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Light-Sensitive Papers as Controls for Testing Textile Colorfastness and Stability of Materials Under Arc Lamp Exposure

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A simple method of control of the integrated exposure of the fluctuating arc lamps used in the textile and other industries for testing lightfastness of textile dyeings and stability toward light of materials in general, is described. A piece of light-sensitive paper is placed in lamps along with materials to be tested, and the exposure is terminated when a match with a standard, observable with the unaided eye, is obtained. The standard is a strip of the same batch of paper that has been exposed in a master lamp to a definite light dosage. The method is based upon standard light quantities and is thus largely independent of variation between batches of light-sensitive paper.

The variations among fading lamps used in the textile industry and the causes, such as differences in lamp models, and line voltage, are discussed. A 4-percent difference in line voltage leads to a difference in radiant output of 11 percent in the waveband from 300 to 480 millimicrons, the region probably causing most of the fading of dyed textiles. Variations in line voltage considerably larger than 4 percent are probable in many communities.

The papers were made in batches of 20 to 30 thousand test pieces by dip-dyeing special cotton-rag or wood-fibers papers with aqueous solutions of Niagara Blue G, or with Victoria Blue B in aqueous ethanol. One paper was made by beater-dyeing wood fibers with Niagara Blue G to give a nonleaching paper and was sized with melamine resin to impart high wet strength, making the paper suitable for lamps with water spray. Other paper-dye combinations were studied.

Data are presented indicating the visual sensitivity of the various types of papers from 1 to 100 hours of usual arc exposure, the permanence of the papers during storage in the dark, the uniformity throughout each batch, and the effect of nonuniformity, temperature effect, lasting qualities of the standard strips during use, correlation with textile dyeings, and the effect of intermittent exposure.

The master lamp used for standardizing the papers, its accessories, and reproducibility of input power and radiant output are discussed.

I. Introduction

The textile and other industries use carbon arcs for the testing of colorfastness of dyed fabrics and of stability of materials in general to light. There is considerable variation in performance among lamps and of a given lamp from time to time. Since the testing is predicated upon comparable performance of such lamps, variation introduces uncertainties and frequently vitiates the results.

The extent of such variation has been the subject of recent surveys by Wood [1],[1] the National Bureau of Standards [2], and Seibert [3]. The results of all three, obtained by distributing various types of dyed materials for test in large numbers of lamps, showed the variations to be very large. Seibert, in particular, showed that some of the weakest lamps required from two to

[1] Figures in brackets indicate the literature references at the end of this paper.

three times as long to produce the same fading as the strongest lamps, and that over one-third of the lamps deviated by more than 15 percent from average.

Although practically all textile fading lamps are of one manufacture (Fade-Ometer) and involve the same fundamental arc characteristics, they differ among the several models as to type of current (alternating or direct), as to power input, and in the arrangements for thermostating, humidifying, and exposing the samples. Such differences in design probably give rise to differences in performance among the various installations [4].

The differences, however, in fading action among identical models, or in a given lamp appear to arise from variations in line voltage. The radiant output in the spectral region, approximately 300 to 480 mμ, probably the most generally effective spectral region in such lamps, changes by 11 percent for a 4-percent change in line voltage.[2]

Data were obtained by regulating, at various values, the line voltage of an alternating-current F D A–R model Atlas Fade-Ometer and measuring the corresponding relative radiant output with an RCA 929 phototube—Corning 5850 filter combination, having a spectral maximum near 385 mμ., in a circuit with General Electric recording microammeter. Typical data were as follows, integrated over ½-hr periods:

Line voltage	Relative phototube response
	μ *amp*
217	6.0
228	6.8
238	7.7

Voltage variations at most substations in the District of Columbia are about 4 percent,[3] which is probably exceeded in most communities. To this must be added the variable voltage drop in the mains, transformers, and individual plant wiring, which may be as high as 11 percent [6].

Another factor is the gradual decrease in ultraviolet near the transmission cut-off of the glass enclosures, through solarization of the glass. However, Cady and Appel [7], who exposed 1,252 textile dyeings to sunlight, showed little difference in fading with and without intervening window glass. Cady and Smith [8] found little difference in the fading of 40 dyeings exposed to the Fade-Ometer with plain and with Corex-D glass globes, which indicates that that region of transmission of glass most affected by solarization, namely, below 330 mμ, may not be of decisive importance for textiles. The visible discoloration of the glass caused by extended use may cause considerable difference between lamps.

