

THE USE OF THE ROTATING SECTORED DISC IN  
PHOTOMETRY.

ERVIN S. FERRY.

FROM the fact that in photometric measurements the minimum error of observation is introduced when the photometer reading is at the middle of the bar, and the error rapidly increases as the reading is displaced toward one end, the comparison of two lights of different luminosities is attended with considerable uncertainty. The most obvious plan to bring the photometer reading into the region of least error is to introduce into the path of the more intense ray an absorbing medium whose coefficient is constant for all wave lengths. A pair of Nicol's prisms is sometimes employed for the same purpose, and the law of Malus used to compute the percentage of light transmitted; but the ordinary method is to use a rapidly rotating disc from which radial sectors have been removed. The assumption here made is that the ratio of the amount of light transmitted to the total incident illumination, is equal to the ratio of the aperture of the disc to the entire disc. Several experimenters have observed, however, that the candle power of an arc light as obtained by the use of the rotating sectored disc is sometimes considerably less than the value obtained without it. It was in the study of this anomaly that the following experiments were undertaken.

The apparatus consisted of an ordinary 1000 division photometer bar, having near one end the sectored disc rotated by a small electric motor. The disc was on a hinged shelf arranged so that it could be quickly moved out of the path of the ray of light. Various photometers were used according to their especial fitness for the particular conditions of the experiment. The Bunsen was found best for the comparison of lights of considerable difference in color; the Lummer-Brodhun was used when the two lights were of the same quality, while a modification of

Ritchie's photometer gave the best results where the two lights differed slightly in quality. The Nichols horizontal slit spectrophotometer was used in the comparison of monochromatic lights.

As the Nichols-Ritchie photometer has not yet been described, it may not be out of place to here give a brief description of it. The principal object in its construction was to have the two luminous spots one above the other so as to eliminate any error due to a difference between two eyes. It consists of two vertical mirrors (Fig. 1), one above the other, at right angles to each other, and each at  $45^\circ$  to the direction of the photometer bar. These mirrors are placed in a box having open ends, and a circular aperture in the front side covered with a thin sheet of celluloid or other translucent material. From this arrangement, it is evident that the upper half of the translucent screen will be illuminated by the light at one end of the bar, while the lower half will

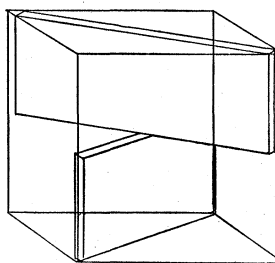


Fig. 1.

receive its illumination from the other end. The reading consists in moving the photometer along the bar till the line separating the two halves of the disc becomes invisible. By exercising proper care in fitting the mirrors together and in selecting the translucent screen, this photometer can be made as sensitive to differences of color and luminosity as the Lummer-Brodhun, and as convenient to use as the Bunsen.

The first experiment made was to determine if the error of the disc depends upon the size or arrangement of the separate apertures. For this purpose, discs were made containing 12, 8, 4, 2, and 1 equal and equally spaced segments; also others having the segments in each disc of different sizes, and arranged unsymmetrically. All of these discs were double, so that quite a range of total apertures could be obtained with each pair. When they were revolved with sufficient rapidity to produce a steady illumination of the photometer screen, it was found that the error of the disc was constant for all arrangements of the segments, so long as the total aperture was the same.

From the preceding experiment, the error appeared to be a function of the total aperture only.

The relation between the error and the total aperture was determined as follows: A lime light was placed at the disc end of the photometer bar, and a 16 C.P. incandescent lamp was used as a standard at the other end. The double disc, containing twelve fifteen-degree sectors, was used in this and the succeeding experiments. This disc had a graduated scale on its edge, so that the aperture of each segment could be varied from zero to fifteen degrees. The method of observation was as follows: a photometer-reading was taken with the rapidly rotating disc in the

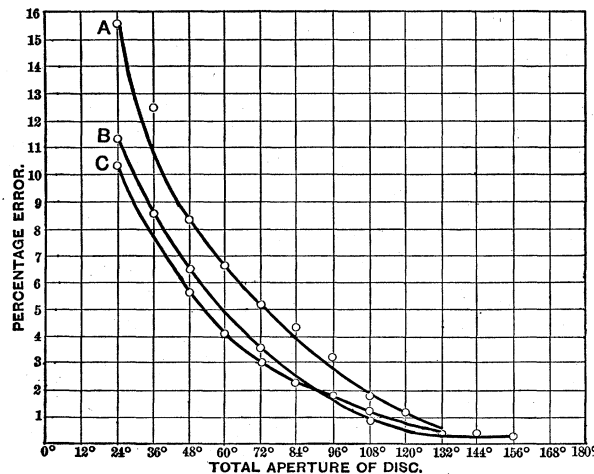


Fig. 2.

