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COLOR AND SPECTRAL COMPOSITION OF CERTAIN
HIGH-INTENSITY SEARCHLIGHT ARCS

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I. INTRODUCTION

The development of high-intensity arcs by the use of specially prepared carbons has resulted in the production of a light which is very blue relative to artificial incandescent sources. In a general investigation of searchlights, including the effectiveness and suitability of their illumination for various purposes, it appeared desirable to have at least approximately quantitative data on the color of this light.

An investigation was made with the cooperation of the Searchlight Investigation Section, Corps of Engineers, U. S. Army. A report was issued to the Corps of Engineers and others January 23, 1919. Another report was made to the American Physical Society, April 25, 1919.¹ These reports are combined in the present paper.

The result of these investigations may be roughly summarized in popular language by saying that the color of the light from these arcs is approximately equivalent to the light of the noon sun at Washington, although relatively more intense in the blue-violet.

II. COLOR MEASUREMENTS BY ROTATORY DISPERSION COLORIMETER

There are considerable difficulties in the spectrophotometry of a source such as the high-intensity arc. It was therefore decided to obtain some preliminary data by the short-cut color-matching

¹ Phys. Rev. (2), 14, p. 184; August, 1919.

method of rotatory dispersion.² By this method one may determine quickly a spectral distribution which gives the same color as the source studied. The spectral distribution for equivalent color of a Sperry 45-volt, 75-ampere searchlamp of the regular type supplied to the U. S. Army, obtained in this way, was found to be very close to that of the noon sun at Washington³; that is, approximately that of a "black body" at 6000° K. (See Fig. 7.)

III. SPECTROPHOTOMETRIC MEASUREMENTS

Preliminary spectrophotometric measurements were made in April, 1918; but inasmuch as no description or specification of the carbons other than the maker's name was available, it was decided to make further measurements with carbons subjected to spectroscopic analysis for the sake of greater definiteness of description. These further measurements were made as follows:

The relative spectral distribution of radiant energy throughout the visible spectrum was measured for the following arcs:

	Amperes
Sperry searchlight arc, Columbia carbons.	75
Sperry searchlight arc, Speer carbons.	75
Ordinary arc, Electra carbons.	10

These relative values of radiant power were obtained visually by a spectrophotometric comparison with a standard Mazda-C 500-watt lamp (B. S. Lamp No. 1717), whose relative radiant powers had previously been accurately determined radiometrically by W. W. Coblentz of this Bureau. The arrangement of the apparatus for this investigation is shown in Fig. 1.

The arc was inclosed in a sheet-iron box. One opening allowed the light to pass to the spectrophotometer, as shown, and a second, over which was a piece of Noviweld (shade 12) glass, enabled the operator to view the arc and thus exert the required control. The mechanism of the arc is such that both carbons are slowly rotated and advanced at a rate which keeps the distance between them constant. The positive carbon is horizontal, as shown, the negative carbon being in front and below (Fig. 3). The diaphragm shown in front of the positive carbon was 5 mm in diameter. In some of the observations it was used and in the others removed. It enabled measurements to be made on the central part of the positive carbon, the light from the outer

² Arons, *Ann. der Phys.*, **39**, p. 545, 1912; Priest, *Phys. Rev.* (2), **10**, p. 208, 1917.

³ Abbot's data. See Priest, *Phys. Rev.* (2), **11**, p. 502, 1918.

portions and from most of the flame being excluded. The current through the arc was kept as near as possible to 75 amperes, a second operator controlling this current by means of an adjustable resistance.

When the standard lamp was in use, it occupied the same position as that given for the arc, this position being located by means of the total reflection prism and ground-glass focusing screen. The total reflection prism was, of course, removed while observations were being made. A second 500-watt Mazda-C lamp served as a comparison source. The voltages on these lamps were kept at constant values by means of a potentiometer and adjustable resistance, being 118 volts for the standard lamp and 125 volts for the comparison lamp. By means of suitable lenses, light from the two lamps, or from the arc and comparison lamp, was condensed and made to enter the two openings in the illumination box, which was fastened to the spectrophotometer support

FIG. 1.—Arrangement of apparatus for spectral comparison of light sources

directly in front of the collimator slit. Errors due to chromatic effects from the lenses were avoided by using on one side a pair of achromatic lenses and on the other side only the light through the central part of the lens.

