Discussion.

Sir John Coode. Sir JOHN COODE, President, said they had listened to an extremely useful and interesting Paper on what, from an engineering standpoint, must be regarded as one of the most important questions of the day. Judging from the acclamations with which it had been received, he had no doubt the members would authorize him to give their best thanks for the Paper with which Mr. Crompton had favoured them.

Mr. Crompton. Mr. CROMPTON stated that since the Paper was read, he had received from America the load-curves of the large Edison stations in New York. It would be seen that they were happy in having load-factors much higher than had hitherto obtained in England. The curve for the residential part of New York was very similar to that of the Kensington district. Another curve for the period between ten in the morning and four in the afternoon was almost entirely made by motors. He had been informed that this highly satisfactory load had only been reached within the last two years. In fact nothing had been more striking than the increase of load in that portion of the day during that period. The same thing was seen in the district above. In one case they had reached a load-factor of 50, and in another of 41·6. But in spite of that he was happy to say that the Americans had not beaten the economy obtained in England. The object of the Paper was to dwell on the important effect which the light loading of plant, during such a large portion of the twenty-four hours, had on the cost of the production of electricity, so that the electrical energy could never be supplied so cheaply for lighting residential districts as for driving electrical railways or for industrial purposes, where the load would be maintained at a tolerably constant rate throughout a large portion of the twenty-four hours. He wished further to explain why he had confined the cost to the few items of coal, labour, and petty stores. It would have been interesting to have included another factor, namely, the cost of upkeep, but no electrical plant had been sufficiently long at work to enable him to give data that would be satisfactory to engineers, and nearly all the companies contented themselves with putting aside a sum which was calculated as a percentage on the first cost. The repairs were now, no doubt, much lighter than they would be in years to come, and any figure which showed the actual cost under that head during the early

Mr. Crompton. years of working would only be misleading. He had said nothing about the other very considerable items which went to make up the real cost of electricity, viz., the fixed charges, for the obvious reason that these were influenced by local circumstances, and those who were capable of supplying them might be loth to make them known to their rivals in business; and they did not much interest engineers. He wished to refer to one omission in his Paper. He had given very little credit to those who had designed the machinery in the stations he had described. It was needless to say that he did not design or carry out the whole of his own station, although he was responsible for it, having been assisted by his staff and others. But in the case of the St. James's station, which he had described rather fully, he believed that a great deal of credit must be given to Messrs. Latimer Clark, Muirhead, and Co., and their staff, who were originally concerned in designing the whole of the plant. The consumption of coal, which had been brought down to 7·9 lbs. at Kensington in December, had been still further reduced, as they got more and more used to the plant; last month it was 7 lbs. With reference to the Table of the efficiencies of dynamos, he had stated in his Paper that there were at least six English makers whose work attained that high standard of excellence. He had omitted to say that besides the six names he had given, there were at least two others, and possibly three, who could make machines as good. The reason why he was able to mention the four dynamos to which he had referred, was that there had been full accounts of three of them, Mr. Kapp's, the Edison-Hopkinson, and the Goolden, in the technical journals, and the figures given had been deduced from those data. He had added to them only the description of his own machine which had not been so published; but the machines by Messrs. Siemens, Messrs. Latimer Clark and Co., and the Construction Company were practically of equal excellence. Attention had been called to the fact that Messrs. Goolden were hardly fairly represented on the list. The figures given on the small diagram more correctly represented Messrs. Goolden's present practice. He had also been able to add figures showing what the efficiency would be at Kensington, with the load-factor at 7·65, if the distribution had been carried out by the alternating currents and with the best transformers at present existing. He had been supplied with figures by the designer of probably the most successful transformer existing, and he found that 30 per cent. of the output at Kensington was supplied to shops and the annual distribution efficiency was 68 per cent.; the remaining 70 per cent. was supplied to private houses, the annual efficiency being 55 per cent., giving a total of 57·7 as the distribution efficiency at Kensington if carried out on the best worked out transformer system. There was a small error in the Table hardly worth noticing. He had plotted the efficiency of his own machine at a decimal point higher at half-load than at full load, which was a mistake. Although he had said in his Paper that it was advisable to use air-condensing or some similar form of surface-condensing in London, he did not confine himself to air-condensing. He included also the various modifications in which a certain supply of condensing-water was employed to cool the pipe-condensers. Mr. Crompton

Mr. W. H. PREECE remarked that the Author had just given some reasons why he had omitted to take into consideration other elements that added to the cost of electrical energy. They could not, however, quite shut their minds to the fact that there were manufacturers as well as users of electricity, and while the Author had shown that it was possible to manufacture it for something like twopence a unit, Mr. Preece thought they ought to know something of the reason why the consumer was called upon in London to pay $7\frac{1}{4}d.$, and in a great many other places 8*d.* per unit. The Board of Trade unit was an exceedingly useful mode of measuring and charging for electrical energy. It was based on the watt, and there were no doubt many present who were not electricians but who believed that the watt was an electrical unit. It was nothing of the kind. It was purely a mechanical unit, as much as the foot-pound. The watt was used because it was such a convenient fraction of the HP., being a 746th part of 1 HP.; it was in fact 44·2 ft.-lbs. per minute. In dealing with electric light they had to do with the expenditure of energy, and the watt was essentially useful in measuring the expenditure of electrical energy for the simple reason that 1 ampere driven by 1 volt would give 1 watt. The Author had adduced indisputable facts to show that 8 lbs. of coal would give 1,000 watt-hours, which meant that 1,000 watts, or a kilo-watt, steadily applied, would produce a power that would maintain thirty-three 10-candle lamps alight for one hour. In other words, a Board of Trade unit would give 333 candles per hour, showing that 1 lb. of coal per hour would give 42 candles. On the other hand, from 1 ton of coal there could be distilled 10,000 cubic feet of gas, which meant that 1 lb. of coal would yield 4·5 cubic feet of gas, which, supposing it to be of such quality as was obtained in London, ought to give 13·5 candles. So that 1 lb. of coal by gas gave 13·5 candles, while 1 lb. of coal by electrical energy gave 42 candles. It might be put in another way. Supposing they wanted to spend Mr. Preece.

Mr. Preece. one shilling in electricity or in gas. One shilling at 6*d.* per Board of Trade unit, which seemed to be the average throughout the country, would give 666 candles. Taking the average price of gas in seven of the largest towns at 3*s.*, 330 cubic feet—one shilling's-worth of gas—would also give 666 candles. They had, therefore, the fact that gas at 3*s.* was equivalent to 6*d.* per Board of Trade unit. In making that calculation he had taken not the theoretical value of gas, such as was given in London, namely, 3 candles per cubic foot, but the actual measured light afforded by the ordinary fish-tail burner, at 2 candles per cubic foot, which Mr. Vernon Harcourt determined it to be. It came to this: that if Mr. Crompton's anticipations were realized, and he had no doubt they would be, namely, that they would be able to generate a Board of Trade unit with $2\frac{1}{2}$ lbs. of coal, it would mean that while 1 lb. of coal would give by gas 13·5 candles, by the glow lamp the same quantity would produce 130 candles; and if the form of electric light used were the arc lamp, then 1 lb. of coal would yield 700 candles. So that drawing a comparison between the light given by gas and the light given by electricity, the result would be very much in favour of the latter. He had occasion recently to inquire rather carefully into the cost of the production of light by gas and by electricity in Malta and Gibraltar, and he found that in those two places it was possible, without even the improvements shadowed forth by the Author, to manufacture electricity at a much less cost than gas. The reason was that in those places there was no market for residuals. If there were no market for residuals in London, there would be no question as to the relative price of gas and electricity. It was a common thing for people to say when they had introduced the electric light into their houses that they were astonished to find how much they had to pay. The explanation was very simple. It always turned out that they had not been satisfied with the plain and simple light they had before, but instead of five wax candles in their drawing-rooms they had fifty candles by electric light, and of course their bills increased accordingly. In addition to that they also came across many cases where there was great want of supervision, and people did not take the trouble to see that the lamps were turned on and off. The cost to the consumer in London was $7\frac{1}{4}$*d.*, and of that the portion Mr. Crompton had dealt with was not a very serious item. They were much indebted to him for introducing the term "load-factor." It was a most useful expression, and one which lent itself to the careful examination of the central stations; but still the improvement or the non-improvement of the load-factor

Mr. Preece.

did not make a serious difference in the cost of light to the consumer, who had to take into consideration the renewal of his lamps, the maintenance of wires and fittings, the cost of distribution, and various other matters which brought the price up to $7\frac{1}{4}d.$ The most careful examination of the bills and of the returns made by the suppliers in the country showed that, allowing for the renewal of lamps and for maintenance, the average price paid by the public per lamp fixed for electricity was 12*s.* 6*d.* per annum. The average price paid in nine of the large towns for gas-burners was 9*s.*, so that really the difference between electric light and gas light was virtually only the difference between 12*s.* 6*d.* and 9*s.* The variation of load shown in *Fig. 2* was extremely useful. The load-curve which enabled the Author to give his load-factor illustrated what Mr. Preece had occasion to refer to when the Paper on "Mechanical Stoking" was discussed,[1] namely, the sudden rise in the load that was shown on December 3rd about four o'clock, and also in the case of the fog on December 26th, which commenced about nine o'clock in the morning. They had yet to learn how to meet those great variations of load. From the study of the load-curve it was seen that by the use of a succession of small engines working up by steps to the maximum engine they could advance as it were along the curve so as to reduce the waste at low loads, to which reference had been made, as much as possible. The great point the Paper ought to lead to was to teach them how the cost of distribution could be reduced. Here they came to what the Author had referred to as the fierce controversy on the relative merits of high and low pressure, or of the alternating-current systems and the direct-current systems. He was sure that before the discussion ceased they would find that electricians were not at all agreed on these points, and that there were as many advocates for the low-pressure continuous-current system as for the high-pressure alternate-current system, but he ventured to think that the latter would come out best. It had been argued against the alternate-current system that there was danger. The newspapers had been teeming with paragraphs of accidents to poor fellows in the United States who had been killed by electric light. Only one case within his recollection had taken place in England, and that was at Brighton. The cause of the accidents in the United States was that they allowed, what was not permitted in England, down their principal thoroughfare, which might be compared with the Strand, four lines

[1] Minutes of Proceedings Inst. C.E., vol. civ. p. 77.

Mr. Preece. of poles with twenty, or thirty, or forty wires on each. Those wires were used for telegraphs, telephones, fire-alarm signals, boy-messengers, arc-lamps, and all sorts of purposes to which electrical energy was applied. Therefore, when a telephone man ascended a pole to remove a fault in the telephone wire and accidentally touched an arc wire he received a shock of 2,000 volts, fell to the ground and was probably killed. Those things, however, did not and could not occur in England. There was no extensive alternating-current system in the country, in which the wires were not placed securely underground and free from all possible danger. He therefore thought that the question of danger might be brushed out of sight at once. Then it was argued that the alternate-current system did not give motive power. It did, or rather he should say it could; but the British public had not yet taken to the use of motive power, and the demand for motors had not yet arisen. It had also been said that it did not give storage. Storage was not wanted. When electric-light installations were established under the Provisional Order of the Board of Trade, the currents must be kept on all day long, and the necessity for storage did not arise. On the other hand, the alternate-current high-pressure system enabled them to supply electric light economically over large areas. They could have, as in the case of London, a central station at Deptford, whence they could extend mains and feeders over the whole of the metropolis. Wherever there was a great area to be covered, the high-pressure system was the only economical way of doing it. But the alternate-current system was the only one, as far as he knew at present, which had succeeded in this country in earning a dividend. Each had its own sphere, and it was for the engineer to decide when, and where, and how, the different systems should be used. If an engineer wanted to cross a river he had to choose whether he would go under or over. If he elected to go over, he must determine whether he could do it by tube, suspension bridge, arch, girder, or cantilever. So when he designed an electric-light system, he had to consider where he was to use a continuous current, where an alternate current, where high pressure and where low pressure. The true system was a combination of all, and not an adherence to one rather than another. The Author had brought forward facts that were most startling evidence in favour of the alternate-current high-pressure system, and he showed that by the use of inferior engines — not to be compared with those of Willans and Robinson— there was an efficiency of 83 per cent. If he had started the alternate-current system with Mr. Willans' engines, he would

Mr. Preece.

no doubt have obtained an efficiency of 90 per cent. Mr. Crompton also admitted that the efficiency of the alternate-current supply could be made as high as that of the low-pressure by the adoption of sub-stations. Mr. Preece doubted whether there was any engineer who would dream of designing an alternate-current system to serve any district without sub-stations. Last autumn he had the pleasure of seeing the system carried out to perfection in Rome. There was no place where electric lighting had made greater strides, or where the alternate-current system had been so fully developed. There were ten sub-stations, served from a central station, and the work was carried out entirely by the Gas Company of Rome. Mr. Crompton's Paper contained important facts, and probably would elicit more. It had given a good record of the progress engineers were making. Although the Author had not trenched upon work done in the United States, he had referred to load-factors in New York. In the United States there were 1,698 central stations going, and of those over 1,200 were worked by the alternate-current system. Mr. Preece had referred to the contrast in prices between gas and electricity. He did not bring the facts before the members as an enthusiastic electrician, but as a cool, calculating gas-shareholder. He had not the slightest fear that the value of his stock would diminish. On the contrary, he believed that gas, like electricity, was in its infancy. As a source of illumination gas would probably disappear; but it would come to the front as a source of heat, and would be the means by which they could get rid of many of the difficulties that electric lighting had to contend with at the present moment—such as the transfer of coal to large cities, and the prevalence of fogs in this abominable city of London.

Professor Forbes.

Professor George Forbes said it was interesting to go carefully into the figures which Mr. Crompton had collected, and to see how far their experience agreed with them, and how far in some cases they might require modification. The Paper seemed to be written not so much in support of continuous against alternating currents as to advocate the system in use at South Kensington, and to point out the great benefits which were to be derived from supplying a certain percentage of the energy from accumulators. It appeared to him that that was really the point which the Author had been trying to bring forward. As a matter of fact, the Paper was not so much on all classes of central stations as on the particular central station which Mr. Crompton had so long and so ably directed at Kensington, together with some remarks on the St. James's and

Professor Forbes.

Pall Mall Company. After having thoroughly warmed to the subject, the Author stated that he had selected those two stations to discuss "because he believes that they represent the most advanced and most economical type of generating apparatus that has yet been introduced in this or any other country." But in a previous part of the Paper, he candidly confessed that the reason why he had given the facts about those two stations only was that he could not obtain them from the others. One of the principal points dealt with in the Paper was that of the load-factor. The importance of that question had been recognized for a long time, and it was prominently brought forward in a Paper by Mr. Carpenter Smith, at a meeting of the National Association of Electric Lighting, at Pittsburg, three years ago, at which Professor Forbes was present. The efficiency of electric lighting engines at low loads was taken into account in earlier designs. Mr. Crompton certainly deserved their best thanks for having introduced the term "load-factor." Such an expression was much wanted, and the only criticism upon it which he had to offer was that, after a very careful reading of the Paper, he had been unable to make out exactly what the load-factor was. There were two definitions given in the Paper, and one concrete example. In the reading of the Paper another definition had been given which did not appear in the pages of the advance proof, and there was still another in the short abstract that had been circulated. Most of those definitions differed; at any rate, he was unable to see that they agreed. The load-factor indicated the ratio of the electrical energy supplied in a given time to a denominator which he had some difficulty in making out—whether it was the maximum quantity which could be supplied by the plant in the station or by the particular plant in use at the time, or the maximum that would be supplied if the maximum rate of supply during the whole year was used, or whether it was the maximum supply that would be given off if the maximum supply during the period under consideration, day, week, or month, was to be used. He hoped the matter would be made a little more clear. The lack of that information rendered it somewhat difficult to test some of the figures given further on. According to the Paper, the Author had made out that in electric lighting stations, such as those he had described, considerable economy was effected by the use of accumulators, which should, during the times of light load, be giving off their energy. The engines and dynamos were to be employed to charge the accumulators when they were working nearly at full load, and therefore using steam at a more economical rate; and the

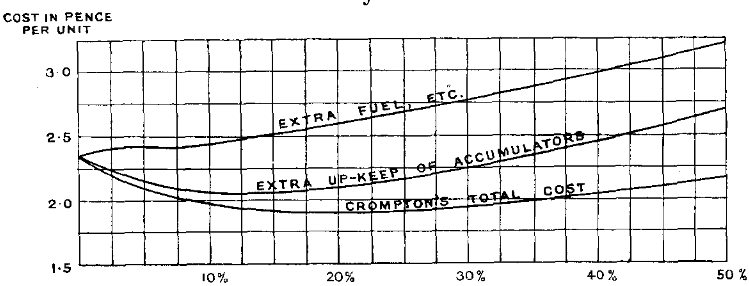
Professor Forbes.

energy thus stored up was to be used at the times of low delivery, thus sacrificing 20 per cent. of efficiency, or whatever it might be, in the accumulators, in order to get some saving in coal. The Author had stated that the only alternative would be to use small engines and dynamos during the times of light load. There were central stations in which that course was adopted, and notably the station at Berlin, to which Mr. Crompton had referred. Professor Forbes had placed on the wall diagrams [1] compiled from statistics prepared by the Berlin Central Station. They showed the interest on plant, the depreciation, the cost of management, and the cost of maintenance, labour, coal and fuel. From these diagrams he found that the cost of maintenance was almost in direct proportion to the energy supplied at all periods of the year, whether it was a light or a heavy load. The cost of a unit of electrical energy in June and November, the months of minimum and maximum output, would be in the ratio of 37 to 86, but the difference in the cost of a unit sold was due almost entirely to the permanent charges, management, depreciation, and interest. The Author had supported the view that accumulators used to a certain extent—about 20 per cent.—would give a greater economy in working central stations, by *Fig. 5*, founded upon certain Tables which were given. Professor Forbes had been unable to verify any of those figures. In the first place, he thought there was a mistake in the position of the decimal point, which ought to be one more to the right. But he could not find any means of estimating the amount of accumulators put in which would give the up-keep and interest on the curve shown. In every way which he had tried, it gave much more. He did not, however, wish to quarrel with the details of the figures, and he would accept the chief data there given, as to the cost for engine-room labour, up-keep, and interest on engines, dynamos, and boilers. Then with the consumption of fuel, &c., given, and the up-keep and interest on accumulators, they obtained the upper line in *Fig. 5*. He would start from that, and show some modifications which he thought would be necessary. The lowest line in *Fig. 7* exactly corresponded with the curve representing the total cost in Mr. Crompton's *Fig. 5*. He thought the general opinion of electricians would be that the up-keep upon accumulators must

[1] These diagrams are published in a Paper read by Professor George Forbes, on "Some Electric Lighting Central Stations in Europe and their Lessons," before the Institution of Electrical Engineers, 28 February, 1889.