Since uniform performance of arc lamps is a practical impossibility at present, recourse must be had to a method of exposure control by estimating radiant output with a light-sensitive material.

Simple methods of exposure control have been described before. Krais [9] used the light-sensitive dye Victoria Blue R on china clay, the latter then brushed on to paper, Robson [10] used eosin on a filter paper, Scott [11] used Victoria Blue B on silk, and Clark [12] used zinc sulfide on paper.

A method using a light-sensitive solution is that proposed by Werkenthin [13] and his associates, of the Bureau of Ships, U. S. Navy, for the control of arc performance in the testing of rubber, in which a solution containing essentially uranyl oxalate in a silica cell is exposed to the arc. The method is a noteworthy, successful attempt to systematize the use of testing arcs, but it is not simple to use, and in its present form is limited to exposures of approximately ½-hr duration. Other details of the method have been studied by Greider and Bowditch [14].

A control for fading lamps has been discussed by Wood [1], who studied various combinations of dyes and appropriate vehicles, such as silk, wool and cotton textiles, paper, etc., and found Formyl Violet S4B on nylon to be the most sensitive. An arc was used as a master, or reference, lamp, but the idea was discarded when it was found that the lamp changed 20 percent in 4 months.

Christison [15] recognized the desirability of a master lamp, but in its absence stressed the reproducibility of shade (rather than of fading rate) of the blended wool materials he developed, which have since been adopted by the AATCC for the grading of dyeings into classes of lightfastness

[2] An unpublished paper presented at a symposium on light aging at The Bureau of Ships, Navy Department, Washington, D. C., Oct. 1945, at a meeting of the Technical Association of the Pulp & Paper Industry, New York City, Feb. 1946, and at a meeting of the American Association of Textile Chemists & Colorists, Philadelphia, Pa., April 1945 [2, 5].

[3] Quoted with the permission of George Bisset, Potomac Electric Power Co.

differing by steps of 100 percent. However, these materials, of which Cady [16] has given historical background, were intended for only rough control.

Seibert [3] proposed a procedure employing a light-sensitive gray paper and gray cotton, with standards based upon a fixed "percentage color change," determined from reflectance measurements. His materials were distributed to a number of lamp users and showed the difference in exposure periods among the various lamps that were necessary to reach a given extent of fading. The materials, however, were rather insensitive to time differences under 20 percent.

In the above methods, the standard with which the light-sensitive materials are compared, in estimating exposure, is either "colorlessness," [9, 10], which is difficult to evaluate, or some final shade [11, 12, 3], defined by preserving a sample or by means of a spectrophotometric reflectance curve. With such a standard, the light-sensitive materials must be reproducible in fading rate from batch to batch, as otherwise the amount of exposure necessary to match the standard may vary for each batch, thus nullifying the method to that extent.

The present article describes a method based upon standards produced with reproducible light dosages, rather than from reproducible batches of the light-sensitive media. The method has been found to be generally satisfactory in large-scale application to textile fading and lamp calibration, [2, 5].

The freedom from the difficulties of batch reproducibility, the ease of recognizing extent of exposure, the reasonable assurance of uniformity within each batch, the wise range of exposure periods available, and the general standardization of procedure constitute the main advantages of the method.

II. Principles of Method of Control of Lamp Performance With Light-Sensitive Papers

Special paper was made and dyed with a light-sensitive dye in quantities of 20 to 30 thousand test pieces per batch in the experimental paper mill at the Bureau.

A portion of the batch is standardized in a master lamp by exposing it to a convenient, measured light dosage, defined in terms of "standard arc hours." This standardized paper becomes the secondary standard used to gage light dosage in other lamps.

In a typical application, a piece of light-sensitive paper is simultaneously exposed with materials being tested in a lamp. When a match between the test piece and the secondary standard is observed with the unaided eye, the materials are assumed to have received the corresponding light dosage. Estimating the degree of under- or over-exposure is facilitated by auxiliary standard strips representing 80, 90, 110, and 120 percent of the light dosage.