The details of the illumination box are shown in Fig. 2. The two compartments are separated from each other by a brass partition. The interior of each compartment was coated white with magnesium oxide put on by burning magnesium ribbon, and blocks of magnesium carbonate were placed as shown. Thus the whole interior was white and the reflection from all surfaces was entirely diffuse.

The magnesium-carbonate blocks were illuminated as shown, and light from these two illuminated surfaces entered the double slit of the spectrophotometer through small openings in the illumination box. The whole interior of the box is, of course, illuminated by diffuse reflection from the magnesium-carbonate blocks, and

two beams of light from the sides of the box next to the spectrophotometer pass through openings in the opposite side and are compared by means of the Martens photometer.

The Koenig-Martens polarization spectrophotometer⁴ and the Martens polarization photometer⁵ are essentially alike except for the dispersing prism. In brief, they operate as follows: Two beams of light are polarized mutually perpendicular, by means of a Wollaston prism, and brought together to form the two halves of a photometric field. This field is viewed through a nicol prism, and in this investigation the adjustments were such that the two halves of the field in either instrument were brought to equality by the analyzing nicol somewhere between 30 and 60° on the scale.

FIG. 2.—Details of illumination box

To bring this about, it was usually necessary to place a rotating sector in the beam of the arc when it was used and in the beam of the comparison lamp when the standard lamp was used. A red glass filter was placed over the eyepiece of the Martens photometer (Fig. 1) to eliminate the color difference between the arc and the comparison lamp, and a ground-glass diffusing screen used, as shown (Fig. 2), to make the photometric field still more uniform and of the proper brightness.

Five people were necessary in making the observations on the arc, one to watch and control the arc, recording the readings of the voltmeter; a second to regulate the current through the arc, recording the readings of the ammeter; a third to observe the

⁴Ann. der Phys. (4), 12, p. 984; 1903.

⁵Phys. Zeit., 1, pp. 299-303; 1900.

illumination through the Martens photometer; a fourth to take readings on the spectrophotometer; and a fifth to record those readings and keep the proper voltages on the lamps by means of the potentiometer. The procedure for taking a series of observations under these conditions was as follows:

The arc was allowed to run a few minutes in order that conditions might become as steady as possible. While this was being done, the comparison lamp was kept at its proper voltage and the variations of the illumination from the arc followed on the Martens photometer. Finally, the photometer was set for equality of brightness between the two sources at what seemed to be the best mean value of the illumination from the arc. This setting was

FIG. 3.—*The Sperry arc in operation, viewed in a direction perpendicular to the plane of the carbons. The positive carbon is horizontal. (Photo by Dr. Enoch Karrer)*

then unchanged during the run. Now, for any given wave length, the variations in the illumination from the arc were followed on the spectrophotometer, the attempt being made to keep the two halves of the photometric field always equal in brightness. Whenever conditions were right, as shown by the Martens photometer, a sharp signal was given and the reading of the spectrophotometer taken at that instant. It was not attempted to do this, of course, if the illumination varied too rapidly through the proper value. Usually the variations were quite slow, the illumination often staying constant at the correct value for a considerable part of a minute. It was noticed during the course of the investigation that the value of the current through the arc would have served nearly as well as the auxiliary photometer for enabling measure-

ments to be made always at the same illumination; for the current was practically always at a given value, about 75 amperes, when the signal was given by the observer at the Martens photometer.

At each wave length from four to ten readings were taken on the spectrophotometer, the number depending on the agreement obtained among the readings. Measurements were made between wave lengths 430 or 440 and 710 $m\mu$, usually at every 20 $m\mu$.

After this series of measurements was completed, the total reflection prism was set up to locate the position of the arc and kept there until the standard lamp had been put in position. It was then removed, and another series of measurements made at the same wave lengths as previously on the arc. Only two observers were now necessary, one to make the measurements on the spectrophotometer, the other to record the data and keep the voltages constant with the potentiometer.