Professor Forbes. be taken at a greater figure than the 12 per cent. adopted by the Author. He had put it at 20 per cent.; and the result was expressed by the second line in *Fig. 7*, which reduced the most efficient of the accumulators from 20 per cent. of the whole output to 12 per cent. He also differed from the Author as to the lowest curve in *Fig. 5*, which showed the amount of fuel required to produce a unit of electricity with different percentages of accumulators and dynamo machines. The Author stated that with 50 per cent. of the electricity coming from the accumulators they used half the amount of fuel to produce the same electrical energy. Now, although he was prepared to admit that there might be great loss if they worked large dynamos at a very low load during the daytime in summer, he could not see why they should not use engines proportionate to the work, as was done at Berlin. He had neglected altogether the waste of energy in passing

Fig. 7.



electricity through the accumulators, and had put that down to extra cost of the small engines. From the experience of Berlin he thought they were justified in assuming that the fuel required to supply a unit of electricity would not be less with 50 per cent. of accumulators than if it was taken direct from the dynamos. Making that alteration in the curve he arrived at the top line in *Fig. 7*, representing the total cost with different percentages of storage. It would be observed that from the commencement of the time when they began to put in accumulators, the cost of the production of electricity was increased. The Author might say that the up-keep of the Crompton-Howell accumulator was less than 20 per cent. Professor Forbes was supporting a very general view in saying that it was 20 per cent. It might be objected that these statistics were not so reliable as those produced by the Author. He could only say that at Berlin the statistical department was pursued with an exactness and precision which he had never seen in any other central station in the world. Mr. Crompton would probably say that he had drawn attention to the advisability of using smaller engines for the lighter loads. He had no doubt unintentionally omitted to notice a very important point in connection with the Table which followed *Fig. 5*. Dividing the third line of figures by the second line, examining the figures for St. James's and Pall Mall, it would be seen that they paid about the same price for their coal in August as in December. By examining those given for the Kensington station it would be found that in December the amount paid was 0·103*d.* per lb. for coal, and in August 0·157*d.* Fifty per cent. of the difference in cost of coal per unit supplied was due to the cost at which the coal was supplied on those two occasions; so that the saving from the Author's system did not seem to be so very great. Moreover, comparing St. James's and Pall Mall with the Kensington Company in the Table there was no gain shown from the use of accumulators by the latter. He was quite sure they would all gladly welcome an accumulator capable of doing economical work in central stations, and he hoped that Mr. Crompton would succeed in producing it with the battery which he was manufacturing. The Author had stated that in April, 1888, he read a Paper on the merits of the two systems before the Society of Telegraph Engineers. "It was shown," he said, "that a modified system of low-pressure supply, by using accumulator stations as a means of transforming electrical energy at a pressure of about 440 volts when generated at the central station to the 110 volts required in the consumer's houses, could compete favourably in all respects with the alternating transformer system." Professor Forbes could not admit that this view was generally accepted. He had not spoken about the relative merits of alternating and continuous currents, because he considered that the Paper was of far more interest as trying to establish the advantage of using accumulators in the low-pressure system of supply. Professor Forbes.

Mr. GISBERT KAPP wished to add a few words to what Professor Forbes had said with regard to *Fig. 5*. He had some difficulty in understanding the exact meaning of the term "load-factor," and now used the term in a very general sense, as showing how much energy they were selling with a given capacity of plant. It was evident that if the load-factor were high—that was, if the engines could be kept at work loaded heavily for long periods— Mr. Kapp.

Mr. Kapp. the shape of the curves in *Fig. 5* would be considerably altered. If, on the other hand, there was so little demand that they began to think of shutting them down altogether for half time, and using accumulators, then the top curve in *Fig. 5* might be correct. He should be glad if Mr. Crompton would state exactly for what load-factor it had been calculated. Table III was really an analysis of steam-dynamos, and would be extremely useful, because it showed where to attempt improvements, or where the dynamos might well be made a little worse, if at the same time they could be produced a good deal more cheaply. He believed the figures in the Table had been calculated on the basis of indicator diagrams, and he had no doubt that under the supervision of Mr. Willans, who was a great master in the art of using indicators accurately, they were perfectly reliable. But it was a troublesome business to indicate engines, especially those of the high-speed type. At least four indicators were required simultaneously, and a well-trained staff was not always available; it was therefore desirable to have a method of analyzing the losses, at any rate in dynamos (not in engines) other than by the use of indicators. He had worked out such a method, which he would describe. It was very simple, and, as far as he had been able to check it, quite accurate. In justice to Mr. Hausmann, it should be mentioned that he had discovered a similar method quite independently of Mr. Kapp. It was used to separate certain losses that occurred in the dynamo. The mode of proceeding was as follows. The field of the dynamo was excited from a constant source of current to a constant degree, leaving the excitation current on throughout the whole test. A current was also sent through the armature causing it to revolve. The dynamo was then acting as a motor, but it was not doing any work. The power supplied in the shape of an electrical current went to overcome the losses occurring in the armature. These losses consisted of several parts, those due to friction and hysteresis being proportional to the speed, while that occasioned by Foucault currents was proportional to the square of the speed. By varying the electrical pressure the armature could be caused to run at different speeds, from the highest possible to that at which it just turned round and was on the point of stopping. To make the test he measured the highest current, and took a note of the speed; then measured a lower current, and found the corresponding speed, and so on, getting three or four pairs of values. On plotting the results, taking the speed as abscissæ, and the current as ordinates, it would be found that they lay in a straight line. The point at which this straight line cut the vertical axis showed the current which would be required to keep the armature going round at a very low speed. That was therefore the current necessary to overcome the torque of friction and hysteresis, which was not mentioned in the Tables, but which ought to be included, because it was a sensible cause of loss. If the current corresponding to the normal working speed were taken, and divided by the current corresponding to zero speed, the quotient would be the ratio of the total loss at the normal speed to the hysteresis and friction at the same speed; and thus the amount due to these causes could be immediately separated, since the total loss at normal speed could be obtained by multiplying the pressure and current observed. Attention had been drawn to the fact that there was no particular reason why the direct current should be economical and the alternating current uneconomical, provided the plant could be run in accordance with the demand; that was, if between four o'clock in the afternoon and eight o'clock they could run big steam-dynamos, and after eight o'clock smaller machines, or fewer of them. In small central stations supplying three or four thousand lamps, there was a certain advantage in having batteries, because the station could be shut about 1 A.M. In such a case it hardly paid to keep a staff working night and day, which required three shifts of men; but in a large station, such as at Berlin, the demand was so great even in the early hours of the day that it was more economical to keep a small dynamo running, and it would therefore be of very little advantage to employ storage. There was even a small station in London where the use of accumulators, he believed, would not increase the profits—he referred to St. James's, in which the amount of current required in the light-load hours was sufficiently great. With the alternating system they could not employ accumulators, and they were compelled to have a small daylight steam-alternator. In order to effect the greatest economy, they must use a variable number of machines according to the demand, and to avoid complication, they must work them in parallel. That brought him to a point as to which electrical engineers unfortunately were not of the same opinion. He did not believe that this was due to any matter of feeling between the advocates of the alternating and of the direct current, but rather to the fact that their ideas were not perfectly clear on the point, and to their want of practical experience. If one electrical engineer was asked whether he could run alternators in parallel, he would say, "Oh, perfectly; I have done it." Another man

Mr. Kapp.

Mr. Kapp. would answer with perfect sincerity, "No, it will not do." Mr. Kapp had had alternators in parallel driven from the same shaft without using synchronizers or any special devices, and they ran perfectly. He had received news from Switzerland of alternators driven in parallel by turbines. He had seen Mr. Mordey running two alternators in parallel with the use of synchronizers, the power being supplied from two independent steam-engines through countershafting. It was with the arrangement usual in central stations, namely, an alternator driven by ropes or coupled to its own steam-engine, that they found the diversity of opinion he had mentioned. As far as he had been able to ascertain, the alternators at West Kensington were running in parallel for a short time during the changing over, but not otherwise. At other stations the plan, he believed, had been tried and given up. The point to which he desired to draw attention was this: It would succeed very well to run alternators in parallel so long as the driving force was perfectly steady, but it should be remembered that the two machines must revolve at absolutely the same speed. If during part of a revolution one engine were to advance in front of the other it would tend to pull its alternator out of step. Whether this would actually happen depended on the construction of the dynamos. At any rate there would be a flow of power to and fro between the different machines and their engines. Taking an alternator with twelve poles, the distance between two poles was 30 degrees. If one armature were forcibly advanced by half this angle the alternator would go out of step. If it was driven by ropes, this forcible advance, reduced to the angular velocity of the engine, would be smaller in proportion as the speed was geared up. Taking as an extreme case an angular advance of the armature of 10°, and assuming that the ratio of speed between the armature and engine was as 5 to 1, the angular advance of one engine over its fellow would only be 2°. It was clear that no engine would have such a steady turning movement as that. The question whether the two would run in parallel or not depended upon whether there was sufficient give and take in the ropes and also between the different alternators. He should not like to rely upon that of the ropes, or upon the electrical give and take between the machines whereby each became alternately a motor and a generator, but should prefer to have two steam engines which would give a very even turning movement. He hoped Mr. Willans would state whether he thought that two of his new engines with three cranks could be run so that one should not lead in front of the other by more than about 10 degrees.

If he could fulfil that condition the whole difficulty of parallel working would be overcome. Mr. Kapp.

Mr. R. H. THORPE said that the absence of all matter of a highly technical nature in the Paper, was perhaps an invitation to those who were not electricians to discuss it. Mr. Crompton had laid particular stress upon the load-factor as influencing the cost of power production, and had referred to diagrams of work done in New York, showing that the use of motors had a very material influence upon the load-factor, especially in the business parts of the city. From that it was fair to judge that if motors were largely supplied from the mains at Kensington, or any other central station, the load-factor would be considerably higher. The largest call for mechanical power in the residential parts and in the City of London was no doubt for lift-purposes, and it might be interesting to compare the cost of electrical power according to Mr. Crompton with that of hydraulic power as used in London. To do so, he would take the figures given in a Paper[1] read before the Institution by Mr. Ellington in 1888. The cost of pumping water at 750 lbs. on a week's service was found to amount to 33·3 lbs. of water per pump HP. per hour, taking the water evaporated in the boiler at 9 lbs., as given in Mr. Ellington's Paper. This was equivalent to 44 lbs. of water evaporated at the boilers per electrical unit. The best yearly electrical results obtained by Mr. Crompton were stated at 64 lbs. of water evaporated per unit, which was much in excess of the cost of producing hydraulic power. The Author had, however, told them that if he could get such a load-factor as that shown on the New York diagram, or even less, he would be able to generate the unit with 36 lbs. of water evaporated, and this, it must be remembered, without condensing engines, which were used by the London Hydraulic Power Company. A better indication of the cost of the two powers would perhaps be given by a comparison of the terms upon which they were offered to the consumer. Electrical energy could now be obtained for mechanical purposes at 8*d.* per unit. Indeed, it was within his knowledge that as low as 6*d.* had been quoted in one or two instances. Taking an actual and representative case of an elevator working from the Hydraulic Power Company's mains, where the water bill amounted to £65 per annum, it came to 4*s.* 5*d.* per thousand gallons, equal to 6·3 pence per HP. per hour, or 8·45 pence per electrical unit, which was slightly in excess of the charge for the Mr. Thorpe.

[1] Minutes of Proceedings Inst. C.E., vol. xciv. p. 1.

Mr Thorpe. same amount of electrical energy, at the highest figure quoted for it. It seemed probable that the cost of generating and distributing electrical energy would be considerably reduced in the future. There was not the same evidence to show that greatly better results were likely to be attained in the production of hydraulic power by pumping-engines. Already a non-condensing compound Willans engine and direct-current dynamo was stated to give an efficiency of 85 per cent. of the power shown by the indicator diagrams. It was doubtful whether any condensing pumping-engines, working under the most favourable circumstances, would do much better. These figures placed electrical power for lift service at once on a par with hydraulic power, provided that such work could be as well performed by it. Electricity had, however, one great advantage. It was well known that hydraulic machinery used power out of all proportion to the load or the service which it was required to perform. The machinery must be designed to do the maximum called for, and must consume the same amount of power whatever work was done. In passenger elevators the average load did not probably amount to more than one-third, or at any rate, one-half of that for which the machine was designed. Electrical elevators as now made, were consuming power very nearly in proportion to the work done, so that electrical power was in advance of hydraulic power in regard to the cost of running for all mechanical purposes. There was little difference between the loss of power in distribution in electrical and hydraulic mains; the balance, if any, was slightly in favour of the latter. It was recognized, when electrical elevators were first considered, that they must be something different from machines which were put in and out of gear by the shifting of belts or other means. Such would be fatal to safety and smooth running. The putting in and out of circuit of the electrical energy itself was a *sine qua non.* He did not propose to describe an electrical elevator, but in order to prove that the load-factor could be considerably increased, and the cost of production reduced to a corresponding extent by fostering the use of motors, it was necessary to show that electrical power was in the market for such purposes, not only on the basis of cost, but also because there was machinery capable of utilizing it. In the opinion of the builders, the Otis electrical elevator was as reliable and as good for certain classes of service as the hydraulic elevator which had borne that name so long, and this opinion must be considered valuable as coming from a concern whose chief interest was in hydraulic machinery. The motor for any lift-service must form part and parcel of the lifting machinery. Mr. Eickemeyer, of New York, whose name would be known to many electricians, had designed a motor which was so connected. All difficulties of "burning out" had been overcome, and ample provision made for safety in working. There were now from fifty to one hundred electrical elevators in the United States, the greater part of which had been put up during the last year, with the exception of two or three which were running previously purely as experimental machines. The motor used was shunt wound. To start in any direction, the current was first admitted to the field winding to excite the field. It was then gradually put into the armature circuit. In order to meet the difficulty of "burning out," a self-acting safety device was used, by which external resistance was included in the armature circuit so long as the current which it would otherwise receive was beyond the limit of safety, as would happen if the car were jammed so that it could not move. As the motor started, the external resistance was automatically reduced, and in order to stop, it was put in again, and the current gradually taken first out of the armature circuit, and then out of the field. A comparison of the load-diagram of the Power Company, published in Mr. Ellington's Paper, would show that the maximum supply of power for motors was at those times of the day when the demand for lighting was at its smallest, and it was apparent, therefore, that if motors were used in sufficient numbers for lifting-machinery, they must, as had been the case in New York, materially increase the load-factor by giving a better average of work. This would be particularly so in the City, and also—though to a less extent—in the West End. Electrical energy would probably never take the place of hydraulic power for certain classes of lift-service, and the Hydraulic Power Company need fear nothing but healthy competition from it, but that it could be used with equal safety was to-day a demonstrated fact. Mr. Thorpe.

Mr. JOHN S. RAWORTH agreed with the remarks of Mr. Preece, Professor Forbes, and Mr. Kapp, but thought the observations of Mr. Thorpe scarcely relevant. They were discussing a much broader question than the mere application of electricity to purposes of passenger- or goods-hoists. He did not see how the introduction of electrical power for the driving of motors would very much improve their position in the matter of flattening the load-diagram. He had had to consider the question of the lighting of the City of London, and it appeared to him that one of the most serious drawbacks they had to face was that the load-diagram, as constructed for the demands for lighting, would Mr. Raworth.

Mr. Raworth. naturally overlap that for the supply of motive power. For instance, in such a case as the lighting of the City of London, he presumed that the hours of maximum supply in winter would be some time between three and five o'clock. It was obvious to every one that if they had motors working electrical hoists, or elevators, for the purpose of carrying on trade or manufacture, they also would be in full use at the same time; and instead of being able to employ the plant in driving electric motors during the hours of minimum supply, they would have to put down additional machinery, so that when the time came, say between three and five o'clock, that the two diagrams overlapped, there might be sufficient plant to provide the current both for the power and the light. The question of supplying motive power from electric generating stations, was an entirely different problem, and must be considered upon its own merits. With reference to the subject of working alternate-current machines in parallel, he might mention that at the Bournemouth Brush Electric Light Station there was a small plant, consisting of one large alternator and two small ones, each half the size of the first. The plant had been designed with the idea that the large alternator should be the unit which they would repeat as required to fulfil the conditions of lighting the town, and that the two small ones should be used to supply the daylight service. There was an advantage in having two alternators half the size of the large one, so that in the event of breaking down, they might be synchronized and used in place of it. Mr. Kapp appeared to be under the impression that alternators were only occasionally put in parallel for the purpose of changing over from one dynamo to another. At the station worked by the Brush Company at Bournemouth, the load every evening exceeded the capacity of one dynamo, and as there was no provision made for working the alternators in any other manner, the man who attended to the station had no option but to run them in parallel, and did so every night. The matter was one of the greatest ease and simplicity. The dynamos were synchronized in about two minutes, and the moment the switch was closed by a string which pulled the trigger, they interlocked as intimately as two cogwheels. The idea expressed by Mr. Kapp that there were certain conditions of driving due to the irregularity of the engine which might cause one dynamo to break out of phase with the other, was in his opinion absolutely erroneous. They had tried everything they could do to break the two dynamos out of phase and had utterly failed. They had gone to such an extent that if

Mr. Raworth. their experiment had been continued much further the dynamos would have been destroyed; yet they could not break them out of phase. It appeared to him to be a condition of affairs very similar to that in which there were two spur wheels geared together. As long as the teeth would stand, the two wheels would drive at exactly the same speed. With regard to the opinion expressed by Mr. Kapp that it was desirable the engine should not vary more than a certain number of degrees from its normal speed during a revolution, Mr. Raworth would remark that on the occasion of Mr. Mordey's Paper, when Professor Sylvanus Thompson raised the question, he had an experiment tried in which he found that the total deviation of an alternator, from being a generator at full load, to becoming a motor at full load, was only some 30° of the phase, or about 3° of the entire circumference of the armature. The result was that with two alternators working in parallel, if there should be a deviation of one of them to the extent of 30° of the phase or 3° of the circumference, and 1° of the engine, it would be changed entirely from a generator to a motor, so that the total power of the dynamo would be concentrated upon pulling the engine round with it. Further, in the dynamos under consideration there was a mass of 4½ tons mounted upon a spindle revolving at 500 revolutions a minute. It required no words from him to show that if the engine did not go fast enough that revolving mass would pull it along; for at that speed the rate could not vary by any great number of degrees within a revolution.

