Discussion.

Mr. J. W. SWAN remarked, through the Secretary, that even if the material was not as large, nor the conditions, under which the observations were made, as perfect as could have been wished, the Paper at least formed an interesting contribution on a difficult and important subject. He doubted, however, whether the facts adduced were sufficient to establish, or even to strongly support, the theoretical views expressed, more particularly with regard to the comparative economy of the arc-light and of the incandescent-light. He failed to see why it might not be possible to obtain as large an amount of light for a given expenditure of energy invested in a series of incandescent-lamps as in an arc-light. It was perhaps not possible to raise the carbon filament of an incandescent-lamp to quite the same degree of intense brilliance as the crater in the positive electrode of an arc-lamp; but there was full compensation for the somewhat lower incandescence of the carbon filament in the large radiating surface obtained through a multiplication of such filaments. He had seen produced by incandescent-lamps the light of between 2,000 and 3,000 candles by the expenditure of 1 HP. He did not say that the lamps were durable at the exceedingly high temperature to which it was necessary to heat the filaments in order to obtain this result; but that was a practical consideration, and he merely submitted the fact, as bearing upon the theoretical view sought to be established by the Tables. He noticed a discrepancy in the figures on which the calculation of the HP. product of light from Swan lamps was based. It was stated that there were twenty-four rows of lamps with two lamps in each row, that the light given by each lamp was 48 candle-power, that the current was 24 webers and the potential 160 volts. The resistance of the lamps cold was mentioned, but the resistance hot was assumed, and this assumption was supposed to introduce an element of uncertainty into the calculation. But if the current and the electromotive force were known, and both these were stated, the one as 160 volts and the other as 24 webers, that was 1 weber through each of the twenty-four lines, and therefore through each lamp—a current more likely to be correct than the 2 webers also mentioned, and which presupposed a total current of 48 webers instead of 24 given as the total; then it followed, that the light per HP. was 438 candle-power, and not 270, as given in the Table of measurements. Probably it had been overlooked that as two lamps were in series, the 160 volts electromotive force, and Mr. Swan.

Mr. Swan. 1 weber current, lighted two lamps, and that the united light of the two must therefore be taken as the product of this expenditure of energy. Whether this was the correct explanation of the error or not, it was certain that with the correction he had suggested the result was much more concordant with numerous other measurements. Referring to the remark, "that from this it will appear in how far the incandescent-light is theoretically more costly than the arc-light, as about 6 to 1," he would only add, that it appeared to him that a much broader basis of observation than that supplied by the Tables of measurement contained in the Paper was required to support the theory sought to be erected upon it.

Mr. Wilde. Mr. H. WILDE observed, through the Secretary, that in considering that part of the Paper which related to incandescent-lighting, the following observations might perhaps be found useful. In the various accounts and descriptions of this method of lighting which had appeared from time to time, a striking feature was the absence of any precise information as to the amount of disintegration of the carbon filament during the transmission of the electric current, and on which the durability or life of the lamp depended. The determination of this question, as would be obvious, preceded all others in order of importance, when the new method of lighting was compared with other illuminants in point of economy and convenience. From experiments which he had made, with Swan's lamps of the most recent manufacture, he had found that the carbon filament, after being maintained at the parliamentary standard of a single gas-light of 16 candles, broke down in one hundred and forty to one hundred and fifty hours. In these experiments care was taken to maintain the light as nearly uniform as possible, and the comparison was made by Rumford's photometer and a standard wax-candle. After the lamps had been lighted for some hours, a deposit of carbon was formed in the interior of the glass globe, which was attended by a visible diminution of the thickness of the carbon filament. This deposit increased in density sufficient to diminish the available light from the filament by 3 or 4 candle-power before it broke down. The depth of coloration of the glass globe afforded a ready means of estimating, approximately, the number of hours which a lamp had been in operation at a given candle-power. Further observations indicated that the durability of the carbon filaments of incandescent-lamps was inversely proportional to the square of the luminous intensity. Hence, the life of a carbon which was one hundred and fifty hours at a power of 16 candles, would be extended to six hundred hours at a power of 8 candles; while with

a power of 32 candles the life of the carbon would be diminished to thirty-eight hours. It would therefore appear that this lamp was only practicable for light below 16 candle-power. There was no reason to expect a better duty from other incandescent-lamps in which a carbon filament was used than was obtained from the Swan lamp, as the metallic lustre and ring of the filament in this lamp showed that the conversion of the hydro-carbon, of which it was composed, into pure carbon, had been complete. The determination of the durability of the filament of an incandescent-lamp thus afforded a basis of comparison with other methods of illumination in point of economy. Now, 750 cubic feet of standard, or 16 candle-gas, were the equivalent of the life of a Swan lamp of the same illuminating power for one hundred and fifty hours, which, with gas at 3*s.* per 1,000 cubic feet, the price in London, amounted to 2*s.* 3*d.* for the same amount of light for one hundred and fifty hours as from a Swan lamp. In this sum was included the cost of manufacture, distribution, and profit on the gas, which was not more than the manufacturing cost of renewing the incandescent-lamp alone. He left untouched the subject of the generation, distribution, and subdivision of the electricity for lighting incandescent-lamps over large areas, as it was attended with so many difficulties, electrical and mechanical, that all comparison with regard to cost would be purely hypothetical; but which, even if these difficulties were overcome, would place the cost of incandescent-lighting largely in excess of the cost of gas-light. While viewing, as he did, the substitution of incandescent- for gas-light as a retrograde step in general domestic and public lighting, there were special applications of the new illuminant which were of undoubted value. The lighting of the interior of steamships by incandescent-lamps had so far been attended with very promising success; but in this case considerations of cost were far outweighed by the superior advantages of comfort and convenience which the new illuminant afforded over oil-lights, for which it was substituted. Other uses would without doubt be found hereafter for incandescent-lighting; and although its application might not be so universal as the promoters of it anticipated, the invention promised to be a permanent and valuable addition to the resources of artificial illumination.

