

ART. XXXVI.—*The Age-coating in Incandescent Lamps ;*
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[Experimental work by Messrs. B. E. Moore and C. J. Ling.]

[Contributions from the Physical Laboratory of Cornell University, No. 11.]

WHEN an incandescent lamp is maintained at constant voltage, it invariably falls off in candle-power. The diminution in brightness is attended by an increase in the amount of energy consumed per candle-power of light; this change being specially marked in the earlier portion of the life of the lamp.

This phenomenon, which seems to take place in all incandescent lamps of the present day, was first studied exhaustively by Mr. W. H. Pierce, who read a paper entitled "The Relation between the Initial and Average Efficiency of Incandescent Electric Lamps," before the American Institute of Electrical Engineers, in 1889.* Mr. Pierce made a careful study of ninety-four lamps, including nearly all the types of glow-lamp then in use. He found no exception to the rule of progressive degeneration.†

These changes may be ascribed to at least three causes: loss of vacuum, increase of resistance, due to the disintegration of the filament, and finally, the deposition of the disintegrated carbon upon the inner surface of the lamp-bulb. It was the object of the experiments to be described in this paper, to make a study of this coating. We endeavored (1) to determine its character; that is to say, whether it is colorless, or is selective in the particular rays it absorbs; (2) to learn something about the rate and distribution of deposit; and (3) to determine how far the absorption of light by the coating is accountable for the diminution in the brilliancy of the lamp.

For the determinations under the first head, we made use of a form of polarizing spectro-photometer which has been more than once described in the pages of this Journal.‡ The standards of light were incandescent lamps. These were maintained at a candle-power considerably below the normal, that the changes taking place in them might be slow. Frequent comparisons of their spectra showed that the relative changes of brightness and quality of light were inappreciable.

The first step in our investigation consisted in the measurement of the absorption spectra of the bulbs of certain unused lamps, which had been selected for study. These lamps were then brought to degrees of incandescence, previously agreed upon, and were maintained in that condition by means of the current from a storage battery carefully kept constant, until they showed coatings of sufficient density to admit of ready measurement. They were then taken out of circuit and the absorption spectra of the blackened bulbs were determined. These readings gave the amount of light of each wave-length absorbed, and by repetition, the rate of deposition during different periods of the lamp's existence. The entire set of photometric observations were duplicated, but since the final results

* *Trans. Am. Inst. E. E.*, vol. vi, p. 293.

† Since the above was written an extended investigation upon this subject has appeared. It entirely confirms the results obtained by Mr. Pierce. (See "A life and efficiency test of incandescent lamps" by Prof. B. F. Thomas and Messrs. Martin and Hassler). *Trans. Am. Inst. E. E.*, vol. ix, 1892.

‡ This Journal, vol. xxxvi, p. 332; also *Phil. Mag.*, V, xxxii, p. 404.

obtained by the two independent observers (Moore and Ling), were in agreement, only the mean of the two sets is given in the following tables.

In order to ascertain precisely what part in the decadence of the lamp is attributable to the coating, it was necessary to keep careful watch of the continually shifting electrical and photometric conditions during its entire life; and in order to maintain in each lamp the precise conditions under which it had been determined that it should be burned, measurements of candle-power and voltage had to be made at short intervals, together with continual readjustments of the current.

Fourteen lamps in all were selected for the investigation. These were of two widely different types, representing the two great classes, viz: lamps with untreated and with treated filaments. Of these, some were maintained at the voltage indicated by the maker, or at predetermined, constant voltages other than this. Others were kept at constant candle-power throughout their entire life, the current being increased whenever the decrease in brightness due to increasing age had become appreciable.

From the data obtained in this way, the life curves of the various lamps were plotted, showing the variation in candle-power or voltage respectively, of resistance and of efficiency expressed in watts per candle, during its entire existence. Some of these curves have already been published.* As these results were quite in accordance with those obtained by Mr. Pierce, to which reference has already been made, it will be necessary to deal with them here only in so far as they bear upon the question of the influence of the age-coating upon the efficiency of the lamp.

I.

Color of the coating.