He had looked carefully through the Paper and tried to understand exactly what the Author recommended in the way of boilers. He understood that Mr. Crompton was employing a considerable number of Babcock boilers, and as Mr. Raworth also had a considerable number of those boilers in use, and was putting up more, he was much interested to find that Mr. Crompton had some other recommendations to lay before the meeting. In the first case he had a boiler of which he was the inventor. He also spoke highly of the Mills' boiler, of which his firm were the accredited agents for London. He further recommended even more strongly the ordinary type of Lancashire boiler. If Mr. Raworth read the Paper aright Mr. Crompton had said he could not quite understand how it was that electrical engineers had not been more ready to use Lancashire boilers for the purpose of electric lighting. With regard to that, it was only necessary to point out that they contained for a given amount of power a volume of water about four times as great as was required for an ordinary water-tube boiler, such as those of the Babcock type; and as it was well known that the conditions of electric

Mr. Raworth. lighting were such that they had from time to time to bring into play additional boilers, it became a matter of the first consideration that they should not have to heat up to boiling point too large a mass of water, or they would immediately introduce conditions which were directly opposed to economical working. The next point appealed strongly to his mind, namely, that the Lancashire boiler required fully twice the amount of ground area occupied by a water-tube boiler. They could not shut their eyes to the fact that in putting down a lighting station to last forty years it was necessary to look forward to the time when those boilers would be so deteriorated that they would have to be pulled out. It was necessary to allow a space in front of the boiler equal to its total length, 30 feet, in order to get it out of its seating, turn it round, and take it out of the station. He thought that those conditions were absolutely impossible in London, and very difficult in a great many towns where they were called upon to put up lighting stations. According to his experience, the Babcock boiler, taking it all round, was a good, substantial, fair-working boiler, and although he had never carried out any very accurate tests as to its efficiency, he considered it to be quite on a par with the average boiler, such as that recommended by Mr. Crompton, and at the same time it could be got into a smaller space, and required much less fuel to heat the included water to the boiling point. With regard to the recommendation given by Mr. Crompton to use the Willans' engine, Mr. Raworth had put in a great many of them, and looked forward to putting in a great many more. He considered that Mr. Willans had given them a most valuable invention. In the earlier days of electric lighting they had dynamos running at 1,000 revolutions and upwards, and they found great difficulty in inducing a steam-engine running at say from 100 to 120 revolutions to keep up a continuous rate so as to maintain a steady light. Then Mr. Willans and Mr. Brotherhood came upon the field and said, "Send us your dynamos, put a mark on them showing how fast they have to run, and we will do the whole work for you." They did it very effectively, and Mr. Willans had gone on improving his steam-engines to such an extent that they now worked with a very small consumption of coal. There were, however, other makers who would undertake to produce steam-engines quite as effective in that respect. He referred to Mr. Paxman and Messrs. McLaren, of Leeds, who had both achieved a prominent position in the matter of making small engines to give a high efficiency. But when they went further and considered not merely the question of

Mr. Raworth.

lighting up small districts in London, such as the parishes with which they were all familiar, bounded by a line beyond which they could not go—Kensington, Knightsbridge, Chelsea, &c.—but how they would deal with such gigantic enterprises as were at present represented in the gas industry by the Beckton Works, he thought that the Willans' engine would become an absolute impossibility. In the lighting of the City of London it had several times been suggested to him to use the Willans' engine. He might mention that taking as the unit 800 HP., which he thought was considerably beyond anything that had been so far designed in that type of engine, they would require, including the engines for the public lighting of the City, which were of 110 HP. each, twenty-four engines, and that with the Willans' engine would mean one hundred and forty-four pistons, one hundred and forty-four metallic packed stuffing-boxes, and two hundred and fifty piston-valves separately packed. In all they would have to look after some five hundred sets of metallic packings. That might not be an appalling figure to Mr. Willans, but to his mind it was distinctly appalling, and he should not like to go into the lighting of London with that enormous number of packings of an automatic character to look after. Mr. Crompton's figures with regard to coal appeared very high from an ordinary engineering point of view. Twelve months ago Mr. Raworth imagined that they could estimate the consumption of coal in a lighting station by first finding out how many horse-power hours they would have to use, then settling upon the amount of coal per horse power, putting on the necessary allowances for loss in the leads in the dynamo and so on. But one day he called upon a friend who was the manager of a large electric lighting station. It happened, luckily, for his argument, that his friend had bought his machinery from Messrs. Crompton, Siemens, and Willans, and he used Lancashire boilers. "Do you know," said his friend, "what it costs to run a lighting station with coal?" He replied that he had not the faintest idea. His friend then showed him the books, and he found that in summer they did it with 26 lbs., and in winter with 20 lbs. of coal per unit sold to customers through the meters; and that was the best they had been able to obtain so far. In that particular station they had the advantage of supplementary accumulators for use during the light-hours of the day. It struck him as being so remarkable a result that he began to make inquiries; and at another station where they had the Willans engine, Babcock boilers and accumulators, he found the amount of coal consumed for each unit passed through

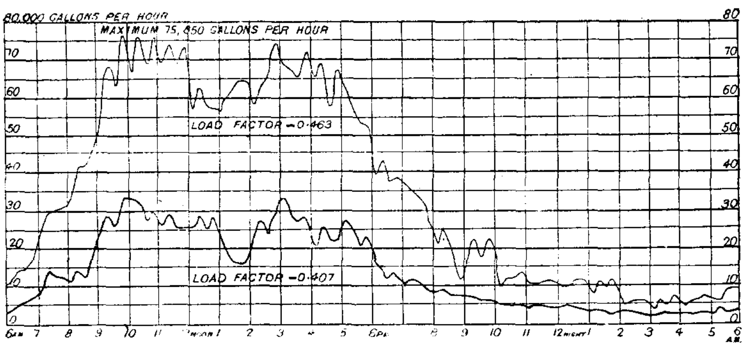
Mr. Raworth. the customer's meters was 19 lbs. That agreed pretty well with the other result. In one of their own lighting stations, where they had the Babcock boilers, their own dynamos, and vertical engines not of their own make, and also accumulators for the light-hours of the day, they used 22 lbs. of coal per Board of Trade unit supplied to the customer. Those were cases in which he had an opportunity of getting accurate results, as in all three stations meters were employed. If Mr. Crompton had got the good results which he stated in his Paper, he had opened before them a new era in which they would have better prospects of making good returns to their shareholders.

Mr. Ellington. Mr. E. B. Ellington wished to express his appreciation of the happy term "load-factor." Other speakers had stated that they could not quite understand what Mr. Crompton meant by it, and Mr. Ellington had experienced the same difficulty. So far as he could gather from the Paper, the Author appeared to have made his calculations on the assumption that the denominator of his load-factor fraction represented the maximum output provided for in all the steam-dynamos at work at one and the same time. But he had also spoken of the diagrams as being load-diagrams, and had then given as the denominator of his fraction the observed maximum of all the load-diagrams of the year, the numerator being the average of those load-diagrams. There was a material difference between the two ways of regarding it, and he submitted that the last definition was more generally applicable. Of course, the yearly load-factor would be the most valuable, as affecting the question of cost; and he would suggest that the best definition would be: the ratio of the average output per hour into the mains during the year to the maximum output per hour into the mains during the year. If that definition were accepted, the evil of a low load-factor was common to every system of supplying energy, whether electricity, hydraulic power, gas, or compressed air; and there were two ways by which it could be minimized, so far as regarded the cost of fuel, and a few other station expenses, namely, by the employment of storage, as in the case of gas, and partly in the case of electricity, or by the multiplication of prime movers. In these respects there would evidently be room for great variety of practice. It appeared to him, however, that unless the particular definition which he had suggested, and which Mr. Crompton had perhaps intended, were adopted, it would be necessary to have a separate one for every system, which would lead to a great deal of confusion. Then it had been suggested that the denominator of the load-factor might

Mr. Ellington

be the total output capacity of the plant, including all reserve plant. That, again, was a very varying amount, because it would depend so largely upon the temperament of the engineer who was responsible for the work. For these reasons he had adopted the load-factor represented by the average during the year in relation to the maximum at any time during the year. It might be useful to refer to the load-curves of the hydraulic-power supply in London. In *Fig. 8* the lower curve was taken from his Paper on the subject read before the Institution three years ago;[1] and the upper curve was constructed from observations made about ten days ago. He wished to point out one or two peculiarities about them. The maximum of the upper curve was at the rate of 75,850 gallons per hour, and the load-factor for that curve for the day was 0·463 or 46·3 per cent. The maximum for the lower curve obtained three years ago was 33,750

Fig. 8.



LOAD CURVES; LONDON HYDRAULIC-POWER.

gallons, and the load-factor was 0·407. Notwithstanding they had such a high load-factor for the day the load-factors for the last three years were as follows:—1888, 0·296; 1889, 0·329; 1890, 0·327. The chief reason why the load-factor for the year was so small in relation to that for a typical day was that they could only get such curves as were shown in *Fig. 8* for about two hundred and eighty days in the year, Saturdays and Sundays and holidays being very light days. Another reason why it was smaller than would otherwise have been the case was that there had been a rapid increase in the total supply, so that the maximum was always at the latter end of the year. The

[1] Minutes of Proceedings Inst. C.E., vol. xciv. p. 16.

Mr. Ellington. figures for the three years were:—1888, 123,000,000 gallons delivered with a maximum delivery in one hour during the year of 46,000 gallons; 1889, 164,000,000 gallons delivered with a maximum of 57,000 gallons; 1890, 206,000,000 gallons, with a maximum of 72,000 gallons delivered. The rate shown on the diagram was about 250,000,000 gallons a year. They began the year 1890 therefore with a maximum per hour during any day of 57,000 gallons, and ended it with one of 72,000 gallons; the load-factor therefore was abnormally reduced. But on the other hand the load-factor of about 33 per cent. was higher than it would be in consequence of the large area which was supplied with power from the same centres. The area embraced the East End of London, the City, Southwark and the West End. It would be observed from the diagram that the West End power came in to fill up the gaps, and made the percentage higher than it would otherwise be. The diagrams did not exactly correspond with Mr. Crompton's, because his began at midnight, while they started at six o'clock in the morning. At nine o'clock there was a rapid rise, the maximum being about eleven. That was due largely to power supplied in the City to the docks and warehouses and the wharves along the river side. There was a sudden drop at twelve o'clock, which continued till two o'clock, or half-past two—meal time. Then in the afternoon they approached the maximum, which was often reached as late as four o'clock, and sometimes later. The two periods of greatest demand were between ten and eleven o'clock in the morning, and three and five in the afternoon. Shortly after four o'clock there was a drop which represented the stoppage of the bonded warehouses. Between five and six there was a further rise, due to the increased demand at the West End. Comparing the lower diagrams with the upper, it would be seen that the curves were much the same. There was exactly the same dip at four o'clock, and then a further rise for the West End demand. It appeared from the lower diagram that there was not then much used at the West End. The increase after six o'clock in the upper curve was due almost entirely to residential and West End demand. He particularly wanted to point out that the points of maximum demand for power would overlap the points of maximum demand for electric lighting, and he failed to see how the supply of electric power for lifting would materially increase the load-factor. The load-factor given by Mr. Crompton for the St. James's and Pall Mall electric lighting was 0·24 or 24 per cent. for the whole year. In order to see the effect of the combined system, it would be

Mr. Ellington.

necessary to plot a curve for the power supplied; and he thought it would be found that the load-factor for that district would be below 24 per cent., in which case no advantage could accrue in that respect. It so happened that they had at Kensington Court, within a stone's throw of Mr. Crompton's installation, a power-supply, which was employed exclusively for domestic or residential purposes. The load-factor at Kensington Court station for the last year was only 0·118, or 11·8 per cent. Mr. Crompton's load-factor for the electric lighting of the same district was, he believed, 0·076 or 7·6 per cent. So that, taking into account the small amount of power required for working lifts and other purposes in that neighbourhood as compared with the large amount of current used for electric lighting, and further considering that the period of maximum demand for the power in Kensington was about six o'clock in the evening, it would be seen that the supply of electric power for such purposes would have no influence in raising the load-factor. Some remarks had been made during the discussion with reference to the relative cost of electrical power and hydraulic power. He did not propose to enter minutely into the question, but it appeared to him that there was no real reason why there should be any difference between them. With electrical power the efficiency of the steam dynamos had been given at over 80 per cent.; the efficiency of a hydraulic pumping-engine was from 80 to 84 per cent.; there was no apparent reason, therefore, why there should be any greater cost in regard to the station, coal, and other running expenses, in the one case than in the other. He could not understand why the cost of producing the same amount of energy hydraulically, taking the same items as Mr. Crompton had given, should be rather less than half, though it certainly was so. The only difference he knew of was that they were using condensing engines, but that was hardly sufficient to account for it. Up to the first week in April, 1891, the power supplied was entirely obtained by Lancashire boilers. In their new station at Wapping they had adopted triple-expansion engines with 150 lbs. of steam and a different type of boiler, but their relative economy had not been determined. They used mechanical stokers, which worked with perfect regularity, and without any difficulty at all. They also employed Green's economisers, and cheap small coal. Whether those facts combined had anything to do with the result he did not know. The variations in the demand and the load-factor were much the same as in the case of electric lighting, and he thought the cost ought to be so likewise. There was no reason to suppose that

Mr. Ellington. electric power would be used largely for lifting-machinery. With regard to the cost there was no advantage, and as to mechanical arrangements, the hydraulic machine was generally admitted to be the perfection of simplicity, safety, and certainty of action.

The Hon. C. A. Parsons. The Hon. C. A. Parsons desired to make a few observations in regard to the working of the Newcastle and District Lighting

Fig. 9.

Newcastle and District Electric Lighting Company, Limited.

——— Diagram taken December 25th, 1890.
——— " " April 14th, 1891.

Station. It had been running successfully in every respect for sixteen months, and there had been during the last six months the

The Hon. C. A. Parsons.

equivalent of nine thousand ten-candle-power lamps coupled to the mains. The distributing current was 1,000 volts alternating, and the transformers in use were chiefly those of the Electrical Construction Company. The running-expenses for December, 1890, which had been remarkably small for a station of that size, amounted to 1·5*d.* per unit sold, the items included being taken on Mr. Crompton's basis. This low cost was chiefly due to the simplicity and completeness of the arrangements, and to the careful management. Four steam-turbine alternators each of 75 units capacity were used, and the coal consumption for the last six months averaged 22·5 lbs. of small cheap coal per unit sold. He thought that Mr. Crompton should have included rates and taxes, and other items also as belonging to the running cost of a station. He had made some experiments on the loss in the transformers and had found it to be between 20 and 30 per cent. of the total energy generated; he also estimated that the loss when running without load was 2½ per cent. of the total power at full load; these two figures agreed closely when the average lamp-hours were taken into consideration. The two load-diagrams in *Fig. 9* were for a heavy day in December and for a light day in April.

Mr. Willans.

Mr. P. W. Willans said that Mr. Crompton had given most interesting figures for the coal and water used in an electric-lighting station in every-day work. When he first saw them he expected it would be his duty to apologise for his share in them, because they appeared to be so exceedingly bad. As lighting stations got regularly to work, and as the variation of the load throughout the day became known and the management of the machinery to meet it was better understood, it would be seen what an effect the running of lightly-loaded engines had, and the figures given by Mr. Crompton would, he believed, come down enormously. He had been astonished to find, from the remarks of Mr. Raworth, that they had been doubted on the ground of being too good. It appeared to him that they were so much worse than they would be in future that he could only apologise for them. He had nothing to do with the particular trial referred to in the Appendix, but starting from the figures there given it appeared that with engines which were proved to be using less than 22 lbs. of water per indicated HP., taken over the varying loads during an average day's run, 7 or 8 lbs. of coal per unit was found to be consumed during a month. That wanted some explanation. Almost any amount of water and coal might be used in an electric-light station if they went the right way about it. It was simply a question of

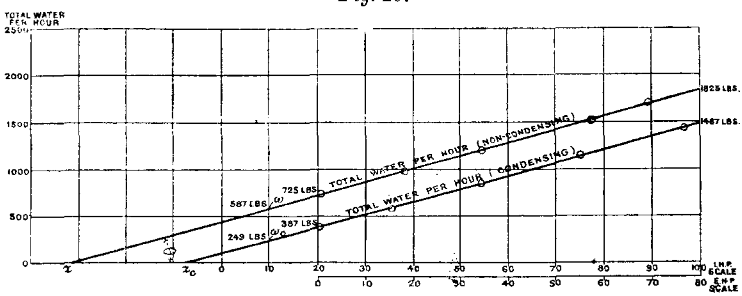
Mr. Willans. working the engines and boilers with a sufficiently low load, lighting up the boilers often enough, and running them for a sufficiently short time. It depended almost entirely on the management of the station, and at those which had been going longest the figures had been steadily coming down. The Kensington Court Station had been at work as long as any in London, and the figures there were perhaps lower than in any other, in spite of the disadvantage which Mr. Crompton mentioned of having the older form of Gramme machines. He had no doubt, however, that even these would be improved upon ere long.