Mr. Wilde.

Mr. H. E. JONES said, although no professed electrician, he had nevertheless been struck with what seemed to him to be two fallacies in the Paper. First, the Author appeared to assume that there was a distinct ratio between the heat-units observed and the amount of light given. That was certainly contrary to his experience of

Mr. Jones.

Mr. Jones. photometric experiments with other lights. In fact, with regard to gas-lights, it was exactly in the inverse ratio, for the most heat from gas-light was coincident with the worst illuminating power. That part of the Paper, however, with which he found most fault was an error in the statements which had been made from time to time about the electric light, and which in his view discredited those connected with it. An attempt was made to draw a comparison between the cost of the electric light and that of gas, but in estimating the cost of the electric light the Author stopped short at the HP. cost of production. In the Appendix to the Report of the Electric Light Committee, June 1879, p. 243, it was stated that of the total cost, 37·11 francs, of a certain number of lamps, something like 31 francs attached to the carbon, altogether independent of machine and HP. In the present case the Author had taken the cost of gas at $2\frac{1}{2}$ dollars per 1,000 cubic feet in New York, and to compare the cost of the electric light with that, there must be added expenses of distribution, management, wear and tear of machinery, and interest upon capital, which altogether was no very small item. The published accounts of a large Metropolitan Gas Company showed that the rates and taxes, the collection and the making up of the accounts in the office, the distribution expenses, cost of inspecting the lighting, and so on, came to three quarters of the net cost of material for the gas, deducting the product received from the coal used. When the advocates of the electric light had obtained a business, which they had not at present, they would be confronted with these expenses; they would also be confronted with the dividend payable to their shareholders, which would have to be met by a balance at the bank, and not by bills and promissory notes, paid for the assumed privilege of lighting some other part of England with a light which, as shown in London, made outsiders think that it was a commercial success. It had been shown in the streets of London; the misguided foreigner came over and thought that the City was being lighted in competition with gas in the most successful manner; the figures of cost were kept out of sight; and the foreigner went and bought a concession of some patent for electric-lighting. That was a profitable operation. He did not wish to wander from the precise subject, but he spoke essentially as a gas engineer. It was said when the electric light was first brought into London that there would be seen on the Embankment lights of 1,000 candle-power, but what was the result? It was found, when tested with the photometer by Mr. Keates,[1] that the light was only

[1] *Vide* Report to Metropolitan Board of Works, May 1879, p. 11.

Mr. Jones.

150 candle-power. If any gentleman drove over London bridge on a dark night he would find the passage a difficult one; he had made it constantly, for the purpose of observing the electric lighting, and the conclusion in his mind was that the lighting of some parts of the City now, practically by the Electric Light Companies, was a ghastly failure. That it was a very extravagant one was proved by a document printed by the Common Council, showing the tenders for electric lighting in the City of London, and proving that it was costing for current expenses three or four times as much as gas; and when the expenses of wear and tear, and so forth, were added, it would be seen what a costly thing electric light was. The Author appeared to have written the Paper for the purpose of bolstering up the electric light at the expense of gas, and claimed for it that which Mr. Jones did not hesitate to say, and which every one practically acquainted with the carrying on of a commercial undertaking on a very large scale would know, was only a fraction of the cost, viz., the HP. of developing the light. No confidence could be reposed in such a comparison. There should have been added the carbons, the wear and tear of the machines, which were running eight hundred revolutions per minute, the original cost of the plant, the depreciation, which, with machinery running at that speed, was 15 to 20 per cent. per annum, and also the managerial and general expenses, which, as shown in the case he had quoted of a Metropolitan Company, where the rates and taxes alone amounted to 30 per cent. of the net cost of the gas for coals, after deducting the value of the products. One other point he wished to notice was this: a great deal had been said of what light could be developed from 1 lb. of coal burnt on the bars of a steam-engine developing electric light, and it was assumed that that was something enormous compared with what the gas engineer made of it. Now he wished to say that 1 lb. of coal could not be treated more economically than by the gas engineer. He took it, distilled it analytically, brought out the fixed, gaseous, and liquid carbons, and then returned a fuel out of the coal which was essentially the fuel of the poor; and besides that, he got the light, and many other things. There had also now been obtained something approaching to a good gas-engine, and it had been found that gas used in that way was really more effective than the coal burnt under the boiler. Therefore all the exaggerated contempt that was poured by ignorant people upon gas, as contrasted with the electric light, was very much misplaced. There was much ignorance abroad; he was guilty of it himself to some extent with

Mr. Jones.

City of London—Electric Lighting, 1880.

Abstract of tenders received by the Streets Committee of the Commissioners of Sewers on the 28th day of October, 1880, for lighting the thoroughfares of New Bridge Street, Ludgate Circus, Ludgate Hill, St. Paul's Churchyard (North side), Cheapside, Poultry, Mansion House Street, Royal Exchange (open space in front of), King William Street, Adelaide Place, Queen Street, Queen Street Place, Queen Victoria Street, King Street, Guildhall Yard, London Bridge, Southwark Bridge, and Blackfriars Bridge.

