AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

New York, September 28th 1898.

The 127th meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS was held this date at 12 West 31st Street, and was called to order by President Kennelly at 8:20 P. M.

The Secretary read the following names of associate members elected at the meeting of Council in the afternoon.

Name.	Address.	Endorsed by
CARTER, FREDERICK WILLIAM	Lecturer in Electrical Technology, City and Guilds of London Institute, Exhibition Road, London, S. W.	Edwin J. Houston. A. E. Kennelly. A. J. Rowland.
COLEMAN, WALTER H.	Supt. and Treasurer, Andover Electric Co., Andover, Mass.	Chas. B. Burleigh. Sidney B. Paine. C. D. Haskins.
DOHERTY, HENRY L.	General Manager and Engineer, Madison Gas and Electric Co., Madison, Wis.	M. C. Beebe. D. C. Jackson. C. F. Burgess.
FRANK, GEO. W., JR.	Secretary, Treasurer and General Manager, The Kearney Electric Co., Kearney, Neb.	J. G. White. W. F. White. D. C. Jackson.
MANSFIELD, R. H., JR.	Electrical Engineer and General Manager, Ward Leonard Electric Co., Bronxville, N. Y.	H. Ward Leonard. F. S. Holmes. F. A. Pickernell.
MILLER, KEMPSTER B.	Chief Electrician, Western Telephone Construction Co., 33 Elaine Place, Chicago, Ill.	S. G. McMeen. Fred'k Bedell. Harris J. Ryan.
ROSENBUSCH, GILBERT	Engineer, Sprague Electric Co., South Orange, N. J.	Frank J. Sprague. Philip Torchio. R. W. Pope.
THOMPSON, JOHN WEST	Supt. Cia. de Luz y Fuerza Motriz Electrica, Guadalajara, Mexico.	F. A. C. Perrine. F. V. T. Lee. F. E. Theberath.
TRIPPIER, HENRI	Counsel and Technical Engineer, of the Campagne des Transports Electriques del Exposition, Paris, France; residence, 16 rue Ganneron, Paris, France.	Chas LeBlanc. Ralph W. Pope. W. J. Hammer.

WAGNER, HERBERT A	Gen. Supt., Missouri Edison Electric Co., and also with Wagner Electric Mfg. Co., 415 Locust St., St. Louis, Mo.	T. C. Martin. Joseph Wetzler. Wm. E. Geyer.
WILLIAMS, WILLIAM HENRY	Professor of Mechanical and Electrical Engineering, Montana State College, Bozeman, Mont.	D. C. Jackson. S. B. Fortenbaugh F. R. Jones.

Total 11.

THE PRESIDENT :—The paper for the evening is on the “Photometry of the Enclosed Alternating Arc,” and copies of the paper are already in your hands. We are not fortunate enough to have Prof. Matthews with us, but the Secretary will kindly read the paper on his behalf.

THE PHOTOMETRY OF THE ENCLOSED ALTERNATING ARC.

BY CHARLES P. MATTHEWS, W. H. THOMPSON AND J. E. HILBISH.

INTRODUCTORY.

The enclosed arc of the direct current type has received a noteworthy development at the hands of Marks¹ and subsequent workers. It has been the subject of more or less experimental study by Houston and Kennelly, Freedman,² Hesketh,³ Nichols⁴ and a number of others on both sides of the Atlantic. The enclosed arc of the alternating current type is of somewhat more recent development and has received less attention experimentally. It was with the thought of observing something of the behavior of this latter type of illuminant that the data of the following pages were taken.

THE PHOTOMETRY OF THE ARC.

Arc light photometry, in so far as it involves the mere determination of luminous intensity⁵ yields unsatisfactory results for three chief reasons: The first of these is the marked difference

1. London *Electrician*, xxxviii, 615; March 5, 1897. See also "Proc. Electrical Congress," Chicago, 1893.

2. TRANSACTIONS, xiv, 361; August, 1897.

3. London *Electrician*, xxxviii, 793

4. Sibley *Journal of Engineering*, xi, 368; June, 1897.

5. That our photometric nomenclature needs standardizing can not be doubted. The quantity that has been called *candle-power* is hardly appropriate if the Hefner unit be used. If we have arrived at the passing of the candle, should not *candle-power* go? This same quantity is variously styled *intensity*, *total intensity* (Palaz.), *luminous intensity* and *brightness* (Nichols). The unit of *illumination* also goes by several names.