He should like to explain how greatly the light-loading affected economy, and why it did so, especially in the case of non-condensing engines. Mr. Ellington had mentioned that the cost of hydraulic power was in his case about one-half that given for electrical power by Mr. Crompton. Mr. Willans found, broadly speaking, that at full power, using the same engine, condensing or non-condensing—that was, not using the very best engine for either case, but one capable of working both ways—an economy of 18 per cent. of the feed-water was effected by the use of condensers, while at smaller loads as much as 40 per cent. might be saved. Mr. Ellington had asked why in electrical work as high a figure was not obtained as in hydraulic work. The simple reason was that hydraulic engines were always working at full load per revolution, although not running at the maximum speed. They would not work quite as economically at very low speeds as at higher ones, because there was more condensation when they were working more slowly, but this was not a large matter compared with the fatal effect of running at a light load per revolution. They had to deal in electrical work with an engine running practically at full speed at all times. They might reduce the speed at light loads 10 or 15 per cent., and that was a very good thing to do, but the engine when running lightly loaded was running with a very low load per revolution, do what they might, and the result in the case of a non-condensing station meant an enormous addition to the cost of coal and water. That was the real question that those who managed lighting stations had to face; and that was why he had for several years advocated the use of a number of engines rather than one or two large ones. Years ago he had only blindly gone at it because he thought it was the right thing; but now he had exact figures which fully confirmed what he had said on the subject. In common with others who had spoken, he thought that the term "load-factor," used by Mr. Crompton, was exceedingly useful. But in electric-lighting stations there were three load-factors to consider. Mr. Willans. First there was the proportion which the load on each engine individually bore to the full load of that engine. That was the load-factor which mainly affected the water-consumption. If the engine was running at half-power and full speed, it was using considerably more water per electrical HP., and this was particularly the case with a non-condensing engine. Then there was the load-factor of the boiler. As an engine must necessarily use a certain quantity of water, even if it was only turning itself round, so in a boiler they must burn a certain quantity of coal, whether the boiler was doing useful work or not. That was a matter as to which he had very few figures, and probably electric lighting was the first case in which the paramount importance of keeping down light-loading, both of engines and of boilers, had come to the attention of engineers. A mill engine was always running at full or nearly full load; but an electric-lighting engine, unless the number of units in the station was carefully considered in relation to the load, was rarely running at full load. The third load-factor, viz., the relation which the average load bore to the full output of the station if all the engines were at work, affected the financial result, because a small load-factor meant more capital lying idle, but did not affect the cost of each unit made.

It had been suggested by Mr. Crompton that in a London station a part at any rate of the work might be done more economically if a certain proportion of condensing plant were used. Mr. Willans had tried the experiment not long ago in a manner which would occur in every-day work, in order to ascertain what the gain would be at the various loads if a condenser were added in the case of an ordinary engine in a London electric-lighting station. Probably there would not be enough water to work all the engines so, but the question was what gain could be got by condensing in the case of each unit, whether by air-condensers or any other way? He proposed to show what the effect would be of simply adding a condenser—both at full loads and at low loads. He had plotted the results on a form of diagram which had made the matter exceedingly clear to him, and which he believed was new. In order that the figures might be as simple as possible he had reduced them so as to apply to an engine of 100 indicated HP. at full load. The trial was made with a rather larger engine, and the figures therefore must not be taken as absolute, but this did not involve any appreciable error. In the diagram (*Fig. 10*), the base represented horse-power, and the vertical ordinates, the total water

Mr. Willans. used per hour at each horse-power. The revolutions were assumed to be constant throughout, and the power was varied by altering the steam-pressure. In an engine of 100 indicated HP., it was obvious that the lowest reading which could be obtained would be one at about one-tenth of the power, or say 10 indicated HP.; at this point the total consumption of water per hour shown on the diagram, when the engine was working non-condensing, was 587 lbs.; at 100 indicated HP., *i.e.*, at full load, the total consumption of water per hour was 1,825 lbs. If a straight line were drawn through the two points indicating the total water used at 10 indicated HP. and at 100 indicated HP., the consumption of water at any intermediate power was given by the point in the straight line vertically above the intermediate power in question. The various observations taken were shown by the small circles on the diagram, and it would

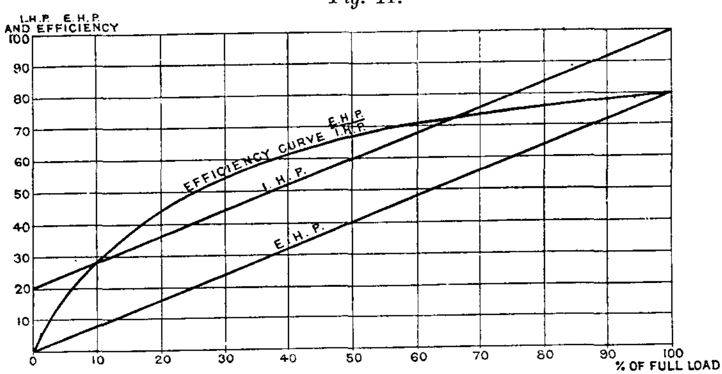
Fig. 10.



Total Water per Hour, Non-condensing and Condensing.

be seen that they fell sensibly in a straight line. This was in the case of an engine in which the expansion was not varied, but in which the power was altered by varying the steam-pressure. He would refer to the effect of varying the expansion later. Now this diagram showed a most important fact, if it was of general application—and this seemed probable, for he had now applied it to the results for three types of engines and it was true for all—it showed that with a fixed cut-off a certain quantity of steam was used to drive the engine doing no useful work, and that after that each horse-power added was obtained at a constant rate. This appeared to be true up to any steam-pressure which had been available for his experiments. In the particular case shown in *Fig. 10*, the water required to run the engine itself at 10 HP. was 587 lbs., and after that each horse-power cost 13·75 lbs. of water per hour. It would be seen that this meant very great waste at low powers, for at 11 indicated HP., or say 1 useful horse-power, the consumption would be 587 lbs. + 13·75 lbs., or 600·75 lbs. per useful HP. per hour. If they were considering the water used per electrical horse-power, the case was worse, for now before the engine did any useful electrical work it must expend power and water on exciting and driving the dynamo. As was well known, in a good dynamo the losses which increased with the load were very small, and in the case which he was considering he would assume that they did not increase at all—which in the best dynamos would involve an error of possibly 2 per cent. due to the excess of losses in the armature at full load over those at no load. Ignoring for the moment, then, this increasing loss, he would take the losses in the engine and dynamo as constant—as in *Fig. 11*, which showed Mr. Willans.

Fig. 11.



INDICATED HP., ELECTRICAL HP. AND EFFICIENCY.

the efficiency, at various loads, of an engine and dynamo giving 80 per cent. efficiency $\left(\frac{\text{E. HP.}}{\text{I. HP.}}\right)$ at full load (a little below the average efficiency in these days). The engine would then develop 20 indicated HP. before it began to do useful electrical work, and the scale of electrical HP. would therefore begin at 20 indicated HP., and reach 80 electrical HP. at 100 indicated HP. It would now be seen that the water per electrical HP. hour was the same as the water per indicated HP. hour, after the initial cost of running the engine and exciting and driving the light dynamo had been paid. The cost of generating *one* electric HP. was therefore—

(1st.) 587 lbs., the cost of running the engine light;

(2nd.) 10 × 13·75 = 137·5, the cost of exciting the dynamo;

(3rd.) 13·75 the cost of 1 E.HP.;

Mr. Willans. making the formidable total of 738·75 lbs. as the cost of the first electric HP. per hour in the case of a quite unusually economical non-condensing engine, viz., one which developed 80 electric HP. at a cost of 22·8 lbs. of water per electric HP. hour.

It would be seen that the straight line (*Fig. 10*), passing through the various points indicating water-consumption, did not cut the base line at the zero of indicated horse-power, but at a point z considerably to the left of it; and it would be asked what this meant? The answer was, that even in a frictionless non-condensing engine, the water required to run the engine light was still a large fraction of that required at full load, for the steam necessary to overcome the atmospheric back-pressure was even in such an engine an enormous source of loss. The distance between Z and 0 indicated HP. meant therefore horse-power wasted as truly as the 10 indicated HP. expended in friction was wasted. This loss was not due merely to the 15 lbs. back-pressure, but included incidental losses in the passages from the friction of the steam required to overcome the atmospheric back-pressure, and the vertical ordinate at 0 indicated HP. included not merely the steam required to overcome the back-pressure but the quantity condensed owing to the differences of temperature which even at that low power would be present. The total water used per hour at any given useful power might be expressed by the following formula:—

$$W = w + S \tan \theta \, H,$$

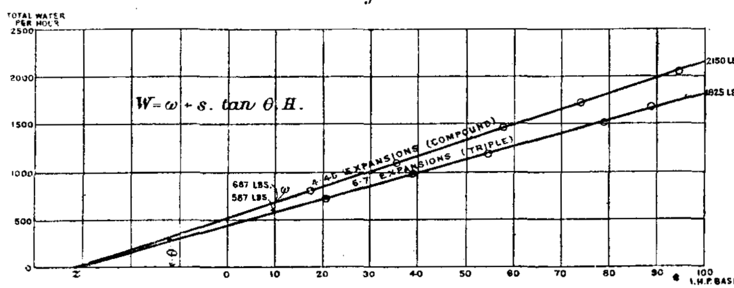
where W was the total water per hour at useful power H,
w was the total water per hour at zero useful power,
S depended on the relative scales of water and horse-power,
θ was the angle which the line passing through the points indicating total water-consumption made with the base line.

The two variables which affected the economy of the engine were w, the water required before any useful work was done, and θ, the angle which indicated the subsequent cost per useful HP. By the use of a condenser, z was brought nearer to the point of zero indicated HP. into the position z_c; in other words, the work of overcoming the atmospheric back-pressure was much reduced; consequently w, the water consumed before any useful work was done in an engine absorbing 10 HP. out of 100 HP. in its own friction, was lowered to the position w_c. Assuming the expansion to remain the same in the condensing as in the non-condensing

Mr. Willans

engine the only change in water-consumption was the reduced cost of running the light engine, each additional horse-power costing 13·75 lbs. of water per hour as before. The lower line on the diagram, like the upper one, was drawn through actually observed points which were marked with small circles. The same scale for electric HP. applied here as in the non-condensing trials. In the case of a dynamo in which the losses increased with the load, the scale for electric HP. would require adjustment, but it was unnecessary to go into this matter, as it only slightly affected what he had to say. The position of the point z in relation to the zero of indicated HP. being determined mainly by the back-pressure, the principal factor affecting the economy of different types of engine was θ. *Fig. 12* showed the total water-consumption per hour in the non-condensing trials given in *Fig. 10*, which were made on a triple engine, compared with the results of trials made on the same

Fig. 12.



VARIATIONS IN EXPANSION.

engine working compound with a smaller ratio of expansion. The lines drawn through the points indicating total water-consumption, cut the base line practically at the same point z. The angle θ which the line passing through the points of water-consumption made with the base line, was however considerably altered. It would be seen that w, the water required to drive the engine light, was increased in the compound engine to 687 lbs., as compared with 587 lbs. in the triple engine, and the rate of consumption per useful HP. subsequently became 16·25 lbs. instead of 13·75 lbs. A comparison of the two lines on the diagram showed the total gain which resulted from increased expansion and the improved conditions under which the steam was used in the triple engine. A further increase in expansion would give slightly better results still; for instance, with ten expansions, assuming that the steam-pressure available was sufficient at the higher powers to

Mr. Willans. drive the engine at full power, the angle θ would become more acute and the water-consumption throughout the whole range of power would be reduced. Beyond that point apparently there was not much gain by increasing expansion in the engine in question, the reason being that the loss due to initial condensation would be so much larger as nearly to balance the gain due to increased steam-pressure and increased expansion. He wanted to make it clear, however, that so far as his experiments had gone, they indicated that if under any particular conditions increased expansion showed a gain at full power, there would be a proportionate or nearly proportionate gain at all powers. This was shown by the water-consumption lines all radiating from practically the same point z, if the back-pressure against which the engine was working remained the same. Further experiment might possibly prove that they did not radiate from absolutely the same point, but it was not likely that the difference would be sufficient to affect the general deductions from the diagrams. He hoped at some future time to be able to explain the bearing which all this had on the question of reducing the power by varying the expansion, and why, in electric-light work, automatic cut-off engines rarely if ever gave any advantage economically; at present, however, he would only say that for electric-lighting purposes, to work at a low power had so very bad an effect on consumption, that it was absolutely necessary to arrange the units in a station so that they were always working at nearly full power. Under these circumstances it was a matter of no economical importance how the power was reduced. They might consider what happened if two half-loaded engines were used instead of one fully loaded. He would take two non-condensing engines and dynamos of the same power and efficiency as in *Fig. 10*, each giving 40 electric HP.; the consumption for each per hour would be—

(1st.) 725 lbs. required to drive the dynamo light;

(2nd.) $40 \times 13 \cdot 75$ lbs.;

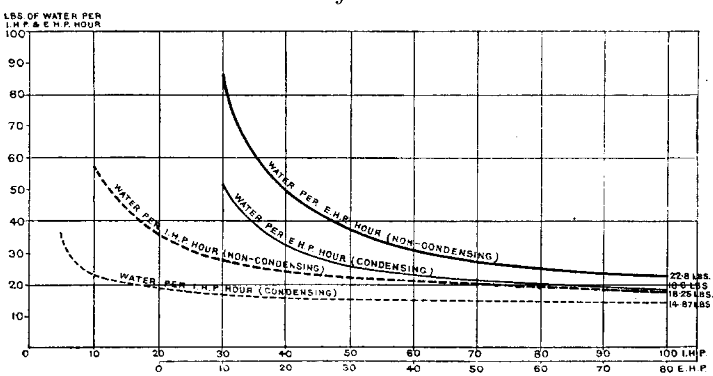
in all 1,275 lbs. per hour for each engine, or 2,550 for the two. The consumption of one fully-loaded engine of the same size would be:—

(1st.) 725 lbs. to drive the dynamo light;

(2nd.) $80 \times 13 \cdot 75$; in all, 1,825 lbs.

That was to say, running two non-condensing engines and dynamos when one would do the work, meant an increase of nearly 40 per cent. in the consumption of steam per unit of electricity generated in the best case, and more if they were run at less than half-load. With a condensing engine the increased cost under the same conditions would be about 25 per cent. instead of 40 per cent. In comparison with that all little questions of valve-gear and their effect when reducing the power were as nothing. The problem was not how best to reduce the power, but how to avoid reducing it. Mr. Ellington had raised the question when he said that with dynamos and engines having 80 or 85 per cent. combined efficiency, 80 per cent. of the indicated HP. ought always to be got at the terminals. That was all very well when working at full load, but if an engine and dynamo had a combined efficiency of 80 per cent. at full load they would have only about 50 per cent. efficiency at quarter load, and that was where the loss spoken of by Mr. Ellington came in. Even if the cost in steam were the same per indicated HP. at all loads, which was Mr. Willans.

Fig. 13.

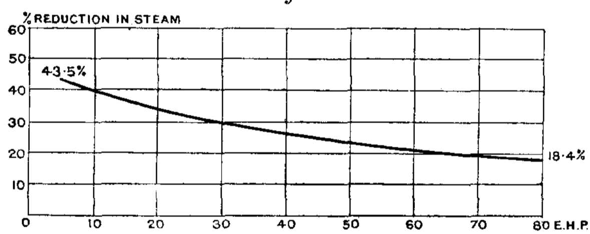


WATER PER I.HP. AND E.HP. HOUR.

obviously impossible, the consumption per electrical HP. would be increased at quarter load to eight-fifths of what it was at full load. In *Fig. 13* he had given, in the more familiar form of water per indicated HP. and per electrical-HP. hour, the figures from the same engine for which *Fig. 10* gave the total water per hour. From the construction of the diagram in *Fig. 10* it would be seen that the curves on *Fig. 13* were hyperbolas. The engine, if worked non-condensing used 22·8 lbs. of water per electrical horse-power at full load, and he thought that was nearly the best that could be done with a non-condensing engine. That same engine used 85 lbs. per electrical HP. at one-eighth electrical load. The condensing engine used 18·6 lbs. at full load and about 50 lbs. at one-eighth load; but 50 lbs. was so thoroughly bad that they did not want to work at one-eighth load if they could help it. *Fig. 14*

Mr. Willans. showed the percentage of steam saved at various loads in the same engine by the use of a condenser without any change in the ratio of the cylinders or of the expansion. Of course against this economy must be set the cost of condensing water, and the increased first cost of plant. There was a very great gain to be made by reducing the speed, instead of reducing the power per revolution, in cases where it could possibly be done; that would be to approach more nearly Mr. Ellington's conditions. If when they were doing half load they could work the engine at half speed, that would not make anything like the same difference in economy. Therefore it was a good thing economically to make an engine and a dynamo the speed of which could be reduced substantially as the load fell off. In the case of boilers they wanted to know what coal was used to do nothing. It was difficult to put the figures for coal-consumption together until they knew how much each different type of boilers took merely to keep up steam.

Fig. 14.



PERCENTAGE REDUCTION IN STEAM USED AT VARIOUS LOADS BY THE EMPLOYMENT OF THE CONDENSER.

He had been asked by Mr. Kapp what would be the variation in speed during each revolution of one of his three-throw engines, as an angular variation of about 10° might be allowed, and the alternators still be kept in step. As far as Mr. Willans could see, in his three-throw-crank engines the angular variation would not be more than about one-third of a degree if working against a fixed resistance, and it would be less when driving two alternators. If the fly-wheel on his engine shaft were revolving side by side with a fly-wheel running at an absolutely constant speed during each revolution, and if a mark were made on each, then the two marks would never be more than one-third of a degree apart, assuming that the engines were running the same mean speed. This was with his ordinary proportion of fly-wheel; the angular variation would be reduced if the engine were coupled direct to a heavy alternator, and might be still further lessened by increasing

Mr. Willans

the weight of the fly-wheel. So far as he could see, the figures which Mr. Crompton gave as to probable economy in electric-light stations ought to be reached—at any rate 4 lbs. per unit ought to be obtained in non-condensing stations. The remarks of Mr. Raworth had reminded him of the time when he began to make single-acting engines, and when people said it was a nice little two-horse engine, but no good for anything bigger. They had now gone on until a 200- or 300-horse-power engine was beginning to be the commonest size. He did not see why he should be tied to twenty-four engines unless that number was the most economical. There was no reason why a smaller number of larger ones should not be used if they could be kept well loaded. The question was not how big an engine could be made, but how big it was worth while to make it for any given electric-light station. Mr. Willans was now making engines of this type for cotton mills of 500 HP. and 650 HP.; but such large engines had not, up to the present time, been generally used for electric-light stations in this country, because it had not seemed probable that with existing load-factors it would be economical to do so.