Name of Contractor Tendering.	To Light for 12 Months, from Sunset to Sunrise.	To provide and fix Machinery, Lamps, &c., and remove same at expiration of Contract.	Total Cost of 12 Months' Trial.	Number of Electric Lamps to be Lighted.	Number of Gas Lamps not to be Lighted when Electric Lamps are alight.	
District No. 1.—Comprising Blackfriars Bridge, New Bridge Street, Ludgate Circus, Ludgate Hill, St. Paul's Churchyard (North side), and Cheapside (from Western end to King Street):—						
	£.	£.	£.			£.
Anglo-American Electric Light Company ("Brush" System).	660 abt. (same price as Commission pays for gas.)	750	1,410	32	150 abt.	=600
Crompton & Co. . .	2,007	500	2,507	17	152	=608
Electric and Magnetic Company ("Jablochkoff" System) . .	1,500	1,550 [1]	3,050	48	144	=576
Siemens Brothers .	2,050	1,650	3,700	29 (viz., 23 small, 6 large.)	144	=576
District No. 2.—Comprising Southwark Bridge, Queen Victoria Street, Queen Street (between Queen Victoria Street and Upper Thames Street), and Queen Street Place:—						
Anglo-American Electric Light Company ("Brush" System).	..	No tender				
Crompton & Co. . .	2,167	560	2,727	16	176	=704
Electric and Magnetic Company ("Jablochkoff" System) . .	1,580	1,350 [1]	2,930	52	161	=644
Siemens Brothers .	1,850	980	2,830	31 (viz., 26 small, 5 large.)	164	=656
District No. 3.—Comprising London Bridge, Queen Street (between Queen Victoria Street and Cheapside), Cheapside (between King Street and Poultry), King Street, Guildhall Yard, Poultry, Mansion House Street, Royal Exchange (open space in front of), King William Street, and Adelaide Place:—						
Anglo-American Electric Light Company ("Brush" System).	..	No tender				
Crompton & Co. . .	2,475	650	3,125	18	132	=528
Electric and Magnetic Company ("Jablochkoff" System) . .	..	No tender				
Siemens Brothers .	2,270	1,450	3,720	32 (viz., 26 small, 6 large.)	138	=552

[1] Should the Commission determine to have the conductors laid underground, the additional cost for each district will be £2,000, and £2,000 more for removing them and making good after.

N.B.—The black figures are not in original, but represent about the cost of the gas lighting.

regard to electricity. As he had frequently replied to people when they had asked him upon the subject, electricity, as applied to lighting and to power, was analogous to water which was pumped into an accumulator under pressure, and liberated through the crane or other machine, being a transmitter of energy and not an original power, which could be gathered anywhere, and turned at once to the service of man. He would like to direct the attention of the members to the article on the subject of the cost of the Electric Light in "The Engineer" of the 13th of January, 1882. Mr. Jones.

Mr. R. E. CROMPTON observed that it had been pointed out how engineers could obtain a cheap source of power by using the gas-engine, and their attention had been called to the point, that with the primary object of supplying the public with light, by means of gas, the manufacturers obtained secondary products of importance, quite equal to, in fact, almost greater than the gas itself. He thanked Mr. Jones for this; in future electric light engineers would be able to obtain all the useful residual products from their lb. of coal by the ordinary process of distillation, and simply use the gas as a means of obtaining motive power for producing the electric current. He had, however, prepared a few notes on a different part of the subject, namely, the purely scientific question of the candle-power of the electric light. He noticed that almost at the commencement the Author confessed that but little was known of the specific heat of the vapour of the electric arc and of its temperature. This admission had greatly disappointed him, as from his own observations he had long since formed an opinion that the candle-power of the electric light, whether the arc-light or the incandescent-light, was a function of, or at all events closely allied to, its temperature, and from the title of this Paper he fully hoped for some information on the point. In incandescent-lamps the relation of temperature to lighting power was self-evident, as the temperatures were comparatively low, and the changes in colour, marking the changes in temperature, could be followed by the eye. But with the arc-light it was different. The greater intensity of the light made it difficult, and almost dangerous, to observe it closely, and it was only by the use of the spectroscope, or by similar means, that changes of these exalted temperatures could be observed. The Author had unnecessarily complicated the matter by introducing the regulating arc-lamps themselves. They occupied but a secondary part in obtaining high efficiency in candle-power from a given electric current. So long as they held the carbons firmly in line, and fed them together with due regularity, so as to maintain a constant difference of potential on the two sides of the arc, they Mr. Crompton.

Mr. Crompton. did all they could towards this efficiency. What had mainly to be looked to was the obtaining of a higher temperature at the arc, and this by perfecting the carbon rods. The carbon rods must excel in two main points; first, they must be extremely refractory and infusible, in other words, be pure, and free from even the smallest percentage of material more easily volatilizable than the carbon itself. Secondly, they must be hard, dense, and compact, so as to oppose as much resistance to the disintegrating action of the current as possible, thus necessitating the much-desired extreme temperatures. The wide discrepancies noticed between different photometric measurements of the same electric light system, were mainly due to the differences in purity and density of the carbons. Pure carbons of little density, or dense carbons containing considerable impurity, were equally adverse to high candle-power. Carbons had been moulded from absolutely pure carbon, yet of loose texture, which would not afford anything more than a pale blue light of 50 or 60 candles, when a 20 ampère current was used, and almost equally bad results had been given by well-made dense rods, containing not more than 5 per cent. of lime, soda, and other ash. Moreover, the same rods varied considerably from inch to inch, and this would often account for the great changes in brilliancy observable in the arc-lights in public use. The blame for the variation in the light was generally visited on the lamps, machines, or engine, but nowadays the blame ought to rest far oftener on the carbons alone. If, as they burnt away, a point was reached where the purity and density exceeded the average, the temperature and the light were greatly increased, and a corresponding decrease in purity or density would greatly diminish the temperature and light. The light given by a pair of carbons in an arc-lamp would vary 60 to 100 per cent. from this cause alone. This change in the light-giving efficiency during the burning away of a single pair of carbons, and consequent wide fluctuations in the photometric readings, had been the cause of endless trouble to observers. The generator of the current, the lamp, the photometer, the difference of colour between the arc-light and standard-light, and lastly the observer himself, had all been objected to. It was uncertain what the Author meant by "axial" and "bi-axial" measurements. Probably, however, he meant what was ordinarily termed horizontal and angular measurements. A strong protest ought to be raised against the absurdity of taking horizontal photometric measurements of continuous-current arc-lights. There was no reason why experimenters should continue making and publishing them without the corresponding angular measurements, unless