The actual time of exposure is thus immaterial, unless it differs consistently, perhaps 30 percent or more, from the number of standard arc hours identified with the exposure, indicating that an adjustment on the lamp may be desirable.

This method has as its fundamental basis the production of secondary standards from each batch of light-sensitive paper, with a definite, reproducible dosage of light. Thus the batches can, and do, vary, or the paper type may be changed without affecting the validity of the method.

Light-sensitive papers can be used, without secondary standards, as light-totaling devices in photochemical or other research with a given source of light. Relative intensities in many parts, otherwise inaccessible, of a given system may be simultaneously measured very simply. The papers dyed with Niagara blue were found to be colorimetrically unaffected by ozone and may thus be used near quartz mercury lamps or lamps of the germicidal type. Combined with photometric measurement of reflectance, precision in using light-sensitive papers may be expected to equal that of acceptable radiometric technique.

III. Light-Sensitive Papers

A variety of types of light-sensitive papers were developed for various periods of exposure and for exposure in lamps with water spray. The method requires that the papers be colorimetrically stable in the dark, both unexposed and exposed samples, producible in large uniform batches, normally responsive to temperature, arc characteristics, and relative humidity, and visually sensitive, as defined by the additional exposure, expressed in percentage of the light dosage already received, necessary to produce a change observable with the unaided eye.

1. Components and Methods of Dyeing

Fifteen kinds of experimental papers, varying in type of cellulose, filler, sizing, and finish were dyed and irradiated to determine the optimum characteristics of papers for the work. Two neutral (pH 6.8) unsized papers were then produced in the Bureau's paper mill. Paper 1444 was made entirely from wood pulps (80% No. 1 soft alpha, 20% hardwood sulfite pulps), and paper 1370 was entirely of cotton origin (40% new rags, 40% old rags, 20% clay). Papers of these types show considerable cellulose stability.

These two papers were tested with 47 representative dyes at various concentrations. It was found that National Aniline Niagara Blue G Conc., lot 64704, Colour Index 502, and, to a lesser extent, DuPont Victoria Blue B, Conc., lot 22, Colour Index 729, gave the most useful products.

By varying dye, fiber, and method of application, papers of differing fading rates were obtained. The exposure times represent approximately the time necessary for most Atlas Fade-Ometers to fade the papers to the region of most perceptible change, which occurs when the paper has sufficient dye left for easiest judgment of the effect of further increments of light.

(a) Paper C, exposure time 3 to possibly 10 hr; paper 1370, tub-dyed with 0.09 percent of Victoria Blue in 1:3, 95-percent ethanol-tap water solution.

(b) Paper E, exposure time 10 to 40 hr. Paper 1370, tub-dyed with 0.54 percent of Niagara Blue in tap water.

(c) Paper F (or A), exposure time 40 to 100 hr. Paper 1444, tub-dyed with 0.65 percent of Niagara Blue in tap water. A somewhat lighter modification of paper F has been referred to as paper A.

(d) Paper S, exposure time 20 to 40 hr in lamps with water spray. This paper was beater-dyed by adding a solution of Niagara Blue to give a 0.5 percent ratio, dye: fibers, using the same kind of fibers as in paper 1444. Melamine resin, 3 percent of fiber weight, was added to the beater to give high wet strength for use in lamps with water spray.

These four types serve to indicate the methods of producing papers of various desired characteristics. The tub-dyed papers, which are finished papers run through a dye bath, must be used dry; the beater-dyed paper is nonleaching and may be used for "weathering" lamps, but is decidedly inferior to the tub-dyed papers in sensitivity. The tub-dyed papers have the disadvantage of tending to exhaust the dye bath, which thus requires replenishing from time to time.

2. Visual Sensitivity

Cooperating commercial and governmental organizations found that paper A had a visual sensitivity of 10 percent; that is, the color differences between pieces exposed for 18, 20, and 22 hr could be easily distinguished, although some observers encountered hue difficulty in matching the standardized strips with their own exposures. Investigation showed that the difficulty was eliminated if the samples were matched in the absence of the unexposed blue border of the test pieces.