in quality between the light of the arc and that of any of the ordinary standards. The photometrist realizes the generally unsatisfactory character of the existing standards⁶ for the study of sources of a quality similar to that of gas light. Nevertheless, he is vastly better off, in this respect, than he is in the matter of a standard of suitable quality and intensity for arc light measurement. The eye estimates accurately an equality of brightness in two surfaces, only when those surfaces are of the same tint. Moreover, with a color difference, the judgment of an equality differs with different observers. It should be said, however, that the difficulty arising from difference of color is less trouble-

FIG. 1.

some in the case of the enclosed arc than in the case of its progenitor, the open arc. The inner, opalescent globe absorbs the rays of short wave-length in greatest proportion, a fact which brings the color of the arc nearer that of the standard. When an outer globe of milky glass is used—the standard being a glow lamp maintained at, or above, its normal voltage—there is no annoyance from color difference.

The second obstacle to careful measurement, is to be found in the variability of the quantity to be measured. These variations are largely due to the wandering condition of the arc—a peculiarity that is especially noticeable in the open alternating arc,

6. See report of Nichols, Sharp and Matthews, *TRANSACTIONS*, xiii, p. 133, May, 1896.

and in both types of the enclosed arc. Indeed, it is to this feature of the enclosed arc that the flat-ended carbons are due. The change in luminous intensity corresponding to a shifting in the position of the arc from one side of the carbons to the other side is enormous. Curves of horizontal intensity showing the magnitude of these changes have already been published⁷. An attempt to get at the intensity of such a source by a few readings might easily lead to results discordant by 100 per cent. or more. The only hope of securing a result that will show the mean intensity of the arc is in taking a large number of settings, distributed, as to time, with some degree of uniformity. To accomplish this it would seem desirable to do away with the considerable and variable interval of time used, in the ordinary process, in reading the bar. This end was reached by the use of a mechanical device for recording a setting as soon as it

FIG. 2.

is made. The essentials of this device will be readily understood from an inspection of Fig. 1. Its collateral advantages, for the study of personal error and for other photometric uses, have been dwelt upon in a note published elsewhere⁸. For our present purpose, it is sufficient to point out that it permits the observer to keep his eye continually trained on the photometer disk, so that all the major fluctuations may be readily followed and recorded, and this, too, without the visual fatigue resulting from introducing light into the photometer room. The act of depressing the rod *r* makes a permanent record on the paper surrounding the drum, and at the same time advances the drum so that the record may be subsequently identified.

The inaccuracy of photometric settings, due to the causes just mentioned, is perhaps more a question of process than of prin-

7. Nichols, *loc. cit.*

8. Matthews. Current number of the *Physical Review*.

ciple. There is a third and more fundamental source of trouble—one, indeed, which brings into question the validity of the term “candle-power” as a measure of worth in illuminants. For the sake of clearness, let us first consider what the term means. A 16 c. p. lamp, for example, is one that produces at a distance of four units the same illumination that one candle produces at one unit. That is, if two similar surfaces be illuminated separately by these two sources at these distances, and if they be viewed in juxtaposition from the same direction, they appear equally bright. This is, in fact, what the photometer shows, and is really all that can be affirmed as a result of the comparison. Having established a distance ratio of 4 : 1, the observer applies the law of inverse square to calculate an intensity ratio of 16 : 1. This intensity ratio is *numerically* equal to the illumination ratio on two surfaces at unit distance, but it is important to note that an observer would be quite unable to assign a numerical value to the relative illumination of these surfaces. In other words, the optical stimulus varies as the inverse square, but, by Fechner’s law, the sensation varies as the logarithm of the stimulus—a fact of which we can not take direct cognizance. Thus the intensity or “candle-power” ratio of two sources is a *derived* quantity, of indirect significance, whose chief value is to be found in the fact that it enables one to calculate an indefinite number of pairs of distances, at each of which will be found an *equality of illumination*. If two sources be compared by some method which takes account of their quality and which gives as a result the ratio of their total luminosities—determined, say by the relative value of their component rays in distinguishing characters—something quite different from their “candle-power” ratio may be obtained. These matters have already been brought to the attention of the members of the INSTITUTE by Nichols⁹. Fortunately the luminosity ratio of sources of nearly the same color, is not widely different from their intensity ratio. Hence it is to be hoped that, in the acetylene flame or some similar source, we shall soon have a suitable standard for the photometry of the arc

ADJUSTMENT AND STANDARDIZATION OF APPARATUS.