it was that the latter were a trifle more difficult to obtain; but even that could be easily avoided by inclining the lamp when taking the photometric readings. At any rate, the commercial efficiency of the light was always taken at the angular measurement, for the simple reason that as all large centres of light, such as electric arc-lamps, must be placed high up, in order to avoid floor shadows, the rays below the horizontal plane were of the greatest commercial value. This angular measurement was at least 80 per cent. in excess of the horizontal one, and it was eminently unfair to compare the electric arc, measured thus horizontally, or at its point of lowest commercial efficiency, with the incandescent electric, or any other source of light, the efficiency of which was nearly equal in all directions. The introduction of heat-units into calculations of the candle-power efficiency of the lamps seemed to be unwise, and likely to lead to confusion. Surely the expression "candle-power per HP." was sufficient to compare the lighting power with the energy. Talking of "Gramme degrees per candle-power" seemed like saying "minutes per ounce." In the table where the arc-lamps were compared with incandescent ones, the arc-lamps were deprived of the 80 per cent. due to the angular measurement not being taken, whereas the average candle-power of the incandescent-lamps was put at 271 candles per HP., instead of 180 candles, which was certainly the maximum efficiency obtained from such lamps up to the present time, under actual conditions of safe working. With these corrections the efficiency of the arc-lamps, compared with that of the incandescent ones, became as 18 to 1. Wide as this gap was, it could not be hoped materially to lessen it, considering that the temperature of the arc-carbons was that of disintegration and destruction, whereas that of the incandescent lamps must not be sufficient to soften, or even change, the form of the delicate carbon filaments.

Mr. Crompton

Mr. W. Sugg wished to offer a few observations upon a different point to that referred to by Mr. Jones. The Author appeared to have taken the cost of gas in New York, when he might just as well have taken the cost of gas in England. The cost, however, was a matter which must be worked out in practice, and if it was found that the cost of the electric light would be very much greater than that of gas, it probably would not be so much employed as gas. That, however, might be left to the future. The part of the Paper with which he wished to deal was the first point, namely, the standard sperm candle. The Author asked what was a sperm candle, and he had pointed out that the light of a sperm candle was that which would be given from the candle

Mr. Sugg.

Mr. Sugg. 1 foot all round the light. That was a very good way of expressing a sperm candle, because it was practically what could be got out of it for use, for reading or for work; but unfortunately it was not the standard looked upon by Parliament as being the standard sperm candle. The light of a standard sperm candle was the light given from a point in the centre of a candle, and the calculations with the photometer were made upon that assumption, that the point of light in the centre of the candle was the whole of the light of the candle. He had found it practically an extremely difficult thing, with such an arrangement as that, to carry out experiments and calculations with regard to lighting various areas, because with that theory to deal with, viz., the central point in the candle being the whole of the light, it was evidently a difficulty, when it had to be worked out for estimating the degree of illumination of areas. The plan which the Author proposed, of taking 1 foot round the candle for that purpose was a good one, and could be usefully adopted for many purposes. As he had pointed out before, the standard sperm candle was an india-rubber rule, and it seemed strange that for so many years it had continued to be used as a standard when so fallacious, and which was known to be fallacious so far back as 1868, through a series of experiments made by Mr. T. N. Kirkham, M. Inst. C.E., then the engineer of the Imperial Gas Company, in which he showed how very different one candle was from another.[1] Those experiments had lately been repeated, and he supposed from time to time they would be repeated again; but what would be the result of these repetitions he could not say. The Standards of Light Commission appointed by the Government had also endorsed the opinion, given by Mr. Kirkham and himself, that the standard of light adopted for England was a bad one. There were other standards of light which were really standards of light, and were not such as that derived from degrees of temperature, as the Author of the Paper seemed to desire. He did not himself see what the temperature of the flame would have to do with its illuminating power, except, as Mr. Crompton had stated, with regard to the incandescent lamps. Incandescent lamps of course would give a very much higher illuminating power as the temperature was raised; and therefore in that respect, supposing one incandescent lamp were measured against another it might be useful, but as comparing the illuminating power of electricity with that of gas, or any other standard, it seemed to him that it was a

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxviii., 440.