Subsequently it was found that this type of dyed wood fiber paper is considerably more sensitive after 40 hrs of exposure, whereas paper E, made of cotton fibers, absorbing less of the same dye, is more sensitive at the 20-hr period.

A comparison of the visual sensitivity of the various papers is given in table 1. The results are based upon the estimates of a limited number of individuals and are probably more reliable on a relative than absolute basis.

Paper E, made from an unusually uniform, soft, base sheet had the highest sensitivity, because its smoothness of texture detracted least from shade differences. The coarser texture of the other

TABLE 1. *Minimum increments in light dosage producing visible* [a] *differences in light-sensitive papers*

Types of papers	Percentage of total light dosage [b] after the following hours of exposure—				
	3	10	20	40	100
C	5	10	White	White	White
E	15	10	2½	5	10
F (or A)	30	20	10	5	5
S (air-dry)	30	20	15	15	15
S (with spray)	30	20	10	10	White

[a] By visible is meant a difference that can be seen, with the unaided eye, between two pieces of paper, one closely superposed upon the other, rather than differences on one piece.

[b] For example, if it is possible to distinguish between a piece exposed for 20 hr and one exposed for 20½ hr, in the usual Atlas Fade-Ometer, the increment producing a visible difference is expressed as 2½ percent.

papers, or the mottled appearance of faded papers using unsuitable dyes, acts like camouflage in appearing to break up the edge of two fields being compared, whereas ease of comparison depends considerably upon sharpness of borderline.

These papers were all uncalendered after dyeing, because it was found that the gain in fineness of texture was more than offset by the production of highlights due to specular reflection.

Paper S, beater-dyed, the simplest to produce, was also the most insensitive. Since all constituents were the same as in F, and since differences in the amounts of dye were largely without effect on sensitivity, the method of applying the dye must account for the difference. A beater-dyed paper can be expected to be more uniformly dyed throughout its thickness than a tub-dyed sheet, in that the latter is darker on the outside. This was strikingly so in paper C, of which the internal fibers remained white. It is, therefore, possible that a lighter interior causes greater contrast, and uniform beater-dyeing, less contrast.

The rate of fading of paper S is dependent upon the wet-dry cycle. As the ratio, time wet/total time, is increased from 0 to 30 percent, the rate increases considerably, apparently because of an accelerating effect of water, remains roughly constant to 70 percent, beyond which, to 100 percent, the rate decreases.

The decrease in rate is probably due to the lower temperatures of the paper when wet, and all of the papers sprayed over 50 percent of the time, except those continuously sprayed, showed less fading at the bottom, where the water tended to remain longer. This was not a leaching process, since papers sprayed in the dark, or those kept continuously wet during exposure, showed no inhomogeneity. The effect of temperature will be discussed in a later section. If this type of paper is used in "weathering" lamps, the wet-dry cycle should be specified. If it is used for outdoor exposures, the amount of rainfall, and, of course, temperature will be a factor.

Fading in this and other experiments was taken from reflectance measurements made at 45° from normal incidence at 578 mμ, with equipment previously described [17]. The papers were sucked flat against a black backing during measurement.

3. Colorimetric Stability in the Dark

During storage periods of 8 to 18 months, the papers were found not to have changed significantly, with the exception of paper C. This was found by measuring the reflectance, at various times, of 100 pieces, taken at random from each batch, the total change being within the limit of reproducibility, 0.002 reflectance, of the instrument.

Paper C, during 8 months, was found to have lost color corresponding to approximately 5 percent of its 3-hr period. This paper for short periods, therefore, must be considered unstable, but can find practical application by frequent standardization. For periods beyond 5 hr, it is probably sufficiently stable.

The other papers, both exposed and unexposed, were subjected to a rather severe process of "accelerated aging," by being kept at 100° C in the dark for 3 weeks. At the end of the time they were found to have lost color corresponding to 5 percent of a 20-hr exposure period.

4. Standardized Strips During Use

The standardized strips are mounted in a comparison booklet that has flexible black cellulose acetate covers to protect the strips from soiling and light during nonuse.