For the photometric measurements, a Krüss-Bunsen photometer was used. The method adopted was the usual one of a swinging crane in connection with a 45° mirror. The total dis-

9. TRANSACTIONS, vi : 158, May, 1889.

tance between sources was 829 cm. The coefficient of reflection of the mirror was determined by the use of two glow lamps connected in multiple. The lamp nearest the mirror was mounted at the end of an arm capable of being swung through an angle of 90° , as indicated in Fig. 2. This arrangement maintains the same length of bar with and without the mirror—a fact which makes for simplicity in the calculations. For the coefficient of reflection the first values obtained by three different observers were:

$$H, .828 \quad T, .826 \quad M, .82$$

An inspection of the image of the arc in the mirror gave rise to the belief that the absorption of the luminous rays was in some degree selective—an undue proportion of the violet rays being taken up. Were this the case, the value of the coefficient determined by glow lamps would be incorrect for use with the arc itself. To test this matter, the electromotive force on the lamps was varied through a wide range and a determination made for each change. The values found were:

TABLE I.

Volts on Lamps.	Reflecting Power.
95.....	.824
105.....	.805
112.....	.785
117.....	.800
122.....	.782
127.....	.836
132.....	.808
137.....	.825

Although the change in the quality of the light was very marked in this experiment, the results do not indicate any regular change in the coefficient of reflection such as was looked for. Hence, in all subsequent measurements, the mean of these various determinations, namely .814, was used.

The standard source was a glow lamp; it was referred after each test to the Hefner lamp. Electrical measurements were made by various portable voltmeters, ammeters and wattmeters, all of which were repeatedly referred to Kelvin balances.

RESULTS ON THE ALTERNATING ARC.

A number of enclosed arc lamps, in their commercial form, were kindly placed at the disposal of the writers by their respective manufacturers. As this paper has no other object than to

exhibit such features of the performance of these lamps as are largely typical, the trade names of the lamps are withheld.

FIG. 3.—Distribution of Intensity. Lamp A.

For each position of the arc, no fewer than 44 photometric settings were recorded. It was found that this number was

sufficient to include the maximum and minimum values, and a sufficient number of intermediate values to give a mean that could be reproduced quite closely at different times, thus showing the reliability of the method.

Lamp A.—The distribution of intensity from this lamp is shown in the polar diagram of Fig. 3; the figures for the curve are as follows:

TABLE II.

Angle.	Intensity.
0° horizontal.....	121.4 H. U.
10° above.....	169.0
20° “.....	155.0
30° “.....	189.0
40° “.....	176.0
50° “.....	46.5
60° “.....	22.4
10° below.....	164.5
20° “.....	134.7
30° “.....	167.4
40° “.....	187.5
50° “.....	203.0
60° “.....	130.5
70° “.....	82.6
80° “.....	64.0

The following is a summary of the results of the test of this lamp:

TABLE III.

Volts.....	103.2
Amperes.....	5.84
Apparent watts.....	602.
True watts.....	407.
Watts in mechanism.....	80.
Power factor.....	0.67
Maximum intensity.....	203.
Direction of maximum intensity.....	below 50°
“ “ “ “.....	above 30°
Mean hemispherical intensity:	
Upper hemisphere.....	91.8
Lower hemisphere.....	129.1
Mean spherical intensity....	110.5
Watts per mean spherical Hefner unit.....	3.68
Watts in arc per mean spherical H. U.....	2.96
Watts in arc.....	327.
Globes, character of.....	opalescent inner.
Carbons.....	½ inch “Electra.”

The lamp was intended for an electromotive force of 104 volts, and the attempt was made to keep it at this pressure, but at the close of the test, the average electromotive force proved to be 103.2. The power factor is due to the inductance of the

FIG. 4.—Distribution of Intensity from Open Alternating Arc. (Uppenborn.)

mechanism, as it has been clearly established by Blondel¹⁰ that, in the arc itself, the electromotive force and current are strictly in phase. It is easy to confirm this fact by current, pressure and power readings taken with reference to the arc alone.