bad thing, and would result in erroneous statements. When there were found differences in the illuminating power of 16-candle gas of from 1½ to 2 candles with the best candles obtainable, it would be seen that when that was magnified up to the high illuminating power of the electric light, errors would arise which were surprising. With respect to the Tables adopted by the Author, he had introduced, as Mr. Crompton had observed, "heat-grammes," and sundry other terms unintelligible to those who did not follow very closely the line in which he had been working; but Mr. Sugg could point out that there were several standards at the present moment better adapted for the purpose of testing the electric light than the standard candle. There was first of all the gas standard introduced by Mr. Vernon-Harcourt, one which could be carried out for the purpose of estimating the standard candle accurately at any time and under any circumstances. The method that he adopted, taking a certain quantity of pentane, a product of petroleum, distilled in a certain manner, mixing a certain quantity of it with air and burning it in a proper apparatus, appeared to give a perfect idea of what a standard candle should be. That was the only one, he believed, in which the value of the light was an exact standard candle; but there were others, for example, that of Mr. Keates, in which he used spermaceti oil, and burnt it in a lamp, producing a light of 16 candles, and that light was much more easily used for the purpose of testing the electric light. He had used it himself for that purpose, and found it going for weeks without variation, so that he believed it to be a much more reliable standard than the sperm candle. The next one after that was a standard of two candles made by Mr. Methven, assistant engineer of the London Gas Company, in which he used the ordinary common gas supplied for lighting; and if there was as he said no variation in that standard when used with common gas, and Mr. Sugg believed there was a great deal of truth in what he said, it would be certainly better than the candles, and that notwithstanding there might be slight variations in it; this standard of his would be found much more suitable to the electric light. The next was a 10-candle gas standard of his own, and there were several others which were very useful; and if the electric light was to be estimated for its illuminating power, it would be better to estimate it by such a standard as these than by the fallacious standard adopted of a parliamentary sperm candle. There was one remark made by Mr. Crompton on which he would make an observation, and that was as to the manner in which testing the electric light for illuminating power could be carried out. In the

Mr. Sugg.

Mr. Sugg. case of gas, the assumption was that the light was given in a circle all round the burner—equal in all directions—and nearly all round in a vertical circle. It was not so with the electric light. With the electric light the light came from between the two carbons, and the strongest light was in one direction; it did not light equally round the vertical circle, neither did it light equally in the horizontal circle; because on whichever side of the centre the carbon rested, one side or the other, a greater light was shown. It could be seen with a Bunsen photometer that this variation would produce very great errors. With regard to the incandescent-light, that, of course, could be tested in exactly the same manner as gas, except that it must be tested as a flat-flame burner; because he presumed that the light was given more strongly in the direction of the one side of the loop than it was across the loop, so that if the mean of the edge and flat of the lamp was taken a very good result would be obtained. But with the arc-light it certainly did seem necessary that a correction should be made when it was tested with a photometer horizontally or at an angle, for an evident error existed in the value of the result, caused by the fact of the light not giving its light in all directions alike, as supposed by the construction of the photometer. With the Jablochkoff light the result more nearly approached that given by a candle than in any other, with the exception of the Jamin, which was the reverse of the Jablochkoff. Either of those could be easily tested in the manner he had stated; but with the arc-lights it would be necessary to make the correction, and he had not seen that that correction had ever been made.

Mr. Shoolbred. Mr. J. N. SHOOLBRED said, he wished to refer to the Tables contained in the Paper. There was a very material difference in the way they were arrived at, which the Author seemed hardly to be aware of, and which ought to be pointed out. All the lights named in the first Table were lights that had been produced and measured directly from the electric machine, or the dynamo itself. The second Table, on the other hand, represented the result of experiments carried out by Sir William Thomson upon a single Swan light, at which Mr. Shoolbred was allowed to be present, and in which the Faure accumulator battery was used, the current being taken direct from that instead of from the dynamo. The results showed points of considerable interest, and, he thought, opened a very large future for incandescent-lighting where a steady current was used. Sir William Thomson not being fully satisfied with the photometric measurements, and having to leave town, allowed him to make some further experiments, and the result of the second series of

Mr. Shoolbred.

experiments shown in the tables and curves annexed. The series of experiments was carried out upon a single Swan light and a single Maxim light; increments of current being made by successive additions of five Faure cells at a time. The photometric measurements in the second case were carried out with the instrument to which Mr. Sugg had referred, and with Mr. Keates' 16-candle sperm-oil lamp as the standard of reference. The oil consumed was accurately weighed, and there was every reason to believe that the measurements were carried out accurately. The curves represented severally the candle-power, the measured potential, the intensity of the current, and the amount of mechanical energy in HP. This last was the simplest manner of putting the mechanical energy expended; he quite agreed with Mr. Crompton, that the Author had needlessly complicated the Paper by introducing gramme-degrees, foot-lbs., or heat-units; all of which could be deduced from the ratio generally made use of—that of candle-light per HP. The amount of mechanical energy converted into electrical energy was indeed the basis of the whole of this mode of generating electricity. In practice the condition of incandescent lights, when working direct off a dynamo-machine, and without an accumulator, was represented approximately by the

TABLE of COMPARATIVE EXPERIMENTS with FAURE ACCUMULATOR on INCANDESCENT ELECTRIC LIGHTS.

1. SWAN INCANDESCENT LAMP in CIRCUIT.

Number of Faure Cells used.	E.M.F.	Current.	Light.		Mechanical Energy.[1]		
	Volts.	Ampères.	Standard Candles.	Becs Carcel.	HP.	Kilo-grametres.	Heat Units (Joule).
30	73	1·28	22·4	2·36	0·125	9·52	5·3
35	85	1·84	65·6	6·91	0·209	15·94	8·9
40	97	2·38	141·0	14·84	0·309	23·53	13·2
45	104	2·50	204·0	21·47	0·348	26·50	16·3