Mr. Halpin.

Mr. Druitt Halpin observed that through the courtesy of the Directors of the North-Eastern Railway he was able to give some figures with regard to the consumption of coal at one of their small stations. There were three engines, but as the load was very light, only one of them was being used. The station was put up by Messrs. Latimer Clark, Muirhead & Co., who also made the dynamos and did the wiring. The engines were made by Messrs. Willans, and the boilers by the company themselves. The engine ran four hundred and ninety-six hours. The load-factor—that was, the ratio of the total output delivered to the total possible output of one engine—was 15·4 per cent. The coal per unit at the terminals of the machine was 7·26 lbs., and the coal per unit sold at the other end, allowing for all losses, was 8·35 lbs. To make the figures comparable with those in the Paper, he had reduced them by taking the value of the London coal, which was supposed to be the best South Wales coal, at 15,000 units. The other was common north-country coal of a lower quality, 13,500. So that the figures, as compared with the London ones, were 7·18 lbs. per unit generated, and 7·52 lbs. per unit sold. There was consumed, in getting up steam, 28·4 per cent. of all the coal burnt; the remainder was used for running. That gave a total evaporation, including the lighting-up and all losses, of 7 lbs., or an evaporation, when running, of 9·65 lbs., which, at the temperatures they were working at, was

Mr. Halpin. equivalent to an efficiency of 71·5 of the total heat in the coal. He might further say that taking the coal, wages, oil, and small stores, 4 per cent. interest on the capital, 10 per cent. for depreciation on the whole of the plant, mains, and machinery, and 5 per cent. on the building, the total cost per unit was 2·63 pence, exclusive of any capital charges in financing or rates and taxes.

Mr. Cowper. Mr. CHAS. COWPER said that Mr. Crompton, in common with many other electrical engineers, had fallen into the error of supposing that it was impossible to have a condensing engine without a large quantity of water. The importance of condensing, to obtain economy, was, he thought, to a large extent ignored. Speaking on broad principles, he would state the case as follows:—Let them suppose a compound, *non-condensing* engine to be indicating 200 HP., and let a third cylinder be added, so as to convert it into a triple-expansion *condensing* engine. It would then give about 300 HP. with the same steam, or 50 per cent. more power per lb. of steam used. It would naturally follow that to get the 200 HP. with the triple-expansion engine, only two-thirds of the number of boilers would be required. In that way he could save one-third of the cost of the boilers, one-third of the cost of the coal, one-third of the cost of the water, and one-third of the space. (He hoped it would be clear that he was not concerned with the actual number of cylinders, but merely with the principles of condensing and non-condensing.) With regard to the quantity of water which would be wanted for that condensation, if he passed the exhaust steam into a pipe, contained in a vessel through which a current of cold water flowed, he had simply an ordinary surface condenser; it was well known that it would require 20 lbs. or 30 lbs. of water passed through for every pound condensed. The steam had, in round figures, 1,000 thermal units in every pound to be got rid of. He took the water at, say, 50°, and heated it to about 100°; then he had 50° to use, and 50 thermal units could be carried away by every pound. It was obvious that it would require twenty times the quantity at least, as each pound of steam had 1,000 thermal units to give up, whilst each pound of condensing water could take up only 50 units. But supposing that, instead of enveloping the pipe in water, he had above it a perforated trough, through which he allowed the water to trickle over it, some would be evaporated by heat, and the rest would run off. He could then use his circulating-pump to pump the water over again; it would be warm, but that did not matter. The work done by the evaporating operation was, roughly speaking, 1,000 thermal units per lb., so that they had

Mr. Cowper.

1,000 thermal units of work done on 1 lb. outside, balancing 1,000 thermal units of work done on 1 lb. inside. A great many of those evaporating condensers were in use, but they were not as well known as they deserved to be. His father had employed them for many years, and a number of them were in work in London and elsewhere. They could be worked with dirty water, for none of it went into the boilers; it was merely pumped over and over again, and the quantity evaporating each time was about the same as the quantity of steam condensed. The shape of the condensers was merely a matter of detail; they were made by Messrs. A. M. Perkins & Sons in the form of a gridiron, consisting of a number of small pipes, with the water trickling over the outside. They were also made by Mr. Henry Cochrane, at Ormsby, in the form of two large cast-iron cylinders, one within the other, the annular space between being occupied by the steam while the water was allowed to trickle down inside. The air had free access to the interior as well as the exterior. They might have long pipes connecting them to the engine, and might be placed out in the yard. The cast-iron pipes were somewhat heavy; those made of small pipes, which might be of copper or wrought iron, could be placed on the top of the engine-house. Condensers of this kind, made of copper, were first used, many years ago, in connection with the manufacture of sugar, for concentrating syrup, which was applied to the outsides of the pipes, whilst steam from the "vacuum-pans" was condensed inside them. Since they had been made more cheaply of iron, many had been employed with steam-engines. An important advantage in using condensing engines for electric-light installations was that they would work economically under much greater variations of load than non-condensing engines; the latter, having always the atmosphere against them, were greatly limited in the amount of expansion which could be employed.

Mr. Hedges.

Mr. KILLINGWORTH HEDGES desired to make a few remarks with regard to what he had recently seen in a tour through Southern Italy, where he had the opportunity of looking at different central stations. One point with which he had been struck was that there was no development of the low-pressure system. Most of the new stations he had seen were using the high-pressure alternating current supply. Another point was that he did not find batteries in any central station on the low-pressure plan. At Milan, the Edison station, one of the oldest in Europe, showed an extraordinary increase. He visited it two years ago, and found there were 11,000 16-candle lamps, but now there were 19,000. There were then 210 arc lamps, and now there were 800, Mr. Hedges. of which 300 were in the streets. The company was very successful and paid a good dividend, although coal was 40 francs per ton. A more interesting station was at Venice, which was started last year and was rapidly developing. Small steam-dynamos were used, driven by tandem compound condensing engines; the alternator and exciter being on the same shaft as the engine, and driven by a flexible coupling. They worked in parallel much in the same way as those at Kensington Court. He could corroborate what Mr. Raworth had said as to the ease with which coupling in parallel took place; it was only a matter of a few moments. He was present when the daylight circuit was being augmented by another group of steam-dynamos. He took exception to Mr. Crompton's statement that "most of the specifications recently issued for the lighting of large towns on the Continent have been for a low-pressure supply, and both from the wording of them, and from the guarantees inserted as to the standard of efficiency in generating and distributing plant, it is evident that those who drew them up are of opinion that the efficiency of distribution of the alternating transformer system is considerably below that of the direct supply." The facts in Italy were exactly opposite. The stations at Venice, Leghorn, Syracuse, and Palermo, had been all started by the Edison Company at Milan, and if they had found that it was so uneconomical to work the alternating plan, they would certainly have not abandoned the Edison low-pressure system which they first initiated in the country. Mr. Crompton had made out a very good case for batteries. No doubt they effected a considerable saving in labour, but he should be glad to know what would be the difference in cost of a supplementary plant worked by a gas-engine, and also the cost of maintenance, as compared with a reserve of batteries. Mr. Crompton had mentioned the St. James's and Pall Mall Company as being one of the most economical of those using the low-tension system. He thought, however, it could hardly be taken as a fair example of what a large town required. In Brighton, for instance, a station was being erected somewhat similar to the St. James's and Pall Mall, except that it was not on the three-wire system. It was sure to be successful, but at the same time it only supplied, according to Mr. Crompton, a distance of 500 yards from the station. Brighton occupied a large area, and there were a number of persons there who would be wanting electric light, which it was only fair that they should have. If the Corporation were going to spend the ratepayers' money to give electric light in one portion of the town, the other districts would also require a supply, but he did not see how they would get one. If they were to put down a net-work of mains like those at Kensington, it would not pay. It did not seem to be paying at Kensington at present, and at Brighton the houses were of less value. It was only here and there that people wanted electric light, and if the Corporation undertook the supply, they ought to give the same facilities as were afforded by the existing electric company. If the distribution had been on the high-tension plan it would be so much easier to give a supply, as they could run to any point where there was sufficient demand in the most simple manner. The district would then be covered by transformer-stations which would gradually be increased, and perhaps after a time it might be better to start another central station. The objection to conduits seemed to be that two systems were required; one, an insulated cable and the other a bare conductor. Mr. Crompton had said that he found it impossible to run conduits everywhere. Mr. Hedges had lately gone into that question, and had found that he could not run them at all because there was so much interference with the services of gas and water. He would ask Mr. Crompton whether, in the comparative cost of conduits and cables, he had taken into account the drainage required, and also whether, in the upkeep, he had included the cost of keeping the drains in order. In the St. James's and Pall Mall Company that was a very serious item. After all the conduits had been laid down, drainage works had to be carried out, because they were so often flooded. He thought that Mr. Crompton was entitled to their best thanks for his valuable Paper, which, however, would be still more valuable if supplemented by one on the distribution of energy by the high-tension system. Mr. Hedges.

Mr. A. P. Trotter said that after he had placed a diagram on the wall, he found that others, giving much the same results, had been provided by Mr. Willans, who had not only said what he had himself intended to say, but had saved him from falling into a rather serious error by taking some information from the Paper which was of a misleading character. Mr. Crompton's curves in *Fig. 3*, giving the pounds of water per electrical HP. and indicated HP., appeared at first sight to resemble rectangular hyperbolas. He had plotted the products of the indicated HP. into pounds of water, against the HP., and the result was shown in *Fig. 15*. He referred only to indicated HP. The full line was the same as Mr. Crompton's lower curve, and was taken from his diagram. The slanting line gave the products of the HP. into the lbs. of water per HP., that was, the Mr. Trotter.

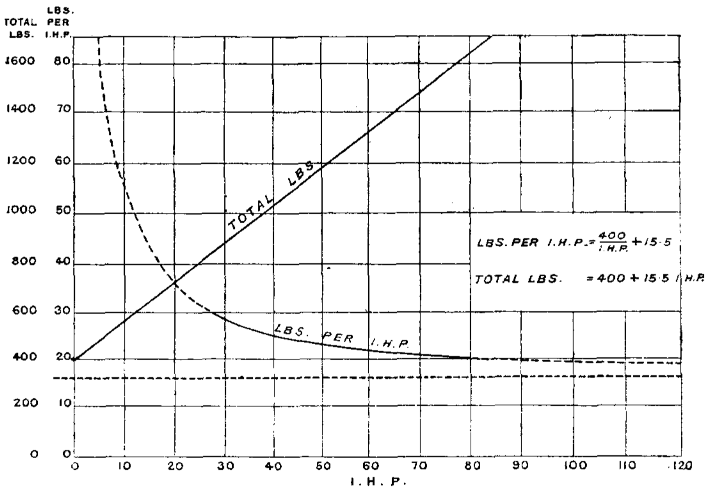
Mr. Trotter. total pounds of water at any given HP. From this slanting line it appeared at once that the curve was a rectangular hyperbola, and it gave an empirical formula for water per indicated HP.,

$$\text{lbs. of water per indicated HP.} = \frac{400}{\text{HP.}} + 15 \cdot 5;$$

$$\text{or, total lbs. water} = 400 + 15 \cdot 5 \text{ HP.}$$

These formulas possessed the advantage that the constants had some physical meaning. The 15·5 became the asymptote to the hyperbola, as shown by the dotted straight line. The 400 meant that if the engine was running at 400 HP. the consumption of water

Fig. 15.



would be 16·5 lbs. per HP. These results were obtained simply by the graphic analysis of the curve. By the help of the formula it was easy to plot the continuation of it in both directions, and this was shown by the dotted part of the curve in *Fig. 15.* These results were confirmed by the experiments of Mr. Willans, who had gone much further, and had developed them into the extremely important communication which he had just given. A similar analysis had been applied to the electrical HP. curve, under the impression that it related to lbs. of water per electrical HP., but the result, when plotted, gave a line partly straight and partly curved. He would not go into this, as Mr. Willans had informed him that "per electrical HP." on Mr. Crompton's curve (*Fig. 3*) meant that the length of any ordinate showed the water per electrical HP. when the engine was giving the indicated HP. represented by that ordinate, and the result would have to be multiplied by the efficiency to give the true amount. Mr. Trotter

As to load-factors, Mr. Willans had mentioned three kinds, and Professor Forbes had spoken of five. Mr. Trotter ventured, with the hope of ultimately simplifying the matter, to give three more, and thought that the upper limiting line should be carefully defined. Three different limiting lines had been employed, and the three kinds of load-factor were: plant load-factor, station load-factor, district load-factor. The plant load-factor was found by taking the circumscribed rectangle closely fitting the output curve. In considering the theoretical efficiency of the plant, or of any one unit of it, the plant load-factor for one day would be found to be a very useful basis of calculation. The station load-factor was limited by a line corresponding to the highest practicable output of the whole station fully loaded. Such a load-factor was important in considering the economy of the plant as a whole, and in analyzing statistics and financial results. It should be treated as for the whole year. Specimen curves might be selected, as had been done by Mr. Crompton, and one such as that in *Fig. 4* might be called a November station load-factor. There was, lastly, one other load-factor, namely, the factor of the district. That had been described by Mr. Frank Bailey before the Society of Arts in December,[1] where he took the top line as the total number of lamps connected, and showed in different districts considerable differences in the character of the output of the station.

Mr. W. Schönheyder wished to say a few words with reference to the consumption of coal by the machinery for producing electric light. So far as he knew there were not any condensing engines in use for driving electrical machines, especially in London, where coal was dear. He had been acquainted with the kind of condenser which Mr. Cowper had described for thirty years, and he was surprised to find how few persons had adopted it. Of course the cost was something, but it was not large in proportion to the benefit gained. According to theory, the amount of water should be about the same as that which was really condensed, but he knew several cases where the quantity was two or three times as large. Unless Mr. Cowper had actually measured it, his remarks might lead to a certain amount of disappointment. Few people paid for surface evaporating condensers, and they might expect to use for condensing water only a quantity equivalent to the steam condensed. Mr. Schönheyder.

[1] Journal of the Society of Arts, vol. xxxix. p. 51.

Mr. Stokes. Mr. WILFRID STOKES remarked that correct comparisons could only be made if the quality of the coal used at the various stations were also taken into account, as it was obvious that circumstances rendered it advisable in certain instances to use the poorer but cheaper kinds in preference to the best steam coal. A simple consideration, therefore, of the number of pounds of coal burnt at any station per Board of Trade unit delivered, would not give the true relative efficiency of the system used.

Dr. Fleming. Dr. J. A. FLEMING said that Mr. Crompton had confessed to certain difficulties in collecting reliable statistics and information as to the cost of distribution in alternate current stations. Dr. Fleming was in a position to give some recent information with regard to one of the largest and best managed alternating-current stations in Europe, viz., that in the City of Rome. Not long ago he returned from a second visit to Rome, where he had an opportunity of carefully examining the working of the electric station, which was now lighting a considerable number of lamps, and of obtaining figures as to the efficiency of the distribution. The electric lighting of Rome was conducted by the Gas Company, who some time ago had the foresight to realize that they would have to reckon with electricity either as a friend or as an enemy, and therefore adopted the wise course of undertaking to be the suppliers themselves. The fuel used was the coke produced in the manufacture of the gas; in a certain sense therefore it might be said that in Rome electricity was one of the waste products of gas manufacture. After careful consideration, the alternating-current system had been adopted, and the whole plant was put up by Ganz and Co., with alternators and transformers designed by Messrs. Zipernowski, Déri and Blathy, and the general arrangements of the station had been thought out with great care and with a view to economy of distribution. At present they had in the station in the Via di Cerchi, four large 600 HP. dynamos by Ganz, and two smaller ones of 250 HP. each, and they supplied an alternating current at a pressure of 2,000 volts to three trunk mains running in different directions through Rome. The dynamos could be worked perfectly in parallel or singly, either four large ones together, or the large and small machines in any combination. They had an elaborate and ingenious switch-board by which the dynamos were combined on the trunk mains or worked together in parallel. The current was conveyed by the trunk mains to certain transformer centres; and the company had early recognized the importance of having a low-pressure distribution. Although the great flexibility of the transformer system lent itself well to pioneer electric lighting, yet in order to obtain economy it was necessary at a certain period of the supply to distribute from sub-centres at a low pressure; and the current taken by the trunk mains was now conveyed partly to separate transformers and partly to certain groups of transformers placed in some of the large buildings in Rome, in the Houses of Parliament, and in some of the large theatres and other places. On each trunk main there was a recording watt-meter, an ingenious device of Prof. Mengarini, which automatically drew the load-diagram, so that a simple inspection of the curve showed what it was at any instant. It was integrated every day, and gave the output at the station in watt-hours. In addition to that there were similar recording watt-meters in each of the transformer stations. When first they began to work they supplied on a distributed transformer system; then afterwards grouping the transformers into centres, and supplying them with recording watt-meters which drew the load-diagram of the transformer station, they were able to obtain accurate comparisons between the number of units sent out from the secondary circuits of the transformer stations and of units generated in the station, and by adopting a practice of disconnecting the transformers during the daytime and during the hours of the night when the diagrams showed that the load was light, they had been able to bring up the efficiency of distribution, as Mr. Crompton called it, from 50 or 60 per cent. to something over 90 per cent. Some of the curves which he was shown indicated an efficiency of distribution on certain days of 93 per cent. That had been achieved only by a system of disconnecting the transformers when they were not required. In the clear and constant climate of Italy it had been found possible to effect that process by hand. They had two men who went round and disconnected them at the hours when it was known that they were doing no work, or that the whole bank of transformers was not necessary for the supply. Such a method, however, would be inapplicable in the treacherous climate of England, where total darkness would sometimes come on at five minutes' notice at eleven o'clock in the morning; and sooner or later it would be necessary to adopt some system of automatic disconnection—some method by which the transformers grouped in parallel at the different sub-centres would be disconnected from the primary circuits, according as the load on the secondary circuit decreased. By having transformers of appropriate size they would be able to connect them singly or in groups, and thus keep those on the Dr. Fleming.