The upper and lower lobes of the distribution curve do not yield the same mean values. The discrepancy is due, no doubt, partly to the fact that the bulb about the arc is not of symmetrical curvature, and partly to the greater reflection from the parts of the lamp situated just above the arc. The shape of the distribution curve alters somewhat as the burning of the carbons progresses. The general shape of the curve is not far from that which has been obtained for the open arc. For comparison, one of the several curves taken by Uppenborn¹¹ for the open arc is here shown. (Fig. 4.) In the enclosed arc the lobes of the distribution curve are shorter, blunter, and extend outward at

smaller angles with the horizontal. These changes are due to the shape of the carbon points. It may be pointed out that the distribution curve as plotted above, is a half-section

10. Blondel, *La Lumière Electrique*, vol. 41, 1892.

11. See Palaz, "Photométrie Industrielle" or translation by Patterson.

of the mean photometric surface, which is a surface of revolution. The actual photometric surface—so far from being a

FIG. 5.—Distribution of Intensity. Lamp B.

surface of revolution—is continually swelling, contracting and twisting in a marvellous fashion. As to whether the light thrown upward is of value, will depend on whether the lamp is suspended

in the open air or under a reflecting ceiling. In most cases considerable benefit will be obtained by the use of a reflector, as is illustrated in the following figure.

Lamp B.—This lamp was provided with a bell-shaped reflector of milky glass. The effect of the reflector on the distribution

FIG. 6.

curve is very noticeable, the upper lobe being largely removed. (Fig. 5.) The minimum corresponding to the horizontal is displaced downward by about 10 degrees. This peculiarity cannot be ascribed to the presence of the shade, as it was found in one or two cases where the lamps were fitted with inner globes only. It is quite surely due to the fact that the carbons so burn, that the planes of their ends, although parallel, are rarely normal to their axes. Thus in the case illustrated in Fig. 6, the minimum intensity might be found displaced either above or below the horizontal, according to the point of view.

FIG. 7.—Comparison of Illumination on Normal Plane, With and Without Shade, Due to Lamps A and B.

TABLE IV.

Angle. Deg.	Intensity. H. U.
0 horizontal.....	150.0
10 above.....	90.3
20 ".....	18.4
30 ".....	12.3
40 ".....	11.5
50 ".....	9.8
60 ".....	8.4
10 below.....	146.5
20 ".....	171.5
30 ".....	180.0
40 ".....	196.0
50 ".....	112.0
60 ".....	102.7
70 ".....	65.4
80 ".....	46.5

That the effect of the shade is distinctly advantageous will be further evident if curves of illumination be considered. And here unfortunately we must resort to an approximation. Data was taken for an exact determination of the effect of the shade on lamp B, but owing to an accident the figures are not now available. However, certain assumptions permit us to draw a comparison in the following way: Let

I_a = mean intensity of B above the horizontal and without shade,

I_b = " " B below " " "

I'_a and I'_b be similar quantities as found for B with shade,

I'' = mean intensity of A below horizontal.

Let it be further assumed that 30 per cent. of I_a is absorbed by the shade. Now since the altered distribution from B is due wholly to the shade—the light incident upon the shade being partially reflected, partially transmitted and partially absorbed—we have, if $I_a = I_b$,

$$\begin{aligned}
 I_b &= \frac{I'_a + I'_b + .3 I_b}{2}, \\
 &= \frac{I'_a + I'_b}{1.7} = 112.2,
 \end{aligned}$$

which is the mean hemispherical intensity of lamp B without shade. If now the radii of the curve B are multiplied by the ratio $I'' : I_b$, we shall have the effect of putting the shade on lamp A.