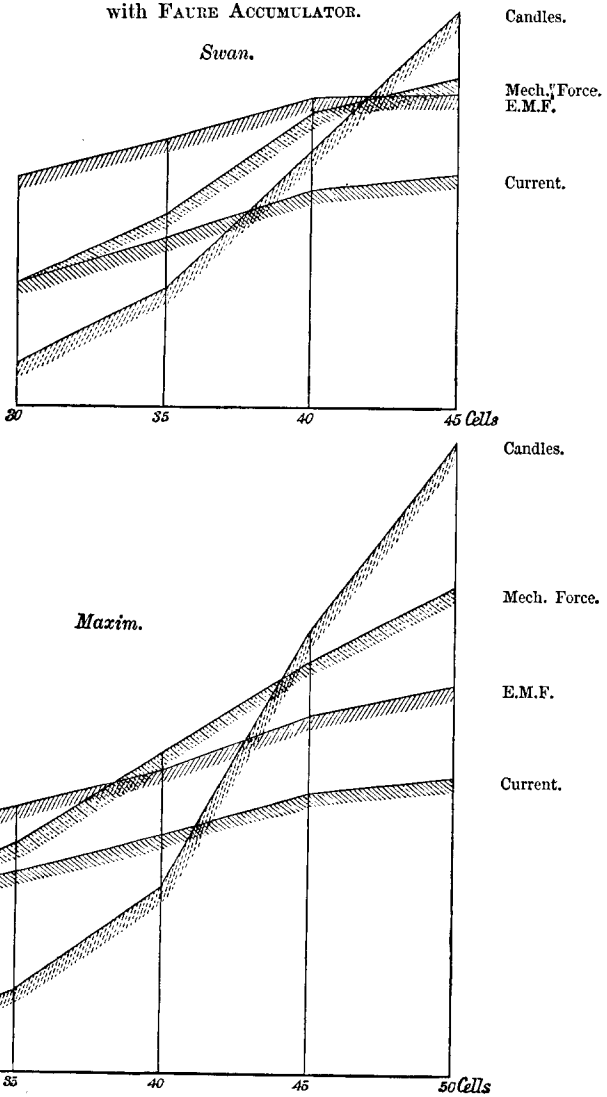
1. MAXIM INCANDESCENT LAMP in CIRCUIT.

30	74	1·81	16·0	1·68	0·179	13·65	7·6
35	85	2·24	45·3	4·77	0·255	19·41	10·9
40	98	2·59	101·1	10·64	0·340	25·87	14·5
45	113	3·00	229·0	24·11	0·454	34·56	19·4
50	124	3·20	333·0	35·05	0·531	40·45	22·6

[1] The mechanical energy lost in charging the accumulator from the dynamo is not included.

Mr. Shoolbred.

COMPARATIVE EXPERIMENTS in INCANDESCENT ELECTRIC LIGHTING with FAURE ACCUMULATOR.



diagrams (see preceding page). Such being the limit under the ordinary conditions, the value of the intervention of the accumulator was represented by the gradual progress towards the right. It would be seen how greatly the intensity of the light could be increased, and at the same time its economic value raised, in proportion to the current expended, by using the steady current of a storage accumulator. In another way the economy of these lights could be augmented; inasmuch as their life would be considerably lengthened owing to the use of the steady current. It had been mentioned, that if the incandescent-lights were urged beyond 16 candles there would be a gradual deposit of carbon on the glass, and the filament of carbon would be destroyed. He had noticed himself the phenomena referred to of the deposit of carbon, but that was owing to the improper use of the lamp; for if a lamp which was only intended for 16 candles was pushed to 25 or 30 candles, there would of course be produced an extra strain. But to say that incandescent-lights were limited by all the makers to 16 candles was totally fallacious; because they could be made of whatever candle-power was required. Just the same as a gas-burner could be made to consume 2, 3, 4, or 5 cubic feet of gas, so the resistance of the incandescent-lamp could be altered so that it would give from 10 to 40 candles or more. With regard to the proportion of candle-light given off per HP. absorbed with the incandescent-lighting, Mr. Swan had himself some two years ago limited it to from 150 to 200 candles at the outside per HP. There appeared to be a great deal of difference with regard to the cause of the large discrepancy between the proportion of light produced per HP. absorbed, with the arc over the incandescent-system; an explanation given some time ago by Mr. C. F. Varley seemed to point to the true cause. It was suggested that a much larger proportion of the current was used in warming up the carbon to incandescence than was required to pass from that stage to the production of the arc; and in this greater light-giving value of this last portion of the current might be found some explanation of the apparent discrepancy. If what was indicated by the diagrams about the use of an accumulator in conjunction with the dynamo was correct (practically the substitution of the 40-cells vertical line, in the diagrams, instead of the 30-cells one), it might be argued that incandescent-lights might, by its use, be very much more economical in their results than they had hitherto been. The fact that more duty could be got out of gas when used in a gas-engine than when used for illuminating purposes was not surprising. In the report of the Committee of the House of Commons,

Mr. Shoolbred.

Mr. Shoolbred. in 1879, On Lighting by Electricity, it was pointed out that the heat-giving properties of gas exceeded considerably the light-giving ones. Bunsen had shown that the light-giving properties were only 6½ per cent. in 100 volumes, whereas the heat-giving properties were no less than 87 per cent.