Dr. Fleming. circuit up to their full load. Another point to which they had paid considerable attention in the new hydraulic station at Tivoli, which had been designed for transmitting 2,000 HP. from Tivoli to Rome by overhead high-pressure distribution, was the question that had been touched upon by Mr. Willans—the choice of a suitable dynamo unit. They had recognized that for a station supplying, like that in Rome, 24,000 lamps, a unit of 600 HP. was too large; therefore, in the new Tivoli station, which was designed for about the same output, they had adopted a much smaller dynamo unit, namely, 350 HP., and they expected thereby to increase the efficiency of distribution. That point had hardly been sufficiently considered in many of the stations in this country. It was a matter of considerable importance so to select the unit not only of generation, but of transformation, that a high economy might be effected by a suitable grouping of them. That of course involved the working of the dynamos in parallel, which had been carried out in the station to which he referred, not only with greater security, but with the additional advantage, as far as generating-plant was concerned, that the percentage of useless or idle plant could be made much less when they were worked in parallel and disconnected as required, and a much smaller proportion of the dynamo plant could be set aside as a reserve.

Mr. Gordon. Mr. J. E. H. Gordon observed that Mr. Crompton had compared the direct current with a form of alternating current, which was by no means the most economical; and Mr. Preece and Dr. Fleming had spoken of the advantages of sub-stations. It was well known that the system had been successfully carried out in Rome, and that Mr. Raworth was about to adopt it in the City of London; but Mr. Gordon had not been able to obtain any definite statistics as to what the saving was. He should like to give a few details of certain definite experiments he had made with the apparatus now exhibited, which was the invention of his assistant, Mr. Tomlinson, and had been designed to meet the very want to which Dr. Fleming had referred. In the climate of Italy, as had been said, transformers could be turned on and cut off by hand; but in London that was impossible. Only a fortnight ago, at one of the Metropolitan stations, in the middle of the morning a fog had come on suddenly, and in eight minutes the load had been quadrupled. That was a common incident, and the apparatus in question was intended to obviate the difficulty. The requirements that were before the designer were these. First, it was not considered that mercury switches were practical things—they always meant trouble. Secondly, the apparatus ought not to be entirely automatic, but should indicate its requirements to the central station, from which it should be worked; and if a mistake were made, there should be some safeguard against mischief being done. There was also another absolutely essential point. All engineers knew that no automatic apparatus could be trusted to work always without attention. If the sub-station regulator got out of order, so that it ceased to take the transformers out, there was no harm done beyond the waste of coal; but if a breakdown occurred when it was putting the transformers in, and there was a demand for more, that failure might mean the burning up of the sub-station, and any amount of damage to the mains and transformers. It was therefore necessary for the apparatus to be so arranged that if any accident occurred, such as something sticking, or a man forgetting to wind it up, every transformer should at once go in; and then, the apparatus having failed, it could not take them out. That only meant waste of coal—as long as the transformer was in there could be no accident. Then there was another requirement, namely, that it must break the circuit without sparking. Lastly, if any switch heated it must short-circuit itself, and put the transformers permanently in. In the apparatus shown there were four sets of switches, and the transformers were divided into five groups, one of which was always in circuit, and the rest were worked by switches. The groups were not equal, but in multiple numbers. Supposing one transformer to be fixed, the first switch would add one more, the second two, the next four, and the next eight; each addition doubling the number of transformers in the circuit. The way in which sparking was avoided could be easily seen. The high- and low-tension circuits being broken simultaneously, the extra currents were in opposite directions, and it was found that on breaking 500 amperes on one switch no spark could be seen. The question arose whether, after all, it was worth while taking so much trouble. Through the courtesy of the Brush Company, and the Metropolitan Electric Supply Company he had tried some elaborate experiments. The Metropolitan Company had lent him a number of transformers, and the Brush Company had placed their testing-room at Lambeth at his disposal with a 100-HP. engine, and one of Mr. Mordey's big dynamos. The machinery was running for two spells of twenty-four hours each, the transformers being connected in the ordinary way in the first trial, and through the apparatus during the second. With the 2,000-light plant it was found that in the course of the twenty-four hours there was a difference of $4\frac{1}{4}$ cwt. of coal, and that meant a saving of $10\frac{1}{2}d.$ a year on every lamp wired, or about Mr. Gordon.

Mr. Gordon. 26 per cent. of the coal bill, and nearly 2½ per cent. in the dividends. Many persons had said that the use of this apparatus would effect a great annual saving, but that the capital cost made it impossible. He had worked out that question, taking the different densities of supply. The first was the density of one 8-candle lamp, which was the pioneering density of the Metropolitan Company, the next, two, and the next, four; and the result was, that at one lamp per yard, the capital cost of the sub-station was about 5 per cent. more than that of the ordinary system; and with all the other densities the sub-station system was cheapest in capital cost. He had taken into account the cost of high-tension mains, of low-tension mains, and of transformers; the cost of fitting up the sub-station, and the rental of the sub-station. The objection had been urged that if there was a cellar in a particular place, the owner of it would run up the price directly. But it had been found that between 600 and 800 yards for the lowest density, there was no difference in the cost. They had, therefore, a choice of 200 yards for the site; so that the sub-station system outlay, he believed, would be as cheap with regard to capital as the ordinary transformer system, and 30 or 40 per cent. cheaper in working cost. It had the advantages for pioneering of the transformer system, together with the economy that Mr. Crompton had claimed for the direct system.

Prof. Kennedy. Professor Alexander B. W. Kennedy desired to say something more about a point which Mr. Preece had raised but had not pursued. Mr. Preece had pointed out that Mr. Crompton had confined himself mainly to the cost of generating in the station only, and had not spoken of the cost involved in rent, taxes, sinking fund, and, above all, in depreciation of the machinery and mains. As a matter of fact, he thought that out of every £100 which the Supply Company had to pay on anything like the capital that most Supply Companies were using, about £45 represented the cost at the stations, and about £55 the depreciation and the other charges which he had mentioned. It had to be admitted that in the accounts that had been published by the Supply Companies hitherto, this £55 did not appear at all, or only very partially; still he believed that the thing would eventually work itself out something in that fashion. Of course the matter was an important one. Mr. Preece had opened the battle, which had been going on more or less ever since in a good-tempered fashion, as being fairly between a high-tension system of some kind, and a low-tension system of some kind. Professor Kennedy supposed most persons would agree that it would be impossible to use a low-tension system at Bournemouth, and unwise to employ a high-tension system in St. James's. Each place should be considered on its individual merits. In the remarks which he had to make, he wished to confine himself solely to the consideration of an urban district not having a less lamp density per yard than Mr. Crompton's district in Kensington. The total allowance for depreciation obviously depended on the expenditure upon mains and upon plant. The cost of mains in a district such as he had named, if they were underground, would not, he thought, be very different, whether they were high- or low-tension, if that of the transformers was taken into account. Whether this was so now or not, it would certainly be the case on the sub-station system, which was said to be the only high-tension one suitable for such a district. Under these circumstances the chief thing to consider would be the difference in plant. The point which he wished to bring out was this, that the two systems had, or might have, similar engines and similar boilers, and although he believed the very high dynamo efficiency that Mr. Crompton had quoted was not easily obtained with alternate-current machines, the two systems might have equally efficient dynamos, which was near enough for the present purpose; therefore, the expenditure in coal per unit generated ought to be about the same in both cases. Mr. Crompton had given some figures as to the consumption of coal, not per unit generated but per unit delivered to customers, and he had also quoted Mr. Dobson's figures from St. James's. Professor Kennedy might mention that the figures he was himself getting in Westminster corroborated them very closely. The last week's report, for example, from one station, gave 9·6 lbs. of coal for every unit delivered to customers. In contradiction to that, they were confronted with Mr. Raworth's figures of 19, 20, 22, and 26 lbs. of coal per unit delivered. He hoped that some engineer responsibly connected with distribution in urban districts would give the figures that were actually reached in London or elsewhere. He should be far from assuming that such figures as Mr. Raworth had quoted were usual with high-tension distribution, for they seemed to be very extravagant; but of course if they were usual it would mean that the cost of plant per unit delivered to customers, and therefore the depreciation expenses per unit, must be much greater in the case of such systems than in those described by Mr. Crompton. He did not say it was so, because he could hardly believe it, and he hoped Mr. Raworth's figures might be officially contradicted, but the point he wished to enforce was that the amount of fuel per unit delivered to customers was a very fair criterion of the Prof. Kennedy.

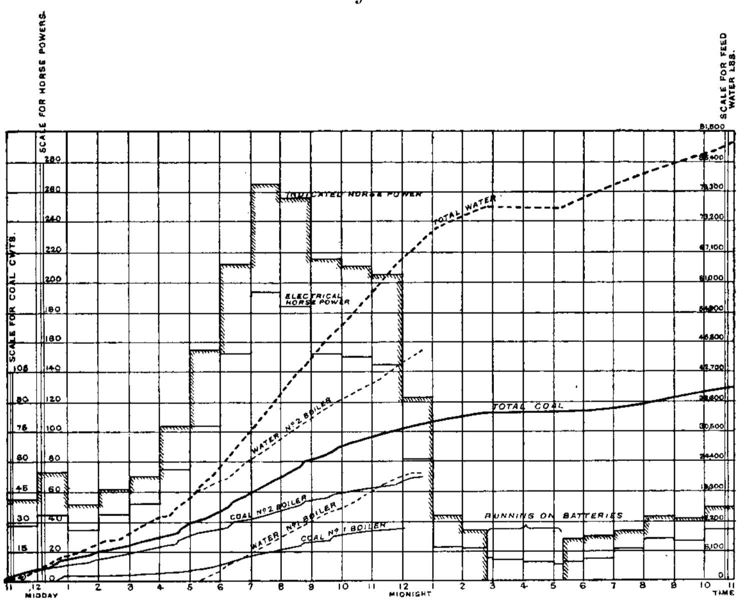
Prof. Kennedy. whole cost of the production of electrical energy, because the large amount of cost which depended on depreciation and so forth, was more or less a function of that particular matter, and he thought Mr. Crompton had been wise in confining himself to it instead of extending his Paper to figures about rates, depreciation, &c., on which they might have endless discussion. The accompanying Table, giving the details of a twenty-four hours run in one of his own central stations, would perhaps be found interesting. The

MILLBANK STREET STATION OF THE WESTMINSTER ELECTRIC SUPPLY CORPORATION, APRIL 9–10, 1891.

——	11 A.M. to 6 P.M. 7 hours.	6 P.M. to Midnight. 6 hours.	Midnight to 11 A.M. 11 hours.	11 A.M. to 11 A.M. 24 hours.
Total coal put on fires. lbs.	3,864	4,452	2,548	10,864
Total water fed into boilers „	22,880	42,730	23,620	89,230
Lbs. of water per lb. of coal .	5·92	9·60	9·27	8·21
Ditto from and at 212° . .	..	10·0	..	8·58
Indicated HP. hours . . .	562	1,366	407	2,335
Electrical „ „ . . .	400	979	260	1,639
Efficiency	71·1 per cent.	71·5 per cent.	63·5 per cent.	70·2 per cent.
Coal per indicated HP. hour.	6·88	3·26	6·26	4·65
„ „ electrical „ „ .	9·67	4·55	9·80	6·62
„ „ unit to consumers .	..	..	..	10·7
Water per indicated HP. hour.	40·7	31·3	57·7	38·3
„ „ electrical „ „ .	57·2	43·8	91·0	54·4
Total units generated . . .	..	..	..	1,242
Units stored in batteries . .	..	..	..	58·6
„ supplied to consumers .	..	..	..	1,013

results were graphically shown in *Fig. 16*, and he might point out a few salient points connected with them. He thought they did something towards elucidating a matter mentioned by Mr. Willans, namely, the cost of maintaining boilers under steam while doing no work. The experiments commenced at 11 A.M. on the 9th of April, and finished at 11 A.M. on the next day. It would be seen from *Fig. 16* that until 5.15 P.M. only one boiler was actually doing work, but that a second was receiving coal and standing by from 12.30 P.M. onwards. The two remained in use together until about 12.40 A.M., after which time no further coal was put upon the spare boiler, but the fire was just allowed to remain, so as to keep up steam-pressure during the night. At about 2.45 A.M. the engines were stopped and the station run on the batteries until 5.20 A.M., after which the machines were started again. In the Table he had separated the day's working into three periods, namely, a seven-hours period at light load, a six-hours period at a heavy load, and a period of eleven hours when the load was very small, and for some time no machines were running. All the coal was drawn from the fires before commencing, and during the first period the fires were gradually thickened so as to be ready for the heavy load as it came on. This period, therefore, was debited with a great deal more fuel than really was consumed during the seven hours, because the fires were much greater at the end than at the beginning of it. The second Prof. Kennedy.

Fig. 16.



Millbank Street Station of the Westminster Electric Supply Corporation, Limited. Diagram showing the Principal Results of 24 Hours continuous working on the 9th and 10th April, 1891.

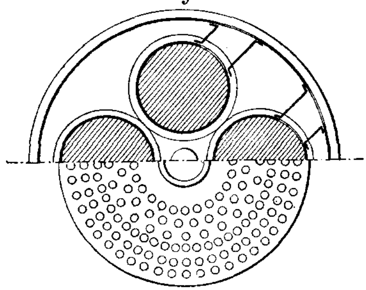
period began and ended with the fires in about the same condition, and therefore, fairly represented the best continuous working. The last period began with a tolerably heavy load which fell rapidly, and therefore was the reverse of the first in that it ended with much thinner fires than those it had at starting. The influence of these conditions on the evaporation was shown strikingly in the Table. In further reference to the first period, he would add that in the boiler which was actually working, the evaporation was at the rate of 7·20 lbs. of water per lb. of coal. The bringing down

Prof. Kennedy. of the average evaporation during this time to 5·92 lbs. of water per lb. of coal was entirely due to the loss in the stand-by boiler. In reference to the coal- and water-consumption during the test, which was far greater than the figures he hoped shortly to reach, he ought to say that his largest dynamos at Millbank Street were constructed for working at 230 volts, whereas at present he was working still on the two-wire system, and required only half this pressure. It was not possible, on account of the noise made by the exhaust, to run the engines at half-speed, and they had therefore to continue at nearly full speed, although with only half the output in watts. This was the cause of the comparatively low average efficiency. All the machines ran in parallel, and in no case was an engine kept turning round and doing no work. With regard to another point which had been raised during the discussion—in order to apply a system with banked transformers instead of a low-tension system to a city like London, the whole of the distributing mains might remain as they were, for they would be identical in both cases, but for each feeder of the low-tension system a high-tension feeder with a sub-station at the end of it would have to be substituted. There would, he believed, be great difficulty in finding sites for these sub-stations, and even when they were found a high rent would have to be paid, and it remained to be seen to what extent they could be automatically worked without personal supervision. It would be interesting to know whether their use hitherto had been accompanied by such a reduction in fuel consumed per unit delivered to customers as to make the economy of working compare favourably with that of low-tension systems in crowded districts. In reference to the batteries he did not agree entirely with Mr. Crompton, but looked upon the matter mainly as one of convenience in enabling a station, or a large part of it, to be shut down during hours of minimum demand, and also as what might best be termed an electrical fly-wheel capable of smoothing over irregularities which might otherwise occur. He had himself found it invaluable in both these ways. He passed at present from 4 to 8 per cent. of the whole current delivered by the station through batteries, and was able to get an efficiency, generally, of 80 to 85 per cent. in energy out of them. The corresponding loss of about 1 per cent. in total efficiency due to the use of batteries was small in itself, but was, he believed, fully made up for by the improvement which they gave in load-factor, as they could be charged when the load was lightest. He wished he could persuade those who made the instruments by which all measurements of economy were obtained, that it was of vital importance to have them thoroughly accurate. He had been scoffed at because he wanted a voltmeter to be right to a volt, and was told that he should not expect it. But his customers knew all about it, and if he was 2 volts out he was sure to hear of it from them. It was the same with ampere instruments. They should not only be exactly right when they left the instrument-maker's hands, but also when on the switch-board, with magnetic fields all round, and currents passing in every direction near them. It might seem a trivial matter, but it was of vital importance to those who had to do with the subject practically. Prof. Kennedy.

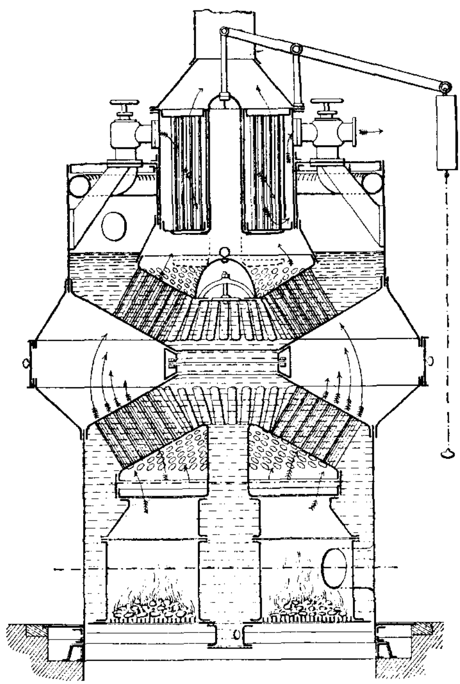
Mr. JAMES SWINBURNE had hoped that more would have been said about boilers. Mr. Willans had clearly pointed out how the waste arose in connection with engines, and had also shown that if the engine units were sufficiently small that difficulty might largely be avoided. It was not contended, however, that all the engine units should be small. In the case of boilers it was not quite the same. It was necessary to keep several in steam ready for fogs or any emergency. He did not know whether those in charge of stations had tried blowing in steam from the live boiler. It appeared to him that that would be more economical. He hoped they would hear from those practically conversant with the manufacture of boilers some opinion as to the merits of the new one invented by Mr. Crompton. He also wished to call attention to one specially designed by Mr. Cawley for cases where rapid heating was required, which was represented in *Figs. 17*. Being a vertical boiler it occupied comparatively little room. There were four fire-boxes, and two sets of short tubes between two pairs of conical plates. The conical form was good because it prevented buckling; very little water was required. It was an expensive shape to make by hand, but with the modern flanging machines it should not cost much. The output was very large. A boiler about 9 feet in diameter had about the same grate area and evaporating surface as a 30-foot Cornish boiler. A superheater was provided at the top, which could be used or not. It could be taken to pieces for travelling, and the whole of the interior was readily accessible by manholes. Before referring to the electrical part of the subject, he would suggest that it was possible that gas-engines might compete favourably with steam. People were apt to look upon gas-engines as a kind of toy; but if used with producer-gas or water-gas, or a mixture, they could compete with the ordinary condensing steam-engine; and they might prove economical in the case of a central station, where Mr. Swinburne.