In plotting the illumination curves shown in Fig. 7, this last was done. Some difference of opinion exists as to whether the

ordinates of a curve¹² like this should be the illumination on a surface normal to the ray or on a horizontal plane. In Fig. 7, the illumination on the normal plane has been used, as this quantity serves very well for the purpose of a comparison. It will be noted that the benefit resulting from the use of the shade is most marked at distances remote from the lamp, which is as it should be, since there is no lack of light in the vicinity of the lamp. The following table gives distances at which an equality of illumination will be found:

Unit of normal illumination.	Without shade. Metres.	With shade. Metres.
2.25.....	6.5	8.2
2.00.....	7.1	8.8
1.75.....	7.8	9.5
1.50.....	8.7	10.4
1.25.....	9.7	11.7
1.00.....	11.0	13.2
.75.....	12.7	15.5
.50.....	15.2	21.0
.25.....	22.9	29.4

Lamp C.—This lamp was provided with an outer spherical globe of milky glass. The data obtained for the distribution of intensity were as follows:

TABLE VI.

Angle. deg.	Without globe. H. U.	With globe. H. U.
0 horizontal.....	132.0	37.2
10 above.....	137.0	42.8
20 "	158.0	42.7
30 "	122.0	38.4
40 "	85.0	28.7
50 "	30.4	17.4
60 "	18.0	7.7
10 below.....	126.0	36.1
20 "	133.8	32.6
30 "	140.7	31.4
40 "	117.0	30.0
50 "	120.0	28.2
60 "	90.0	30.7
70 "	68.0	29.3
80 "	47.5	24.7

12. It is probable that the unit of illumination most consistent with the c. g. s. system is $H. U. / cm.^2$. This unit is many times too large, however, and throws the numerical expression for an illumination far into the decimal places. The unit $H. U. / m.^2$, obtained by multiplying the first named unit by 10^{-4} , is preferable in this respect.

The foregoing values are plotted in Fig. 8. This distribution is in some respects anomalous. The larger area below the hori-

FIG. 8.—Distribution of Intensity. Lamp C.

zontal is due to the presence of a narrow reflector placed inside the outer globe. No reliable reason can be given for the presence of the maximum at 20 degrees above. It may be due to

some lack of accurate centering of the carbons. The peculiar shortening of the radii of the inner curve in the lower angles, baffled the observers for some time. It was finally found that the milky glass of the outer globe was much more dense in the lower hemisphere than in the upper, and the absorption was correspondingly greater.

It should be said in connection with the inner curve that the amount of light cut off was in reality not so great as the figure indicates. The dispersion is so great, with a globe of milky glass, that the globe plays a strong part as a radiant. Now, the mirror used was not sufficiently large to furnish rays on the photometer disk from all parts of the globe, and hence the lamp was not given quite full credit for what it was doing.

The results of the test of this lamp may be summarized as follows:

TABLE VII.

Volts.....	110.0
Amperes.....	7.0
Apparent watts	770.0
True watts.....	484.0
Watts in mechanism.....	116.0
Power factor.....	0.63
Maximum intensity.....	158.0
Mean hemispherical intensity :	
Upper hemisphere.....	68.5
Lower ".....	99.0
Mean spherical intensity.....	83.8
Watts per mean spherical H. U.....	5.76
Watts in arc.....	364.0
Watts in arc per mean spherical H. U.....	4.34
Globes, character of.....	opalescent inner.
Carbons.....	"Electra."

In the course of the measurements on this lamp, the terminal electromotive force was varied between the limits of 87 and 118 volts, and readings of intensity, power and current taken for each step. The results are plotted in Fig. 9. It will be noted that the power increases directly as the voltage; while the intensity is a rapidly increasing function of the voltage. The change in the current is slight. The high intensity at high voltage is partly due to the longer arc, but more especially to the higher temperature of the carbon points and consequent increased surface in the craters.

FIG. 9.—Effect of Varying Impressed Electromotive Force. Lamp C.

FLUCTUATIONS IN THE INTENSITY.

In Fig. 10 are shown the fluctuations in intensity which occur in the enclosed alternating arc. With the recording device already described, it is possible to get settings of fair accuracy

FIG. 10.

with a considerable degree of rapidity, as is here shown. The large changes in intensity are plainly noticeable in watching the

arc, but the eye does not furnish an estimation of them comparable with that to be gained from the curves, for the psychophysical reason already referred to. It will be noted that the higher values shown in Fig. 10 are of more infrequent occurrence than the lower values. Indeed, it is only when the arc is towards the photometer and flaring out in the manner shown in Fig. 11, so that both craters are inclined towards the disk, that these extreme values are obtained, and then they last but an instant. For all other positions of the arc, whether on the sides or on the back, only the lower values are obtained.