Professor Tyndall. Professor TYNDALL remarked that he had not dealt much practically with this question of determining the candle-power of the electric light. He had, in association with Mr. Douglass, done something of the kind, but that was a long time ago. He noticed, of course, that contending parties were here upon the platform, but from those he begged to entirely abstract himself. With regard to Table I., he believed the results might have been predicted *à priori*. It must be remembered that the so-called electric light was a thing of an exceedingly composite character. It had an outflow of rays that were entirely incompetent, even when they impinged upon the retina, to excite vision. Years before the present amazing powers of the electric light were developed, he had experimented upon the light produced by a battery of fifty Grove cells, which evoked what in those days might be called a very powerful electric light, and found the invisible radiation, meaning by that the radiation which was incompetent to excite vision, to be 90 per cent. of the whole. He was afraid it was impossible to get rid of this condition. This invisible radiation appeared to be, so to say, the substratum of the visible. The luminous rays must be built, as it were, upon the non-luminous rays. The same was the case with the sun itself, as Herschel was the first to prove. Müller found that the luminous rays of the sun were only one-third of the total emission by the sun; that the invisible, obscure, calorific rays emitted by the sun were two-thirds of the total radiation. In the case of the electric light the invisible rays were by one series of experiments proved by himself to be 7·7 times the visible; and in another series of experiments, made according to a totally different method, the invisible calorific rays proved to be 8 times the visible. With regard to the sun, as he had said, its invisible radiation was twice as great as its visible radiation; but higher in the atmosphere, above the screen of aqueous vapour that overspread the earth, if a spectrum of the sun was obtained, it would be found that then the obscure radiation of the sun approximated to that of the electric light. He had received a letter some time since from a gentleman who had been experimenting at a height of 12,000 feet above the sea, in a very dry region of the earth in the Sierra Nevada Mountains in California, and he declared

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that there was an enormous extension of the invisible spectrum of the sun in those regions. Probably at the limit of the atmosphere the invisible radiation of the sun would represent six times the energy of the visible radiation. With regard to the Table, the Author of the Paper took into account the total amount of power absorbed, and the question was, how much of that power was converted into luminous rays, into those rays that were effectual for vision, and how much into rays that were not effectual for vision. On theoretical grounds he should have inferred that the Table must be as the Author had stated, and that, as Mr. Crompton had remarked, the more intense the power was made by the introduction of a resisting interval between the two carbons of the arc, and the higher the electromotive force invoked to urge the electric current across the interval, the greater was the proportion of the luminous rays introduced into the total radiation. In the first lamps mentioned, the number of foot-lbs. per candle-power was very small compared with the smaller lights. This simply expressed, in the case of the Werdermann and in the case of the incandescent-light, that the energy was in great part expended in the production of invisible heat-rays, and that in the intense arc-lights a greater fractional part of the total energy was converted into wave-motion competent to excite vision.

Mr. Atkinson.

Mr. W. Atkinson did not know whether the Author had stated at what distance the experiments had been made with the light. He understood that there was great difficulty in arriving at any conclusion as to the power of the electric light, dependent upon the different distances at which the experiments had been tried. He believed it had been discovered that, even in comparatively very short distances, in a room within the space of a few feet, very varying results would be obtained. The rays of the electric light were probably readily absorbed by the atmosphere when humid, as Dr. Tyndall had mentioned, in the case of the sun. Then with regard to the economy or the cost of gas, the element of the destruction of fittings in a house had not been referred to. If the electric light and the gas light were compared, it was clear that, to a consumer, the electric light would be more economical, because there would be no destruction and no dirt.

Mr. Douglass.

Mr. J. N. Douglass said his experience with the electric light had been entirely with arc-lamps. It was a pity that the comparison in the Paper as to the cost of gas and of the electric light, had not been made with gas in London instead of in New York, because the cost of gas in New York was about $2\frac{1}{2}$ per 1,000 cubic feet, while in London it was about 3*s*. Following the figures

Mr. Douglass. of the Author, he found he had given a 4-light chandelier of 64-candle power, as costing per hour in New York 20 cents for gas, the burners being of the efficiency of the London standard burner. A burner would give about 5 candles per cubic foot of gas consumed; therefore, the above result would be got in London at the cost of about 1·8 per hour, as against 8*d.* per hour in New York. As Mr. Jones had pointed out, the only cost given in the Paper for the electric light was that of the motive power, and that was stated to be 4·1 cents, being more than twice the cost of the gas-light in London. There appeared here the same difficulty of comparison that was met with in lighthouse illumination; and, from his experience, he might say that if the electric light could be fairly compared with oil or gas as consumed in lighthouses, it would be found that, with the arc-light about ten times the amount of light per unit of cost was obtained with electricity above that of gas. Unfortunately, the element of cost of plant and of additional cost of labour came into play; and up to a certain intensity, at a lighthouse, oil was the cheapest light. But then an intensity could be attained ten times that of the oil with the electric light; and there would be about five times the amount of light per unit of annual cost than with the oil; however, the first cost and annual maintenance were doubled. If that first cost could only be reduced to that of the oil or the gas-light, electricity would, no doubt, prevail. With regard to the measurement of candle-power, there appeared to be difficulties with the electrical mode of measurement; and he, for one, would not be disposed to accept any apparatus for electric light, unless he measured the light photometrically in addition to the system proposed by the Author of the Paper, because, as pointed out by Mr. Crompton, there was the quality of the carbon coming into play, which was liable to considerable variation. It was quite possible in the same bundle of carbons to get differences of quality of certainly 50 per cent. With regard to the candle-power, he saw no difficulty in using an ordinary candle with care. Any one who was used to it could arrive at results, certainly within 5 per cent.; and to measure the electric light, which varied within an hour 50 per cent., surely the candle was near enough as a unit of comparison. The great difficulty with the candle was the difference in colour. That was, however, easily got over if it were wished to reduce the actual candle-measurement to the intensity at the actual candle-flame colour by colouring the electric light with yellow glass, and bringing it to the colour of the candle.

Sir William Armstrong.