Mr. Swinburne. steam engines were at a great disadvantage because of the boilers. The gas could be stored, so that a small producer might be worked

Figs. 17.



SECTIONAL PLAN.



VERTICAL SECTION.

CAWLEY'S VERTICAL BOILER.

Scale 1 inch = 8 feet.

continuously, and the only thing needed was a large number of the engines. He thought electrical engineers were greatly in-

Mr. Swinburne.

debted to Mr. Crompton for his figures. There appeared to be a feeling of rivalry amongst electrical-light Companies which prevented the publication of their figures, but as each was now limited to its own particular area, there could be no reason why the figures should not be made known. Mr. Crompton had asked for the statistics of alternating stations, but had not been able to get them. Perhaps they were so bad that people did not like to publish them, and judgment therefore should go by default. Though Mr. Crompton did not want to enter into any controversy, it was impossible to avoid comparing the alternating with the direct system; but Mr. Swinburne did not think it fair to compare the present direct system with the alternating systems now in use. The plan of putting transformers in houses was a temporary arrangement; some form of sub-station must be adopted, and the whole alternating-current system put on a different basis. He thought that electric lighting might be divided into four types, namely, (1) when the area was small and compact; (2) when it was small and straggling—he did not mean as regarded the houses, but when the customers were far apart; (3) when it was large and compact; and (4) when it was large and straggling. When it was large and straggling he thought the alternating current must have it to itself; when it was large and compact it was a doubtful point; when it was small and straggling the alternating current would be best; and when it was small and compact the present direct system would usually be the most economical. It seemed to be generally assumed that the alternating current must work at high tensions up to 2,000 or 1,000 at least. There was, however, no reason why they should not supply in small and compact districts at 100 or 200 volts, or on a feeder system at 400 or 500 volts. It really came to the question of losses in the transformers on the one hand, and the convenience of storage by batteries on the other. In the case of a small compact station like Mr. Crompton's, if it was thought advisable to use alternating currents, on account of their greater convenience of manipulation and flexibility, there was no difficulty in applying batteries so as to have storage too. It appeared from Mr. Crompton's figures that about 500 amperes was the day load. A 500-ampere motor was nothing; a storage battery could be used, and a small alternator worked. It was not expensive, and the cost of the motor would be much less than that of a switch-board to manipulate the batteries. In the case of a large and compact area the best proportion of batteries was lower. He desired to express his admiration of the ingenious apparatus exhibited by Mr. Gordon, Mr. Swinburne. but he could not help thinking it unnecessary. Working with a really well-designed closed-circuit transformer at the end of the feeder, the loss was so small that it would be better to neglect it than to risk putting in an automatic appliance. There was a general idea that each sub-station should have a large number of transformers, but he thought it would be far more economical to have at the end of each high-tension feeder a transformer, which need not be in a cellar at all, but simply in a hole in the ground. Mr. Kapp had referred to Mr. Mordey's ingenious way of measuring the Foucault currents in a machine. That method was unfortunately inaccurate, as it only measured the loss at no load, which was much less than that at full load. It had been said that the load-factor was not improved by motors, because the curves overlapped to some extent. But the overlapping of two curves produced no serious harm unless the two tops were at the same time, in which case the addition of motors did good by increasing the output of the station as a whole; but apart from that, the motor load-factor was generally better than the light factor, and the top seldom corresponded with that of the light curve. There had been a great deal of discussion as to what Mr. Crompton meant by the load-factor, and five or six different kinds had been mentioned. After reading the Paper carefully he could not see where the difficulty lay. The Author had explained exactly what load-factor was being dealt with, and it did not matter how many others there were. Electrical engineers ought to be grateful for the term and all that it carried with it.

Mr. Smith. Mr. Holroyd Smith remarked that Mr. Crompton had told them what had actually been done, while others in reply had contented themselves with showing what might be done when certain improvements had been made in the transformer system. He thought that with the light then before him he should be obliged to declare in favour of the battery system advocated by Mr. Crompton, but it would be of great value if some one in authority would give a decisive opinion on the subject. They were greatly indebted to Mr. Crompton for the way in which he had given them the benefit of his own experience. The cost of supply of electrical energy did not depend entirely upon the electrical details, but also, as Mr. Crompton had pointed out, upon the source of power. The subject divided itself into two problems, first, how to produce the power, and secondly, how to use it. A good deal had been said about the Willans engine, and he regretted that the discussion had not brought out the merits of other engines also. He was inclined to think that the efficiency

Mr. Smith. obtained by Mr. Willans was as much due to the excellent work put into his engines as to their peculiar design. A well-designed machine might be spoiled because of its bad workmanship, whilst another, no better in design, might give excellent results because it was well made. During the discussion the boiler illustrated in *Fig. 14* had been described as Mr. Crompton's invention. He believed that Mr. Crompton did not claim to have originated that type of boiler, which was really brought forward in 1853 by a Mr. Pearce, whose design was essentially the same as *Fig. 14*, but possessed two advantages. In the Crompton-Longridge boiler the stoker's place was on a level with the bottom of the fire-box flue. Those who had spent hours shovelling in the coal, knew what an unpleasant position a stoker occupied. In the Pearce boiler the fireman's stand was lower down than the stoke-hole—a practical feature that he was surprised Mr. Longridge should have omitted. The next point was that the 1853 boiler was provided with a steam dome, which the other did not possess. He had not been able to obtain any record of how Mr. Pearce's boiler behaved. Mr. Crompton had stated that he had put a reproduction of it in practice, and he should be glad to know what was the result. It appeared to him to be an excellent design, and he had already advocated its adoption, because he believed there was a great future before it.

Mr. Henwood. Mr. E. N. Henwood said that the design of the boiler referred to by Mr. Holroyd Smith was tolerably good, but he believed far better results would be obtained from it by the use of liquid fuel, such as petroleum residues. He had been credibly informed that the cost of the coal consumed with a set of three boilers in an electric-lighting station in the City, amounted to £30 per week, to which must be added the wages of six stokers at thirty shillings a week each, making a total of £39; whereas with liquid fuel it could be done for £20, including the wages of three stokers, effecting a saving of £19 per week.

Mr. Mordey. Mr. Wm. Mordey had been amused by Professor Kennedy's reference to the inaccuracy of electrical instruments, some of which would not measure correctly within 1 per cent. He should like to ask him how often he complained to the makers of the inaccuracy of their steam-gauges. Electricians had only been working for a few years, but they had certainly produced instruments a great deal more accurate than the ordinary—or even the very best—steam-gauge of commerce. He was glad to welcome Mr. Gordon back to the field of alternate-current working, but when an engineer completely changed his front on an important

Mr. Mordey. matter in his profession he ought to give his reasons. The last time he had heard Mr. Gordon speak upon the subject, he was fighting shoulder to shoulder with Mr. Crompton for batteries.[1] He had then said that after years of experience with alternating currents he had been so convinced of the superiority of the method of distribution by storage batteries that he felt compelled to abandon what was identified as his own system. Since then Mr. Gordon had had a good deal of experience of batteries, as well as of modern alternate-current working. He was sure, therefore, that it would be most interesting if he would give the reasons for his present significant change of front. In making comparisons between direct and alternate-current working, they should discriminate a little more as to the special qualities of the two systems. Frequently there was no comparison to be made. Sometimes it was not possible to work by anything but the alternating-current system, while in other cases, like those represented by Professor Kennedy, it would be unwise to employ anything but direct currents. In most places, apart from the rich districts, such as those in the centre of London and at the West End, the conditions seemed to favour the use of alternate currents, because, amongst other reasons, they could be conveyed to such great distances with so small an amount of material. Reference had been made by Mr. Raworth to the station which he had put down for the Brush Company at Bournemouth. They had there about 2 square miles covered from a little station 2 miles out of the town, the lamps being so scattered that they only averaged one per acre. He should like to ask Mr. Crompton how he could profitably light 2 square miles from a place 2 miles away, as they were doing at Bournemouth. The alternate-current system owed its rapid advance to the fact that it combined the best features of both high- and low-tension working. It gave them high pressure from a dynamo without a commutator, and with a stationary armature; low pressure from a stationary transformer of simple form, having nothing to wear out; economical transmission over long distances and large areas by means of high pressure; and, at the same time, all the advantages and the simplicity of ordinary low-tension parallel working—safety to users—self-regulation (the power to turn lamps on or off without affecting others)—a voltage suitable for the best arc- or glow-lamps—everything, in fact, that they were accustomed to in good low-tension supply, except the necessity of having to

[1] Journal of the Society of Telegraph Engineers, vol. xvii. p. 195.

Mr. Mordey.

put the plant in an inconvenient place. It was important to know whether the top curve in *Fig. 5* really dropped or not. Professor Forbes had said that the curve rose from the commencement. If so, Mr. Crompton's irreducible minimum of cells must disappear. He was not surprised to find that Mr. Crompton reduced his cells to 20 per cent. Professor Forbes, using the same figures, said that the curve rose, which of course meant that no cells should be used. Everything depended upon the depreciation that was to be allowed, and Mr. Crompton was the only person who could state how much it should be. They wanted a figure that contractors could rely on for cells that might be put into the hands of ordinary people in distant parts of the world, and subjected to the usual conditions of working and supervision. The ability to shut up the station during the hours of small output was a convenience of some value with small stations, but continuous running was not so wasteful as was often supposed, as after the heavy work there was a good deal of energy available in the boilers, enabling steam to be kept up easily for a small plant. He wished to point out one or two ways in which central stations had to be looked at in regard to the choice of ground, which had much to do with the system to be used. In towns, direct-current working was very successful if the "central" station could be put in the middle of the district. That, however, was a difficult thing to do in the best parts of towns, but they could go outside, if necessary for a considerable distance without much difficulty, if alternate currents were used; and they could then get cheap land, where there was no squeezing of the plant into a small space, where coal and water facilities were good, where there was no smoke nuisance or trouble in connection with the vibration or noise of the machinery, and where there was plenty of room for extension. The suburbs could be lighted from the same place as the busy central district, and there was no need for two systems. A good many central stations were now being planned in which the idea was to light the first, or "A" division, a small dense district, by direct currents, and to use the other system in the outlying parts. He thought that most engineers who had gone into the figures, would agree that it would pay much better to start one system in the town, even if the intention were to work only immediately around the station in the first instance, and afterwards to extend it, using the same kind of plant to light the suburbs and villages all from one station. By this method the plant required was least, because the demand moved from the business to the residential districts; thus making the best use of the machinery. With reference to

Mr. Mordey. the question whether transformers should be used singly or in groups, it appeared to him that both plans were good. The usual way in which central-station work grew was from a very thin amount of lighting (as at Bournemouth), in which case separate transformers were best; then, as the houses lighted came close to one another, the transformers were grouped, or large ones used, instead of having one in each house, and the distribution-centre system was adopted. By this plan the initial expense was a minimum. The distribution-centres gradually and naturally spread from the busy parts of a town, and a network formed itself, the separate transformers being moved out to take up fresh work in the outskirts. In all cases where there was not an assurance of starting with a heavy output, the best pioneer system was undoubtedly that of placing separate transformers where they were wanted, as distinguished from the establishment of a secondary network. But when sub-stations were established, the method of turning transformers in or out might be used or not according as they were well or badly made. Although he had, two years ago, perfected and used an automatic switch of this sort, he had not been sure of the wisdom of applying it. It had seemed to him that if the money were spent on the transformers, instead of on automatic devices, they might be made so good that in many cases it would not be necessary to turn them out. They ought to be looked at from the same point of view as that from which Sir William Thomson had taught them to regard cost and loss of power in conductors. They should go on increasing the efficiency until the cost of the power wasted equalled the increased cost of the apparatus. He admired the ingenuity of the Tomlinson apparatus shown by Mr. Gordon, but in towns it would be impossible to get room for it for the control of a small number of transformers. The space occupied would suffice for transformers for several thousand lamps.

The question of power-transmission had been referred to in connection with town central stations; but the wider question of the cost of generation of electrical energy was associated with that of the transmission of large powers over long distances. He thought the advantages of electrical transmission had always been acknowledged in principle, but electrical engineers had never successfully solved the problem of making large direct-current dynamos or motors suitable for long distance transmission. For short distances and small powers direct-current machines were, and had long been, excellent, and improvement was scarcely to be looked for. The larger problem had now been solved, he might say, in an unexpected way, and they were on the eve of important applications. The great difficulty in electrical power transmission on a large scale hitherto had been the insulation of the dynamo and objectionable features in connection with the commutator of the direct-current dynamo; but now that the part which received the current was stationary and never had to be touched, and the insulation difficulty in the dynamo and in the motor was solved by the use of transformers, the answer to the objection that alternate currents were not suitable for power transmission was, in short, that power could be transmitted much more economically and successfully by alternate currents than by direct currents, especially on a large scale. In one case his Company had to inquire into the economic possibility of transmitting a very large power from a waterfall 36 miles away, and they found that it would actually pay to distribute it as power or light, and sell it at 8*d.* per unit. using alternate current transmission. He spoke from some experience, because the Company with which he was connected had done a certain amount of direct-current power transmission for many years, and he knew the difficulties that were met with in ordinary cases. He wished to ask one other question, whether they had obtained the best possible results out of lead cells? He supposed Mr. Crompton had recognized that no further improvement was to be looked for in connection with such cells, and under the circumstances he was to be congratulated on having satisfied himself that 20 per cent. was the most that need be used. Remembering the cells at the Crystal Palace Exhibition of 1882 and those now used, they might well ask whether any improvement had been made. He had recently put the question to one of the most experienced makers, and he replied, "No; they were then as good as those we have now; but we have learned how to use them a little better." If it was a fact that engineers and electricians and chemists had been working hard to improve lead cells for the last ten years without making any real progress, it might fairly be concluded that they had reached their highest point of development, and must be taken as they were. Mr. Mordey.

Mr. HENRY DAVEY expected from the title of the Paper that a debtor account would have been furnished of all the charges incidental to the production and delivery of electrical energy to the consumer; but, unfortunately, that given by the Author was not complete, and probably no complete record of figures obtained at the present time would be reliable as a standard, because of the rapid rate at which economy was being effected in this new Mr. Davey.

Mr. Davey. application of science. The chief interest of the Paper appeared to centre in the saving effected in the application and distribution of steam-power. An improvement in the character of the load-curve would aid in producing the desired effect. It did not, however, appear that any great advantage was likely to be gained in that respect from the employment of current for power purposes, for reasons already advanced in the discussion. They were indebted to Mr. Willans for putting on record the results of so much experimental work, and the figures he had given were especially interesting from more than one point of view. As regarded the steam used, there was the question of the economy to be secured by the application of condensers, and also that which would result from working a greater portion of the time with the most economical load. These questions were intimately linked together. Many definitions of load-curves had been given, but for the purposes of his argument he intended to refer to another. Let A *b*, *Fig. 18*, represent the load-curve for the first three hours, requiring a maximum of 300 effective HP. If one engine were employed to do the work, it could only have its most economical load for a small fraction of the time; whereas if there were three engines, each of 100 HP., the most economical load would be on the first for two hours, and on the second for one hour. In this respect, then, the advantage was greatly in favour of using several small engines instead of one large one. Variations in load did not tell so much against the economy of the condensing engine as of the non-condensing. In other words, the application of a condenser secured a greater percentage of economy at light than at full loads. It was the character of the rising and falling part of the load-curve and its time-proportion to the full-load part of the curve which was to be taken into consideration in determining the relative economy of the employment of large or small units of power. Mr. Charles Cowper had advocated the evaporating condenser. Mr. Davey had put up several of them, and could bear out the statement that the quantity of water required was much more than the feed-water; but he had not ascertained what the minimum might be. Those condensers which used too little water, caused the air-pump water to be so hot as to tell against maintaining a good vacuum. The water of the air-pump should be at a lower temperature than that due to the back-pressure of the condenser. It was, therefore, a good plan to pass the cold-water supply through a small supplementary surface-condenser or cooler, *Fig. 19*, on its way to the evaporator. The colder water might afterwards mix with the circulating water, as shown by the arrangement of pipes. Coming to the commercial question of the economy of the evaporative condenser, it appeared Mr. Davey.

Fig. 18.