During use, the strips are exposed to interior daylight and artificial light. It was of interest to determine the additional fading of the strips during normal use. Some exposed pieces of paper A were placed under Corex D glass to keep out dust and exposed to the daylight of a well-lighted room for 3 weeks in the late fall of the year. This corresponded roughly to a daily exposure of 10 min for 2 yr. The reflectance change was found to be 0.004, corresponding to less than 1 hr of lamp exposure out of 20, and constituting an error of less than 5 percent for this rather severe test.

Under conditions of extreme atmospheric dryness, such as prevail in northern latitudes in winter, or in desert regions, it has been found desirable to humidify briefly, with the breath, the test piece before comparing, inasmuch as the reflectance of the warm, dry piece, just removed from a lamp operating under the extreme conditions mentioned, is too high by approximately 5-percent exposure time. Under all other conditions, including extreme humidification, the reflectance is unaffected.

During the comparison, it has been found advisable to keep the test piece in the exposure frame so that the unexposed blue border shall not have a disturbing chromatic effect.

5. Uniformity of Batch

The reflectances of 100 pieces each of papers C, E, F, and S, and 255 pieces of A, chosen at random, were measured. The resulting frequency distributions were analyzed statistically for standard deviation,

$$S=\sqrt{(Sfx^2-S^2fx/n)n-1},$$

which were found to be 1.07, 1.12, 1.40, 1.60, and 1.85 for papers S, E, F, A, and C, respectively, indicating increasing dispersion and nonuniformity in that order. As might be expected, the beater-dyed S was the most uniform, with the soft E a close second. Dyeing from a partially nonaqueous solution, as in the case of C, resulted in least uniformity of product.

The real test of uniformity is, of course, the uniformity of fading rate of pieces having various values of initial reflectance. Pieces within the lowest, middle, and highest reflectance ranges of each type of paper were simultaneously exposed to light dosages appropriate for each type. The changes in reflectance were then measured. It was found, for paper E, that the final reflectance was practically independent of the initial reflectance. For paper F, however, it was found that the lowest reflectance group faded 6 percent more slowly, and the highest group 5 percent more rapidly than the middle group. For papers A and C, the corresponding values were 7 and 2 percent, respectively, for both extremes. These represent the errors involved in using off-color pieces of the papers. Apparently, the papers made from cotton fibers were considerably more uniform in fading rate than those made from wood fibers.

6. Effect of Temperature on Fading Rate

Although the papers are stable in the dark and temperature alone has practically no effect, it was found that temperature has considerable influence during exposure to light.

The results in table 2 show that the extent of fading of two typical papers for a given exposure was considerably increased by raising the temperature. The effect is seen to decrease with rising temperature, and as the AATCC specification for air temperature in the Fade-Ometer is 46° C, the temperatures of various materials therein will be near the higher values.

From the results in table 2 for papers E and A, neglecting the last value for the latter and using instead a value obtained from a smooth curve, and from the fading rates of the two papers, it can be estimated that an error of 10 percent would occur using the paper in two lamps operating at 40° and 50° C, disregarding the fact that the materials being tested may also show temperature effects and thereby decrease the error. It is obvious that temperature specifications for the testing of all materials are necessary if the paper is to perform satisfactorily.

TABLE 2. *Fading rate of papers A and E as a function of temperature*

Temperature [a] of paper	Change in reflectance	
	Paper A	Paper E
°C		
20	0.083	0.179
30	.109	.225
40	.130	.262
50	.142	.303
60	.143	.329

[a] Temperatures of the papers were closely controlled during exposure by sucking the sheet against a thermostated metal backing. The light of a Fade-Ometer arc, operated from controlled voltage, was passed through an 11-mm layer of cool flowing distilled water in a Corex-D cell. The relative humidity was maintained near 58% for all experiments with a solution of Na Br, saturated at the same temperatures as in this table. This equipment is described in detail in reference [18].