Two causes, it was thought, might contribute to these fluctua-

FIG. 11.

FIG. 12.

tions, namely, the changing length of the arc and the "wandering" character of it. To test this, the curve in Fig. 12 was taken with a fixed length of arc, the clutch being entirely out of action. The result plainly shows that the chief cause of the fluctuations is the hunting of the arc. While the intensity varies with the length of the arc, the motion of the carbons is so slight, in a well-regulated lamp, that it plays little if any part in causing the variations shown.

COMPARISON WITH THE ENCLOSED DIRECT-CURRENT ARC.

Lamp D.—Measurements were made on a direct-current lamp of the same manufacture as lamp A, with a view of bringing this

type of lamp under conditions identical with those of the tests of the alternating arc. The lamp was fitted with an inner opalescent globe only. The distribution of intensity is as follows:

TABLE VIII.

Angle. Deg.	Intensity. H. U.
0 horizontal.....	218
10 above.....	165
20 ".....	237
30 ".....	159
40 ".....	144
50 ".....	121
60 ".....	60
10 below.....	410
20 ".....	391
30 ".....	341
40 ".....	377
50 ".....	369
60 ".....	416
70 ".....	172
80 ".....	106

In Fig. 13, these values will be found plotted in the usual manner. This curve was taken with great care and may be taken as typical of the distribution due to the enclosed arc fed by a direct current. The peak at 20 degrees above is due to the small crater of the negative carbon. Here also the depression in the curve due to the low luminosity of the arc is found displaced by 10 degrees above the horizontal. This lamp will give an excellent illumination at points somewhat remote, because the curve is so full in the region just below the horizontal. A shade would still further improve the lamp in this respect. Detailed results are given in the following table:

TABLE IX.

Volts.....	108.
Amperes.....	4.96
Watts.	536.
Watts in mechanism.....	152.
Maximum intensity.....	416.
Mean hemispherical intensity :	
Upper hemisphere.....	106.5
Lower hemisphere.....	288.
Mean spherical intensity.....	197.3
Watts per mean spherical H. U.....	2.73
Watts in arc.	384.
Watts in arc per mean spherical H. U.....	1.95
Globes.....	Opalescent inner
Carbons.....	"Electra."

As regards efficiency, or better *economy*, say in watts per Hefner unit, the direct current lamp is superior to its alternating

FIG. 13.—Distribution of Intensity. Lamp D. (Direct Current.)
current competitor. The performance of lamp A was the best found in these tests, that of lamp C the worst. The other lamps

tested showed different degrees of economy lying between the limits set by these two.

The writers feel justified in saying that the lamps of low economy could, by improvement in mechanism, be brought to a performance equal to that of lamp A. All the lamps tested, with one exception, were furnished with the same brand of carbons. With similar carbons and similar globes, a difference in economy must be attributed largely to the mechanism.

If the alternating arc be regarded apart from any regulating device, the physical reasons for its poorer qualities as a light source are to be found in the lower temperature of the glowing points and in the diminished area of crater surface. In the direct current arc, we find two bright surfaces of unequal area and of widely different temperature. In the alternating current arc we find two bright surfaces of the same area and of the same temperature. According to Rossetti, the temperatures in the first case are 3900 C. and 2700 C. Now the points in the alternating arc are as much positive as negative, and hence, whatever the unknown law connecting the temperature of glowing carbon with the intensity of the light due to it, we should expect the mean spherical intensity of the alternating arc to have a value intermediate between the values of mean hemispherical intensity for the upper and lower lobes of the distribution due to the direct current arc. A comparison of lamps A and D shows this point, although the total power is not the same. If the power consumption of the alternating arc were raised from 327 to 384, it is very probable that the mean intensity would be found raised from 110.5 to a considerably higher intermediate value.

The values of the intensity of the direct-current lamp are lower than those found by some earlier observers. In fact, the enclosed arc has been reported in some instances as quite equal to the average open arc. It is difficult to see how these results can be accurate for a lamp fitted with an opalescent globe. The results of a test recently reported by Nichols agree closely with those given for the direct current lamp in this paper.

Electrical Laboratory, Purdue University, }
Lafayette, Ind., September, 1898. }