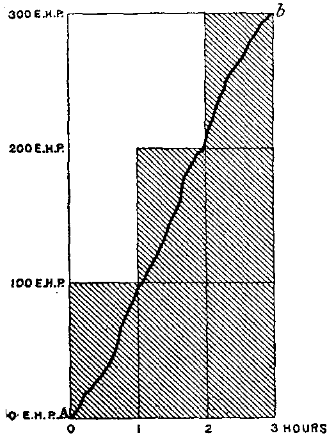
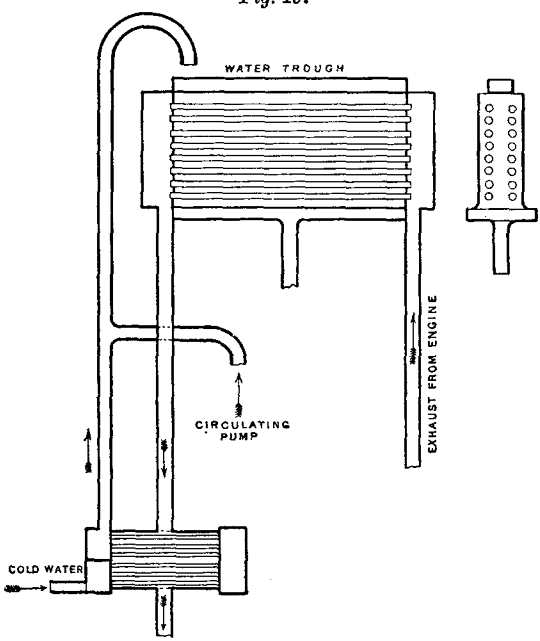


Fig. 19.



that if water was purchased at $7\frac{1}{2}d.$ per 1,000 gallons—the price in London for such purposes—only a small saving could be effected at

Mr. Davey. full loads over the non-condensing engine. Taking as standards 20 lbs. of feed-water per effective HP. for the non-condensing, and 16 lbs. per effective HP. for the condensing engine at full loads: the cost of coal and water would be, per 100 HP. per hour, for the non-condensing engine 17·5*d.*, and for the condensing engine 15·8*d.*, or a difference of 1·7*d.* per hour per 100 effective HP. He doubted whether this small saving would warrant the extra addition to capital and upkeep account. At half-power the figures would be different, and there would appear to be a saving of 5·7*d.* per hour per 100 effective HP. In this calculation he had assumed that 10 lbs. of water would be evaporated per lb. of fuel, and that the cost of coal was 17*s.* 6*d.* per ton delivered at the works, which was about the price of smokeless coal in London. The Author had brought forward a question of equal importance to that of the engine, viz., that of the most suitable and economical type of boiler. Mr. Davey believed it would be found that, all things considered, Cornish and Lancashire boilers were superior to any others. The unit of boiler-power, even with Lancashire boilers, would generally be smaller than that of the engine-power, and he saw no reason whatever in the argument that it was an advantage to have a small amount of water in the boiler. He considered it was an advantage to have great staying power in the large amount of water which a Cornish boiler contained. With a knowledge of the daily load-curves, there should not be the slightest difficulty in keeping steam at a constant pressure all through the day. There was no other boiler which cost so little in upkeep, and, taking all expenses into consideration, none so economical. He had known many instances where economy had been secured in the engine and thrown away in the boiler.

Mr. Crompton. Mr. Crompton, in reply, said that the discussion had been greatly prolonged because so many speakers had misunderstood the object of his Paper. Mr. Preece and several others had credited him with wishing to revive the old controversy between high- and low-pressure systems, but he deprecated this, although he fully admitted the importance of the matter, which merited a Paper to itself. He had been asked why those portions of the cost, which were mainly dealt with in the Paper, formed such a small part of the present selling price of electrical energy. He thought he had made this matter clear in his remarks before the discussion commenced, but as Mr. Preece had called prominent attention to this matter he would repeat that the items of cost under discussion in this Paper were in reality only those which could be reduced by improved engineering practice. The remainder was due to fixed charges, and although these now formed the major portion of the cost, they would be reduced as the sale increased until they would be eventually insignificant. He begged to assure Professor Forbes that the Paper was not intended to attempt to establish the merits of accumulators for the low-pressure system of supply. He had been obliged to mention the subject in order to explain that the bad effects of the low load-factor at Kensington were not so marked as they would have been if he had not used storage. The curves shown in *Fig. 5*, and explained in Table No. 2, were certainly not prepared in order to advocate an extended use of accumulators, but on the contrary, to show that all the advantages of such a course could be obtained when the accumulator plant formed a very small portion of the whole. Professor Forbes, in common with some others, in criticising *Fig. 5*, stated that he had been unable to verify any of the costs on which it is based. He did not, however, state what experience he had had with accumulators on which to base his estimate of 20 per cent. as the cost of their upkeep. The Author fully admitted that this item was extremely difficult to calculate with any degree of correctness. The early accumulators, on the behaviour of which no doubt Professor Forbes and Mr. Mordey based their estimate, were very imperfect, and not at all well suited for the irregular demands of central-station work; but with regard to those employed by the Author, and on which the data given in the Paper were founded, they had been in use for central-station purposes for four years, and as yet had given no signs that the cost of upkeep would be excessive; in no case had it exceeded 5 per cent., and it had generally been far less than this. The largest makers of accumulators on the Continent, who manufactured the Tudor type of cells at Hagen, had given substantial guarantees with the accumulators they supplied that the outlay for upkeep should not exceed 7 per cent. of the original cost of the accumulators. The Author thought that with his own experience and such data as these before him, he put down a very fair and safe figure when he estimated the upkeep at 12 per cent. Professor Forbes also criticised the same Table in the sense that the outlay for fuel, water, and petty stores, would not be diminished by the use of accumulators, but, on the contrary, increased. He perhaps did not see that in doing this he practically refused to accept any of the conclusions to which the Author had arrived as to the fact of low load-factor increasing costs of fuel, &c. As the Author had shown, however, facts were against him. One interesting fact came to the Author's knowledge during the course Mr. Crompton.

Mr. Crompton. of the discussion, from two Directors of gas-works, who had come from Dessau to hear the Paper read. In that town there was a central station belonging to the Gas Company, and worked by large gas-engines. The station was commenced without accumulators, but after a certain date they introduced accumulators of the Tudor type, and the reduction in the gas used for driving the engines exceeded the amount claimed in the top line of Table 2; in other words, the quantity required was less than half the former consumption. Professor Forbes and several others had considered that the definition given by the Author of the term "load-factor" was not sufficiently clear. He thought, however, that his second definition, with the addition of a few words, was perfectly clear, and fairly described what he intended to convey. It would now stand as follows: "A second way of describing the load-factor is to say that it is the relation which the area of the load-diagram of any period bears to the area of the rectangle, having the same base line as that on which the load-diagram is drawn, and the upper boundary of which is a line drawn parallel to the base line through the highest point of maximum load observed at any time during the year." The height at which this line of maximum load should be drawn appeared to have puzzled many members. He preferred to draw it through the highest point of load touched during the year. This, of course, did not indicate the full capacity of the station, as it was evident that enough machinery must be held in reserve to provide for a breakdown or other contingency. In this case the reserve was one additional third. While on the subject of load-factors, he would refer to what other speakers had said. Mr. Swinburne, Mr. Willans, and Mr. Trotter, had pointed out that there were several load-factors, but he preferred to say that there was only one, but that it affected various portions of the plant in different ways. He considered that a bad or low load-factor increased the losses which must be debited to the various parts of the plant to the extent indicated by the order in which he now named them, *i.e.*, 1. The staunchest supporters of the alternating transformer system admitted that a low load-factor increased the distribution losses of that system, especially when separate transformers were provided in every house. And at the generating station it affected:—2. The evaporative efficiency of the boilers; 3. The duty of the engines; 4. The duty of the dynamos; 5. The cost of labour and petty stores. Going for a moment outside the present discussion to consider the total cost of the electrical energy, it would be found that a low load-factor affected most of all the cost due to fixed charges. Professor Forbes had said a good deal about the large central stations in Berlin, and had pointed out that the Berlin figures, although carefully kept, did not show the startling differences between the cost of summer and winter production that the Author had spoken of. If Professor Forbes had looked carefully into the matter, he would have found that the circumstances under which the load-factor was produced in Berlin differed widely from those which obtained in England. In Berlin, as was generally the case on the Continent, the inhabitants, after leaving their offices, took their evening meal at a restaurant, then went to a theatre, and came back to a restaurant for their supper. Private lighting as it was understood in England was almost unknown in Berlin. Nearly the whole of the load on the stations was made up by the demands of restaurants, theatres, and hotels, and as a consequence the load-diagram had a long flat top, and was as different as possible from the sharp-peaked diagrams which were everywhere obtained in England, except perhaps in the one case of the St. James's and Pall Mall Company which served a number of clubs. It followed that the Berlin load-factor was better in summer than the Kensington load-factor was in the winter, and moreover, the difference between summer and winter load-factors in Berlin was less marked than in England. The Berlin load came on in summer later, and was prolonged to a later period than in winter. The methods of differentiating what might be called the obscure losses in dynamos, worked out independently by Mr. Kapp and Mr. Hausmann, were extremely useful, and electrical engineers were much indebted to them for their discovery. Mr. Kapp had pointed out that the advantages of using accumulators were more obvious in the case of small stations than of large ones. This was true with regard to the economy of fuel and water, for as soon as the all-night load of the station reached a certain figure the economical advantages of the accumulators disappeared, but there still remained the increased safety and regularity in working which their use entailed. He did not think he was speaking too strongly in saying that no one outside the electrical profession had any conception of the harassing life of an engineer in charge of a central station which depended for the regularity of its supply entirely upon moving plant. The reputation of the station was dependent on the men in charge. If anything had occurred to the engines or dynamos which necessitated their being stopped, and the reserve plant was brought into operation a few seconds late, short extinctions, or, at any rate, irregularities, occurred in the light, Mr. Crompton.

Mr. Crompton. which were excessively annoying to the public. The recurrence of such irregularities had been the principal cause of retarding public confidence in electric light. For many years to come, in fact, until street lighting by electricity became far more general than at present, the all-night load of most of the London stations would be so small that it could be easily dealt with by the existing accumulator plant; and the saving in labour and other expenses effected by closing the stations at an early hour in the evening could not be over-estimated. Mr. Kapp had admitted that the alternating system, in order to compete safely with the direct system, must have equal facility in running its dynamos, and, in fact, its various separate stations in parallel, and he pointed out that until this was done as easily and as an every-day matter, as is the case in direct-current systems, they could not expect to compete with the latter in the regularity of supply. He was unable to follow Mr. Raworth, who had stated that 19,200 HP. was required for the offices and street lighting of the City. The Author considered this must be an oversight, as such a gigantic plant was entirely out of proportion to the income likely to be obtained from the lighting of the City of London. Mr. Raworth also quoted figures of coal-consumption to show that those given by the Author in the Paper were too good to be true. He would find, however, that in the case mentioned, where 28 lbs. of coal per unit in summer and 20 lbs. in winter were used, they employed a very inferior class of fuel, and had at that time no accumulators; but that the same station had since shown vastly improved results.

The question of the improvement of the load-factor by the addition of electric lifts, referred to by Mr. Thorpe and Mr. Ellington, was a useful addition to the discussion. The Author believed that at the West End of London the addition of electric motors, whether used for lifts or other domestic purposes, would improve the load-factor. He had noticed that domestic lifts were employed to the greatest extent in the early part of the morning by household servants at the time the houses were being cleaned. He had a lift in his own house, and he particularly observed that it was worked the greatest number of times between nine and eleven o'clock in the morning. In London, therefore, they would have the great advantage of this lift-motor load in the early part of the day. He thought the result at Kensington would be to raise the present annual load-factor from 12·8 to possibly 16 or 17. Mr. Ellington's remarks were exceedingly interesting, and went far to show that the cost of generating and distributing hydraulic energy was almost identical with that of generating and distributing electrical energy. Mr. Ellington had thought there was a discrepancy between the two, but he had taken the wrong figures in the Table. The comparison of the cost of the two forms of energy should be made with approximately equal load-factors. If the figures belonging to Mr. Ellington's 32 per cent. load-factor were compared with those of the Kensington station at the 21 per cent. load-factor, it would be found that in both cases the *generating* cost was about 1*d.* a unit. With the advantages Mr. Ellington had in condensation and in other respects, pointed out by Mr. Willans with regard to the working of his pumps, it might have been expected that he would do a little better than the electrical engineers did at Kensington, but apparently the results were about equal. The figures given by Mr. Parsons of the Newcastle station costs were interesting. The total amount was so low as to be very encouraging. The Author had already explained that he did not include the rates and taxes, because they were fixed charges, which could have no interest for the purposes of this Paper. Mr. Willans had greatly added to the value of the discussion by his remarks on the why and the wherefore of the increase of water-consumption when the engines were running light. The Author was further indebted to him for showing what savings could be effected by a partial application of the condensing plant recommended in the Paper. Both Mr. Willans and Mr. Halpin, who looked at the matter from a point of view of a mechanical engineer, appeared to thoroughly appreciate the Author's object in producing the Paper. Mr. Crompton.

In reference to the remarks of Mr. Cowper and Mr. Schönheyder on what might be called evaporative surface-condensers, the Author believed that the reason why these had not yet had a trial in the London central stations was the fear that their use might be objected to on account of the clouds of steam that would be given off from the surface of the cooling apparatus during certain states of the atmosphere. If this difficulty could be avoided there was a great future for this class of apparatus. Mr. Hedges had drawn attention to the Author's assertion that most of the specifications recently issued for lighting large towns on the Continent had been on the low-pressure supply, and, in order to disprove this, had given the names of several towns in Italy and Sicily using the alternating-transformer system. The grounds on which the Author made the assertion referred to were that the recently-issued specifications for the electric-lighting plant for two capital towns, viz., Copenhagen and Stockholm, were both for

Mr. Crompton. low pressure, and included the use of accumulators, and they had evidently been prepared with great care by competent Continental engineers. It was not easy to obtain an even approximately correct list of the number of central stations in Europe and of the systems they employed, but, after considerable correspondence with the editors of various foreign technical journals, the Author found that, out of sixty of the largest stations now at work on the Continent, forty-three were on the low-pressure system and seventeen on the alternating-transformer system. In England at the present time about two-thirds of the total electrical energy supplied from central stations was on the low-pressure system. In reply to Mr. Hedges' question, the cost of drainage of the culverts mentioned in the Paper had been included in the upkeep, and there had been no trouble or extra expense due to this cause. The speech of Dr. Fleming with regard to Rome might have been made by Mr. Crompton himself to prove his point. Rome was a case in which, owing to the exceedingly good load-factor, distribution by means of alternating currents would be at its best. The climatic conditions enabled those in charge to know exactly when and to what extent the current would be required. Moreover the light was entirely turned off during the daytime, a state of things which could not be permitted in London. It could not be safely argued from the satisfactory experience at Rome and other Continental stations of the same kind, that the system there used would be equally satisfactory from a commercial point of view when applied to towns in England having English load-factors. He had shown that in the case of an alternating station under his own care at Chelmsford, where the distribution resembled that of a foreign town, in that the current was used almost entirely for public lighting, the efficiency of distribution was exceedingly high, viz., 83 per cent. Mr. Preece, in commenting upon this, had attempted to show that it was an argument in favour of the alternating system, and had gone so far as to say that if Mr. Crompton had used an improved engine at that station he could have pulled up the distribution efficiency to something higher. In answer to this Mr. Crompton pointed out that engine efficiency could have no effect whatever upon distribution efficiency. Mr. Gordon's apparatus showed considerable ingenuity, but it was doubted whether space could be found for it in any of the London lighting districts. Mr. Crompton agreed that transformer sub-stations were desirable, and had said so in his Paper, but thought that the apparatus fixed in the transformer sub-stations must be something much smaller and simpler than that

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exhibited by Mr. Gordon. It should not be larger than a cylinder of 2 feet diameter, possibly 6 feet deep, which could be sunk into the ground, and not occupy more space than the entrance to the sewers. Otherwise, as he knew from experience, there would be great difficulty in getting permission from the authorities to place it in the streets. He had to thank Professor Kennedy for the cordial support he had given to the views expressed in the Paper, and for offering him the use of figures which were entirely corroborative of those obtained at the Kensington and St. James's stations. He did not, however, employ them, because they were for the winter months only, and for this reason they might have been objected to. Professor Kennedy was quite right in pointing out that the efficiency in fuel-consumption was a measure of the efficiency in most other particulars of the cost. His figures for the trials at Millbank Street station on April 9th were very instructive, corroborating as they did the points which the Author wished to bring to the notice of engineers, viz., the effect of short hours of boiler-efficiency.

The questions raised by Mr. Swinburne had been already dealt with, and the Author agreed with him that more ought to be done in developing large-sized gas-engines for central-station purposes. Mr. Holroyd Smith was right in supposing that neither the Author nor Mr. Longridge had ever heard of Mr. Pearce's boiler, or they would certainly have given him the credit for it. Mr. Mordey and other engineers, who advocated the alternating-transformer system, appeared to admit that the present system of distribution by that system was wrong, as they proposed to remedy it by the adoption of a sub-station system. While agreeing with them, the Author wished to point out that his remarks as to the comparative efficiency of the two systems related to them in their present state, and the comparisons were made from data obtained from installations which have been at work for some years. The alternating-transformer system with sub-stations was, so far as England was concerned, a thing of the future. There might be difficulties in the way of adopting sub-stations so great as to entirely prevent their use, and, at any rate, the remedy that had been so glibly proposed, of replacing the whole of the present system of alternating mains by a low-pressure network extending over the district, was a proposition that took his breath away. The cost of the low-pressure network in London formed a considerable portion of the total capital of the Supply Companies, whereas the cost of laying the feeders, which after all was the only thing in which the alternating

Mr. Crompton. high-pressure system (as now proposed to be altered), would differ from the low-pressure system, was after all a trifling matter. He had prepared calculations of the economy that might be expected supposing such changes were carried out, basing them on data furnished by Mr. Mordey, and adopting the efficiency figures of the most perfectly-designed transformer. He would suppose that for each low-pressure feeder a high-pressure feeder should be substituted, having at the end of it a transformer situated in a pit, not supplied with any of the complicated devices proposed by Mr. Gordon, but depending for its mean annual efficiency on the excellence of Mr. Mordey's design. He found that in this case they might expect to get an average annual efficiency of 90 per cent. with a 12·8 per cent. load-factor, which corresponded to the present Kensington one. He found that if the size and cost of the present system of low-pressure feeders was so proportioned that the annual average loss in the low-pressure feeder was the same as that in the high-pressure feeder and transformer taken together, then the high-pressure system began to be more economical than the low-pressure when the distance from the generating station exceeded 2,400 yards. This was when 110-volt lamps were used on the three-wire low-pressure system. Therefore up to that distance, taking equal loss and efficiency all round, from the one point of economy only, the low-pressure system was superior to the high-pressure one. He believed that these figures would be found substantially correct, and the practice of the Edison Illuminating Company in New York was in agreement with them.

Correspondence.

Mr. du Bois-Reymond. Mr. A. du Bois-Reymond said the main difference between English, and especially London, lighting stations and those of continental towns seemed to be caused by the numerous foggy days which unexpectedly upset the regular variation of what Mr. Crompton called the "load-factor." This might partly be the reason why Mr. Crompton had altogether omitted to notice the share taken by the load-factor of the darkest day in the year, in determining the maximum value of the ratio, accumulative plant : motorial plant. Although in his explanations of *Fig. 5* and the accompanying Table, giving the corresponding numerical values, he casually mentioned this ratio, no great importance was