Sir WILLIAM ARMSTRONG, President, said he had had considerable experience with the incandescent system of lighting. He had used it at his house in the country for nearly a year. He had gone through many troubles and difficulties, such as early experimenters always had to encounter; but, upon the whole, he could decidedly say that his experience had been satisfactory. No doubt the comparison of candle-power between the different systems of lighting was a very important matter; but it was by no means the only consideration that presented itself. He commenced with attempts to make the arc-light available for domestic use; and after trying various systems and various arrangements, he came to the conclusion that no possible improvement that could reasonably be hoped for would make it suitable or desirable for domestic purposes. He then tried Mr. Swan's system, and with the lamps which he furnished in the first instance, and which were made very carefully, no doubt, by hand, the endurance and illuminating power were exceedingly satisfactory. He came to the conclusion that each single lamp gave about as much light as an ordinary duplex kerosene lamp, usually estimated at about 25 candles. When the company commenced their operations, they changed the system, and instead of using single lamps, they used two lamps in series—at least they recommended the employment of two in series, instead of one in parallel. Owing, perhaps, to imperfect experience, he found the durability of the new lamps much less than that of the first lamps supplied; but after a good deal of disappointment and change he eventually obtained lamps which, in pairs, fairly represent what the single lamps did before. It was premature to attempt any comparisons either as to the illuminating power or cost of renewals, for it was quite clear that the whole system was yet in its infancy. He could state from his own experience that there was the widest possible difference between the lamps supplied. He had some lamps at the present time which had been in use from the very first, whereas he had also had some that failed after a few hours' use; therefore, until the manufacture settled down to something mature, and the difficulties of starting were fairly got over, there could hardly be a judgment as to the capabilities of the lamps, either with reference to endurance or illuminating power. This much he could say, that no deficiency of candle-power or endurance such as had been attributed to them would induce him to abandon the system. Gas was an admirable means of lighting in its proper place, but in private rooms it was undoubtedly very objectionable. The incandescent-light had no connection whatever with the

Sir William Armstrong.

atmosphere, and therefore had no contaminating effect upon it; it had very little heating effect; it was perfect in colour, perfect in steadiness, and in fact was the perfection of lighting for domestic purposes. That, at least, was his experience; and he had no doubt that difficulties which had arisen, and were arising, would be got over, and that the incandescent lamp would attain to a perfectly satisfactory state. The number of lights in his house was sixty, that was thirty pairs. He had more, but could work that number at the same time. The source of power was a turbine situated nearly a mile off; and with 7 HP. he was enabled to maintain those sixty lights. Most of the lamps that had failed had not failed through the actual wearing out of the carbons so much as from defects in their manufacture, from points at which there seemed to be some defect which made them liable to give way in use. He felt, however, sure that, when the manufacture of the carbons was perfected, all difficulties of that kind would be got over. The light in his case, using water-power, was highly economical. There was the cost of the labourer's attendance upon the machine at night to supply the sixty lights, and the only other expense was the cost of renewals, which would certainly not be very serious, according to his past experience. One point he might mention was the extreme importance of having an absolute uniformity of motion in the generator. The smallest variation immediately produced a disagreeable twinkle upon the lights; and so sensitive were they, that while he used belts made in the ordinary way with joints he could count the revolutions of the wheel; that was to say, every time a joint ran over the pulley it made a sufficient variation to cause a slight effect on the light. He could not obtain an absolute uniformity until he used an endless belt made like a flat chain of leather links stamped out of the sheet, and joined together by putting a pin through, a form of belt now pretty generally used in cases where very even and regular motion was required. He was afraid that unless the gas-engine was supplemented by means to obtain a very steady and uniform motion, the absolute steadiness of light which he had attained would hardly be obtained from it; but no doubt there were means, when attention was directed to the attainment of that particular object, which would be found to remedy any inequality.

Dr. Higgs.

Dr. HIGGS remarked in reply, through the Secretary, that the results given in the Paper were intended partly to be intercomparative, and partly were an endeavour to reduce the observations of different authorities to a common standard. This common

standard he assumed to be represented by the "energy" absorbed in the light-centre. He did not suppose that "temperature" and light were related; but that if light were any form of energy, then that light would be related to the energy of the light-centre; he had measured this energy in heat-units and not in "foot-lbs. per candle-power" as suggested, because he did not know what a candle-power was, in which ignorance it seemed he did not, judging from the remarks of those who had favoured him with their criticism, stand alone, and he thought he did know what a heat-unit was. Between the energy as measured in heat-units, not the temperature, he had found the relation to be, as stated. But besides criticism, he had thought to elicit facts and measurements from others. Dr. Higgs.

Correspondence.

Mr. K. W. HEDGES observed that the Author, in referring to the way in which he measured the electric light in comparison with the method adopted by Sir W. Thomson and Mr. Bottomley, did not mention what that method was. The great difficulty with powerful electric lights seemed to be the variation of their colour as compared with the present standards, the sperm candle and carcel burner. He thought that, failing a better standard, the difficulty might be obviated by photography, either as adopted by Captain Abney by photographing the spectrum, or in a simpler manner by photographing the luminous crater in the positive carbon. The intensity of the light was greatest at the latter point, and by interposing glass of known opacity between the light and the sensitive plate, and noting the time taken to produce a photographic image, the comparative amount of light from any two sources might be ascertained. He noticed the Author's opinion that incandescent-lighting was theoretically six times the cost of arc-lighting. This would make the incandescent-light as dear or dearer than gas, and might deter the introduction of the electric light into theatres and crowded rooms where it was much needed. The cost of arc-lighting was considerably less than that of gas, the only drawback being the colour which did not harmonize with gas. He thought the difficulty might be got over by enclosing the arc-lights in coloured globes so as to tone the light to the colour of gas. From an experiment in one of the picture galleries at the South Kensington Museum, he found the loss of light to be less with a suitably coloured globe than with an opal one. If two Mr. Hedges.