·80	19