Measurements upon all fourteen of the lamps which were subjected to the spectro-photometric tests, showed the color of the coatings upon lamp-bulbs containing treated and untreated carbons, respectively, to be practically identical in character. The color of the coatings obtained in lamps of either type, under widely diverse conditions (as for example, by maintaining a sixteen candle-power lamp at sixty-four candles throughout its life), was the same as that produced under normal conditions of service. The color in question is very nearly neutral, the percentage of light transmitted being approximately the same for all parts of the visible spectrum. The effect of the

* The Artificial Light of the Future: Electric Club Pamphlets, No. 24, New York, 1890; also *Electrical World*, 16, p. 387, *Electrical Engineer*, 10, p. 595.

"age-coating," as the deposit which we are considering may be called, is therefore to dim the lamp, without appreciably changing the quality of its light.

The most complete set of observations obtained with lamps of untreated carbon are those referring to a lamp designated in our list as No. 2.* This lamp was maintained at normal voltage for over eight hundred hours. Frequent readings of candle-power and current, during this time, afforded the means of tracing the progressive changes of light-giving power, efficiency and resistance. Measurements of the age-coating were made after 100, 200, 400 and 800 hours of life, readings being taken in ten regions of the spectrum. The results are given in Table I, together with data indicating the condition of the lamp at the above mentioned periods of its life. These are taken from a set of sixty-seven readings of voltage and current, distributed over the entire life of the lamp at nearly equal intervals. The variation in voltage during the entire eight hundred hours was never more than 0.3 volts above or below the initial value.

TABLE I.

Lamp No. 2 (untreated filament).

Initial Conditions.

Volts.	Amperes.	Ohms.	Candle-power.	Watts per candle.
101.8	0.474	214.8	16.00	3.015

Conditions after 100 hours.

Volts.	Amperes.	Ohms.	Candle-power.	Watts per candle.
101.9	0.453	225.3	12.50	3.697

Light transmitted by the coating, after 100 hours.

$\lambda = .750$	88.9 per cent	$\lambda = .507$	92.2 per cent
.713	90.2	.481	92.8
.635	91.8	.460	92.3
.658	91.5	.443	92.4
.538	91.9	.429	92.4

Conditions after 200 hours.

Volts.	Amperes.	Ohms.	Candle-power.	Watts per candle.
101.8	0.421	225.9	10.8	4.250

Light transmitted by the coating after 200 hours.

$\lambda = .750$	83.5 per cent	$\lambda = .507$	86.4 per cent
.713	84.5	.481	86.9
.635	85.6	.460	87.6
.580	85.4	.443	87.9
.538	85.9	.429	85.4

* This and other numbers used refer to the records of these experiments as given in full in the thesis of Messrs. Moore and Ling, a manuscript deposited in the library of Cornell University. (The Life and Duration of Incandescent Lamps; with special Reference to the Light absorbed by the Coating within the Bulb, by B. E. Moore and C. J. Ling. 1890.)

Conditions after 400 hours.

Volts.	Amperes.	Ohms.	Candle-power.	Watts per candle.
101·8	0·428	237·7	9·67	4·510

Light transmitted by the coating after 400 hours.

$\lambda = \cdot 750$	79·3 per cent	$\lambda = \cdot 507$	83·5 per cent
$\cdot 713$	80·9	$\cdot 481$	83·6
$\cdot 635$	82·3	$\cdot 460$	84·0
$\cdot 580$	82·0	$\cdot 443$	84·3
$\cdot 538$	82·6	$\cdot 429$	82·1

Conditions after 800 hours.

Volts.	Amperes.	Ohms.	Candle-power.	Watts per candle.
101·9	0·415	245·6	7·20	5·880

Light transmitted by the coating after 800 hours.

$\lambda = \cdot 750$	75·7 per cent	$\lambda = \cdot 507$	78·7 per cent
$\cdot 713$	75·9	$\cdot 481$	79·4
$\cdot 635$	78·0	$\cdot 460$	79·9
$\cdot 580$	78·6	$\cdot 443$	80·5
$\cdot 538$	78·4	$\cdot 429$	77·3

Another typical case was that of lamp No. 10, which was a lamp with a treated filament. It was maintained at a very different degree of incandescence, being a lamp of low efficiency, which when set at the voltage indicated by the manufacturer, required an expenditure of 5·16 watts per candle. The age-coating of this lamp approached even more nearly to complete neutrality of shade than did most of those which we had occasion to measure. The results obtained at two hundred and nine hundred hours are given in Table II.