From a fundamental standpoint, the fact that the fading rates of these papers have temperature coefficients larger than unity shows that thermal reactions, with appreciable heats of activation, accompany the photochemical reaction. The temperature coefficient, corresponding to the error of 10 percent is 1.1, in fair agreement with the findings of Schwezow [19], who found coefficients ranging from 1.040 to 1.084 for four dyes in collodion films. Luckiesh and Taylor [20] found little effect of temperature on the fading of silk ribbon between 29° and 49° C, but "appreciably" more at 66° C. Both of these studies were, however, too limited in scope to allow conclusions regarding temperature coefficients of fading of textile dyeings in general. It seems probable that temperature would affect the rate of change of textile dyeings and other materials during irradiation.

7. Correlation With Textile Dyeings

The trend in the design of textile fading lamps has been in the direction of closer control of temperature and relative humidity of the air in the sample space. Also, greater uniformity of spectral distribution may be expected with the increasing prevalence of installations by using alternating current, of which the voltage is more easily controllable than with direct current. Thus, with the later models it is possible to draw up standard procedures to minimize these sources of difference. However, many old models are not only in use, but validity of comparison of performance is frequently expected.

It was, therefore, desirable to determine how well a light-sensitive paper could serve as a control in lamps differing in type of arc, relative humidity, and temperature in their fading action on textile dyeings.

The open-arc lamp, in which the humidity could be varied over a wide range, since the humidifier consisted of an electrically heated water trough, was used for this experiment. Two sets of conditions, probably more extreme than general practice, were used: dry trough, relative humidity 13 percent, air temperature 38° C; water in the trough at 85° C, relative humidity 37 percent, with air temperature 54° C. Textile dyeings were exposed under both sets of conditions to the same reflectance of paper A, and the reflectances of the dyeings were measured, before and after exposure at 436, 546, and 578 μ, The results at the wavelength of greatest reflectance change, which for all of the dyeings studied was one of the latter two wavelengths, usually agreed well with visual judgment.

The results showed that the fading rates of paper A and of most textile dyeings studied were affected to much the same extent by moisture and temperature. Of 42 dyeings, 22 faded equally (within 5 % of reflectance change), 17 faded less and 3 faded more, at the higher temperature and relative humidity.

In another series of experiments, dyeings were exposed in two widely differing lamps, enclosed and open arc, to the same reflectance of paper A. Of 33 dyeings, 16 faded equally, 13 faded more under the enclosed arc, and 4 faded more under the open arc.

In spite of the agreement, however, the results, even for the limited numbers of dyeings, indicate the desirability of standardizing such factors as relative humidity, type of arc, voltage, etc., as well as temperature, in test procedures. If that were done, the method could be expected to have general validity for many types of materials.

8. Effect of Interrupting Exposure

The light-sensitive papers showed excessive fading whenever the exposure was interrupted through failure of the arc in overnight runs. Paper E, for example, changed in reflectance by 0.158 for a continuous 16-hr exposure, whereas for two 8-hr exposures, interrupted by 16 hr. of darkness (during which no changes occurred), the reflectance change was 0.200. Further, if instead of 20 hr continuous exposure, interruptions of 1, 2, 3, or 4 hr occurred at 16 hr, followed by 4 additional hr of exposure, the increase in reflectance change over continuous exposure was 0.013, average, after all four periods of interruption. (In all of these experiments the arc was allowed to reach normal operating conditions before exposure.)

This intermittancy effect in light-sensitive papers, and perhaps also in textile dyeings and other materials, requires a more extended study, which is beyond the present scope.

IV. Master Lamp for Standardizing Light-Sensitive Papers

The original intent was to develop a lamp that would provide a given light dosage, and fractions thereof, in given time periods, the light dosage being related to a given number of photons of constant wavelength distribution. The various measures to be described resulted in a lamp in which a given light dosage could be reproduced, but it was not possible to obtain a precise fraction of such a dosage, that is, 80, 90, etc., percent, for the auxiliary standard strips, because of variation of electrode resistance during the burning of the carbon electrodes. For this reason light dosage is measured by means of a "exposure meter." This is an adaptation, to high intensity sources, of a device developed by Douglas [21] for the measurement, over periods of time, of extremely small quantities of light. This device will be described in detail in a subsequent publication.