In this manner all the data were obtained, either a complete run or check points being taken on the standard lamp between any two of the runs on the arc.

The spectral distribution of radiant power of the arc was computed as follows: All the values of the angles of the nicol prism read on the spectrophotometer for the standard lamp were plotted at the proper wave lengths and a smooth average curve drawn through these points. All values for the standard lamp used in the computations were taken from this curve. Thus the same values of the standard lamp were used for all computations. For each wave length the square of the cotangent of the average angle, read on the spectrophotometer when the arc was in position, was divided by the square of the cotangent of the angle as read from the curve when the standard lamp was in position. When this is done for all the wave lengths, the radiant power of the arc relative to that of the standard lamp is obtained. By multiplying these values by the known relative values of radiant power of the standard lamp at the different wave lengths, the relative spectral distribution of radiant power in the arc was obtained.

These values are plotted in Figs. 4 to 7, the legend in the figures making clear the interpretation of the data. The values of all curves are made 100 at 590 $m\mu$.

There seems to be no consistent difference between the data for the Columbia carbons and for the Speer carbons. In both cases the values obtained when the diaphragm was used are lower in the blue than those found with the arc undiaphragmed.

In the red, however, the diaphragmed values are higher than the undiaphragmed values in one case (Columbia carbons) and lower in the other (Speer carbons).

The curves for the plain carbon arc at 10 amperes show nothing unusual, except the low values at 610 $m\mu$.

Perhaps the most striking characteristic of the spectral distribution of radiant power of the 75-ampere arcs is the preponderance of blue. This was to be expected from the bluish color of the arc when run at that current. The sudden increase of radiant power below 450 $m\mu$ is too large to be due to errors of measurement, in spite of the difficulty of obtaining accurate values in this region, and is undoubtedly due to a selective emission band in this region. (See Fig. 8.) Other irregularities in the 75-ampere curves which are thought to be real are the low values at 450 and the high values at 630 $m\mu$. Other small irregularities in the curves are probably due to experimental error, although, considering the great number of bright lines in the spectrum, it may perhaps be considered surprising that an approximately smooth curve was obtained at all.

IV. SPECTROSCOPIC ANALYSIS

Photographs of the spectra of these three kinds of carbons, the current in each case being 10 amperes, are shown in Fig. 8. The spectra were made with a large diffraction grating, using light from the center of the arc stream so that the line spectra characteristic of the metals in the vapor could be photographed, while the spectrophotometric measurements were made mainly on light from the central part of the positive pole which gives a continuous spectrum with bright lines superposed. The spectrograms, made for the purpose of defining the chemical constitution of the carbon electrodes, therefore have little relation to the spectrophotometric observations.

Spectroscopic analysis revealed the fact that the Columbia and Speer carbons were cored with a mixture of rare earth elements, among which cerium, thorium, lanthanum, and yttrium were represented. The emission spectra of these rare earths are very rich in lines, especially in the blue and violet spectral regions, so that a combination of them gives practically a continuous spectrum. Spectroscopic analysis of the incandescent vapors in the center of the arc showed that the rare earths in the Columbia and Speer carbons carried most of the current and suppressed the

FIG. 8.—Spectra of arcs at ten amperes

spectrum of carbon, while the Electra carbons, which contained no rare earths, gave a very discontinuous spectrum in which the carbon bands of short wave lengths were most prominent.

Various circumstances have prevented extending and amplifying this work; and since there is no immediate prospect of opportunity to resume it, and there appears to be little authentic data available on this subject,⁶ it is considered advisable to publish now the data which we already have.

It is also believed that the methods described above will be found useful by others for the investigation of light sources of the kind considered in this report.

WASHINGTON, October, 1919.

⁶ Since this report was first written, some data attributed to Abbot have been published by Lichtenberg (Convention, Ill. Eng. Soc., Chicago, Oct. 20, 1919). It appears that these data are not entirely consistent with ours; but Lichtenberg's treatment of it in the advance copy of his paper received here is not sufficiently complete to enable us to judge what the actual discrepancy may be.