TABLE II.

Lamp No. 10 (treated filament).

Initial Conditions.

Volts.	Amperes.	Ohms.	Candle-power.	Watts per candle.
36·0	1·171	30·63	8·2	5·16

Conditions after 200 hours.

Volts.	Amperes.	Ohms.	Candle-power.	Watts per candle.
35·9	1·145	31·27	7·1	5·91

Light transmitted by the coating after 200 hours.

$\lambda = \cdot 750$	91·9 per cent	$\lambda = \cdot 507$	90·7 per cent
$\cdot 713$	90·4	$\cdot 481$	90·4
$\cdot 635$	89·5	$\cdot 460$	90·7
$\cdot 580$	90·5	$\cdot 443$	90·5
$\cdot 538$	90·5	$\cdot 429$	90·4

Conditions after 908 hours.

Volts.	Amperes.	Ohms.	Candle-power.	Watts per candle.
36.14	1.14	31.70		(unknown)*

Light transmitted by the coating after 908 hours.

$\lambda = .750$	86.6 per cent	$\lambda = .507$	84.5 per cent
.713	85.2	.481	85.0
.635	83.1	.460	85.5
.580	83.6	.443	86.0
.538	84.5	.429	86.0

The normal life of a lamp starting at 5 watts per candle, is many thousands of hours. Lamp No. 10 was prematurely broken at 908 hours, at which time the coating had reached a density corresponding to that of a 3 watt lamp (No. 2) after 200 hours of life. A comparison of Tables I and II will show that while the coatings on these two lamp bulbs were not quite neutral nor precisely identical in tint, that they both transmit light with much greater uniformity than do such materials, for example as optical glass, calcite, etc.†

II.

The distribution of the age-coating within the bulb.

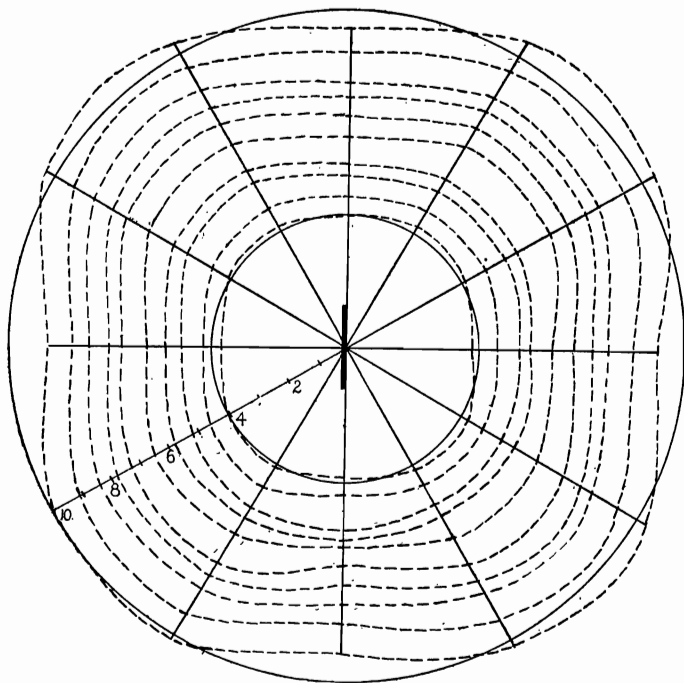
The distribution of the age-coating was determined indirectly, as follows: Two of the lamps under examination, were measured for horizontal candle-power according to the "Franklin Institute" method;‡ measurements being made in twelve meridians, 30° apart. The readings were repeated at frequent intervals throughout the life of the lamps. The results were plotted with polar coördinates. They show (figure 1), by the diminishing area of the successive curves, the progressive loss of brightness due to age, of which about one-half is ascribable to the coating. The similarity of the curves, from first to last, indicates that the coating is deposited uniformly within the bulb, or in uniform lateral zones, so that the density of the film, is symmetrical with reference to any given meridian. The case chosen for illustration is lamp No. 7. The results obtained with lamp 8, were in every essential respect the same as those shown in the diagram.

* The lamp was broken before the photometric measurements had been completed.

† See Kruess, *Kolorimetrie*, p. 243; also, Nichols and Snow, *Phil. Mag.*, V, vol. xxxiii, p. 379.