1. Lamp and Accessories

During operation, the globe of the enclosed arc acquires a deposit of soot and ash from the electrodes, varying in thickness and transmittance, apparently as a function of the composition of the arc gases and of the ash content of the electrodes and thus changes the radiant output. Therefore, an arc was used that burns in a current of air that removes the arc residues and makes deposition negligible upon the 18-cm Corex-D tube that surrounds the arc and aids materially in simulating the fading action of the enclosed arc by providing a short-wave cutoff near 290 mμ.

The open arc burns cored electrodes, and as the nature of the core material determines to a great extent the spectral distribution of the arc, it is necessary that the electrodes be uniform throughout the batch. An effort was made to achieve this by purchasing a large quantity of electrodes, specially manufactured at one time from one lot of ingredients, culled to very close tolerances as to diameter.

During standardization the paper is mounted on a drum rotating at 1 rpm around the arc. The vertical face of the drum was machined to within 0.003 in. of perfectly circular and the paper mounted under tension against the machined face by wrapping around the drum, thus minimizing any tendency toward curvature in the other direction. As the paper extends downward from the drum by 5 cm, and its midpoint is 25 cm from the arc (which, furthermore, is not a point source but is about 15 mm long), the amounts of incident radiant energy differ vertically over the paper by less than 1 percent, and probably not at all horizontally, during rotation.

The lamp is housed in a special room at 25 $\pm$0.5° C and 50 $\pm$1 percent relative humidity, in order to avoid seasonal effects.

2. Power Input to Arc

Regulation of arc current and line voltage is necessary for reproducible performance of the arc.

A device, which is essentially a contact-making ammeter, regulates the arc current at 30 amp by controlling a reversible motor that regulates the arc gap.

The line voltage is kept within a tolerance of $\pm$0.5 percent by means of an induction voltage regulator, mechanical type.

The line voltage is applied to a fixed transformer that operates the arc near 40 v.

Constant power input during the burning of a trim of the carbon electrodes is not obtained by regulating line voltage, because the IR-drop in the electrodes changes with length. In a typical case, as the electrodes were consumed, the carbon resistance[4] changed from 0.19 to 0.44 ohm, and the electrode holder voltage (the "arc" volts actually measured) changed from 42.5 to 40.5, the current remaining at 30 amps. From these values it can be calculated that the true arc voltage rose from 36.7 to 39.2, accompanied by a rise in power input.

3. Reproducibility of the Arc

By limiting the tests to a definite portion of the electrodes, it was possible to obtain a measure of the reproducibility of the arc by relating radiant output to power input.

The experiments were spread over a period of 2 weeks, each test as described in the footnotes of table 3. An exposure meter, the receiver of which was mounted on a drum rotating at 1 rpm around the arc, thus scanning it from all angles, was used to measure radiant output.

The results in table 3 show the following: (1) The power input to the arc is quite reproducible, as the coefficient of variation in the wattage was only 0.59 percent, with an extreme difference of 2.7 percent. (2) The radiant output, in terms of counts per hour and counts per watthour, is reproducible to the extent indicated by the corresponding coefficient of variation, and the extreme differences. This reproducibility reflects variations among electrodes, variations in average line voltage, shifts in wavelength distribution, as the exposure meter is spectrally selective, and errors in the latter. Since, in ordinary practice, triple trims of electrodes are burned simultaneously, electrode variations will probably be less than indicated.

The problem of variations among textile fading lamps was suggested by William D. Appel. Members of the lightfastness committees of the

[4] Data furnished through the cooperation of F. T. Bowditch of the National Carbon Co., Cleveland, Ohio.

TABLE 3. *Reproducibility of master lamp in the spectral region [a] approximately 300 to 480 m, mμ*

Run [b]	Time	Arc power [c]	"Photon counter" values	
			Counts per hour	Counts per watt-hour
	min	*w*		
1	113.0	1,062	1,311	1.234
2	112.0	1,071	1,322	1.234
3	111.9	1,072	1,297	1.210
4	111.8	1,073	1,300	1.212
5	111.2	1,079	1,292	1.198
6	111.6	1,075	1,289	1.199
7	111.5	1,076	1,293	1.202
8	112.3	1,068	1,293	1.210
9	111.4	1,077	1,280	1.188
10	111.8	1,073	1,276	1.188
11	111.9	1,072	1,299	1.212
12	111.0	1,081	1,293	1.196
13	111.2	1,079	1,294	1.200
14	111.6	1,075	1,312	1.220
15	110.5	1,086	1,312	1.208
16	110.0	1,091	1,303	1.194
17	111.4	1,077	1,293	1.200
18	111.8	1,073	1,306	1.217
19	111.4	1,077	1,290	1.198
Mean		1,076	1,298	1.206
Standard deviation [d]		6.31	11.4	0.013
Coefficient of variation,[e] percent		0.59	0.88	1.1
Extreme difference, percent		2.7	3.5	3.8