‡ See Franklin Institute Tests (International Electrical Exhibition, 1884), Philadelphia, 1885.

1.



III.

The age-coating considered as a factor in the diminishing efficiency of the lamp.

It may be seen from the Tables (I and II) that the absorbing power of the coating is in itself sufficient to account for a very considerable falling off in the candle-power, as the lamp, within the bulb of which it forms, grows old in service. By summation of the values in the tables, we may obtain the average absorbing power for the entire spectrum; and since selective absorption is almost entirely absent, these averages will give very closely indeed the loss in candle-power, which at the time in question was ascribable to the influence of the coating. From the data in Tables I and II, also, we may compute the efficiencies of the lamps at various stages in terms of their initial efficiency as unity; likewise their brightness from time to time, in terms of their initial candle-power, as unity. In Tables III and IV are given, for purpose of comparison, the relative brightness and efficiency of lamps 2 and 10, at

various periods, also the average absorbing power of their coatings.

TABLE III.

Relative brightness, efficiency and transparency of lamp No. 2, at various periods (each expressed in terms of its initial value taken as one hundred).

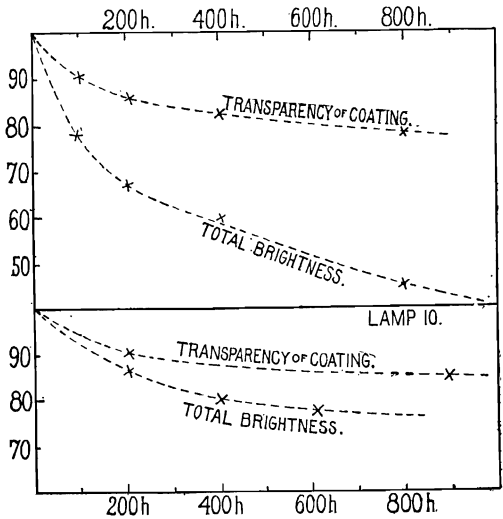
Time.	Relative brightness.	Relative efficiency.	Relative transparency of bulb.
000· hours	100·	100·	100·
100 “	78·1	81·5	91·44
200 “	67·5	70·9	85·91
400 “	60·4	66·8	82·46
800 “	45·0	51·3	78·24

TABLE IV.

Relative brightness, efficiency and transparency of lamp 10, at various periods (each expressed in terms of its initial value, taken as 100).

Time.	Relative brightness.	Relative efficiency.	Relative transparency of bulb.
0· hours.	100·	100·	100·
50· “	92·6	92·6	----
109· “	91·4	90·1	----
200· “	86·6	87·3	90·5
400· “	80·5	81·6	----
511· “	78·7	80·0	----
600· “	78·0	79·5	----
900· “	----	----	85·0

2.



The curves in figure 2 are based upon these data. They show that the loss in candle-power and efficiency are only in part due to the opacity of the coatings. It is of some interest to compare lamps 2 and 10, since the former is a three watt lamp, whereas the other required 5.16 watts per candle at the beginning of the test. It is to be regretted that the tests did not extend over the normal life-time of such a lamp; the results obtained, however, suffice to show that the loss due to coating is a much larger portion of the total loss in the low efficiency lamp than in the other. Measurements with several lamps, maintained at abnormally high temperatures seemed to indicate that the higher the state of incandescence the less marked (relatively) is the influence of the age-coating upon the decadence of the lamp.

Summary of results.

1. The rate of deposit of the coating in incandescent lamp bulbs is greatest in the early part of the life of the lamp. For example, in the case of a lamp which lasted 800 hours, (see Table III) more than half of the coating was deposited during the first 200 hours.

2. The loss of brightness due to the absorbing power of the age-coating is a variable part of the total loss, being greatest in lamps of high initial efficiency.

3. The coating does not appreciably modify the character of the light which emanates from the lamp.

4. The distribution of the coating within the bulb is a nearly uniform one (see figure 1).

5. No marked difference between treated and untreated filaments appears to exist, as regards the density or quality of the coating produced from them.*

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*Since this article was written it has been pointed out by Professor B. F. Thomas (in the paper already cited), that in the case of lamps exhausted without the aid of mercury the age-coating is scarcely perceptible.