[a] The spectral region was defined by the spectral sensitivity and transmission curves of the RCA 929 high-vacuum phototube and the Corning 5850 polished filter, respectively, the maximum occurring near 385 *mμ* (manufacturers' data).

[b] A fresh single trim of cored carbon electrodes was used for each run, and the measurements were started 60 minutes after the first striking of the arc.

[c] The energy input to the arc for each run was 2000.0 watthours, measured with a Rotating Standard watthour meter, General Electric model IB9Y, capable of being read to 0.01 watthour, using the proper current and voltage transformers. Thus, the number of counts were divided by 2,000 to obtain the values of counts per watthour. The values for watts were obtained by dividing watthours by hours.

[d] Standard Deviation$=\sqrt{\frac{(x_1-\bar{x})^2+\ .\ .\ .\ +(x_n\bar{x}-)^2}{n-1}}$

[e] Coefficient of variation$=100S/$mean.

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V. References

[1] P. J. Wood, Am. Dyestuff Reporter **31**, 595 (Dec. 7, 1942).

[2] NBS Letter Circular LC785 (Mar. 31, 1945); News item in Daily News Record, New York, N. Y., p. 21 (Apr. 25, 1945).

[3] C. A. Seibert, Bull. from the Tech. Lab., E. I. du Pont de Nemours Co. (Wilmington, Del., Oct. 1945); Am. Dyestuff Reporter **34,** 272 (July 2, 1945).

[4] Report by the Subcommittee on Light Fastness, Am. Dyestuff Reporter **23,** 283 (Nov. 5, 1934).

[5] Herbert F. Launer (abstract), Am. Dyestuff Reporter **34,** 264 (July 2, 1945).

[6] Utilization voltage standardization recommendations, Publication No. J. 8 (Edison Electric Inst., 420 Lexington Ave., New York, N. Y., Oct. 1942).

[7] William H. Cady and William D. Appel, Am. Dyestuff Reporter **16,** 707 (Nov. 14, 1927).

[8] William H. Cady and William C. Smith, Am. Dyestuff Reporter **20,** 326 (Nov. 23, 1931).

[9] P. Krais, Z. Angew. Chem. **24,** 1302 (1911).

[10] Alice Robson, J. Soc. Dyers Colourists **34,** 185 (1918).

[11] W. M. Scott, Am. Dyestuff Reporter **7,** 14 (1920).

[12] J. Clark, J. Opt. Soc. Am. **21,** 240 (1931).

[13] T. A. Werkenthin, David Richardson, R. F. Thornley, and R. E. Morris, India Rubber World **105,** No. 2 (Nov. 1, 1941); Federal Specification ZZ–R–601a.

[14] C. E. Greider and F. T. Bowditch, A study of the uranyl oxalate actinometer, Report of the Research Laboratories, National Carbon Co., Inc.

[15] Hugh Cristison, Am. Dyestuff Reporter **17,** 33 (Jan. 17, 1944).

[16] W. H. Cady, Am. Dyestuff Reporter **33,** 29 (Jan. 17, 1944).

[17] Herbert F. Launer, J. Research NBS **27,** 429 (1941) RP1430.

[18] Herbert F. Launer, J. Research NBS **24,** 567 (1940) RP1300.

[19] B. Schwezow, Z. wiss. Photochem. **9,** 65 (1910).

[20] M. Luckiesh and A. H. Taylor, Trans. Illum. Eng. Soc. **20,** 1078 (1925); Am. Dyestuff Reporter **14,** 613 (1925).

[21] C. A. Douglas, Electronics **20,** 106 (1947).

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