path of the stronger ray; the shelf containing the disc was then quickly raised out of the path of the ray, and another reading taken. The aperture of the disc was then changed, and another pair of readings taken. Denoting by  $I$ , the light ratio when the disc is in the path of the stronger ray;  $I_0$ , the light ratio without the disc;  $a$ , the angular aperture of the disc; and  $a+b$ , the whole circumference of the disc, we have the equation.

$$I = \frac{a}{a+b} I_0.$$

The relation between  $I$  obtained in this way and by direct observation will then give the error introduced by the disc. The observations and deductions thus obtained are given in the following table, while the results are graphically shown in Curve C, Fig. 2.

TABLE I.  
COMPARISON OF LIME LIGHT WITH 16 C.P. INCANDESCENT LAMP.

Observations.			Deductions.			
Aperture.	With disc.	Without disc.	$I_0$ .	$I$ calculated.	$I$ observed.	Per cent error.
24°	546	227	11.596	0.77	0.69	10.4
36°	493	227	11.596	1.16	1.06	8.6
48°	453	227	11.596	1.55	1.46	5.8
60°	424	227	11.596	1.93	1.85	4.1
72°	403	229	11.335	2.27	2.20	3.0
84°	385	230	11.208	2.61	2.55	2.3
96°	371	232	10.958	2.93	2.87	1.7
108°	358	223	10.836	3.25	3.21	1.2
120°	347	234	10.716	3.57	3.54	0.8
132°	339.5	237	10.365	3.80	3.79	0.2
144°	345	250	9.000	3.60	3.60	0
156°	342	255	8.536	3.69	3.70	0
168°	335	256	8.446	3.94	3.94	0
180°	328.5	257	8.358	4.18	4.18	0

Several attempts were made to obtain a similar curve for the case of the arc light; but these attempts were all unsuccessful with ordinary arc lamps, on account of their unsteadiness. But finally, through the courtesy of Mr. L. B. Marks, an "incandescent-arc" lamp<sup>1</sup> was obtained, which met the required condition of steadiness excellently. Table II. and Curve A, Fig. 2, give the disc's error in the case of the arc light.

<sup>1</sup> For description, see *Electrical World*, Sept. 9, 1893.

TABLE II.  
COMPARISON OF ARC LAMP (65 VOLTS AND 8.2 AMPERES) WITH  
16 C.P. INCANDESCENT LAMP AT 110 VOLTS.

Observations.			Deductions.			
Aperture.	With disc.	Without disc.	$I_0$ .	$I$ calculated.	$I$ observed.	Per cent error.
24°	521	205	15.039	1.002	0.846	15.6
36°	458	200	16.000	1.600	1.400	12.5
48°	410	195	17.042	1.136	2.071	8.2
60°	373	190	18.175	3.029	2.826	6.7
72°	350	190	18.175	3.635	3.449	5.1
84°	336	193	17.484	4.079	3.905	4.2
96°	320	193	17.484	4.662	4.516	3.1
108°	318	202	15.606	4.682	4.600	1.7
120°	297	195	17.042	5.681	5.603	1.2
132°	290	198	16.407	6.016	5.994	0.3
144°	279	197	16.615	6.646	6.678	0
156°	261	188	18.655	8.083	8.017	0
168°	256	190	18.175	8.481	8.446	0
180°	249	190	18.175	9.088	9.097	0

When a 16 C.P. incandescent lamp was compared with a standard Methven slit, Curve B, Fig. 2, was obtained.

Two 16 C.P. incandescent lamps were then compared. Two were selected that were as nearly alike in every respect as possible, and connected in multiple to a storage battery circuit. Their spectra were examined photometrically, color for color, and found to be nearly alike in luminosity throughout. They were then mounted on the photometer bar, and light ratios obtained with and without the sectored disc. The electromotive force of the lamps was varied from 70 to 120 volts, and the aperture of the disc varied throughout its range, without any appreciable difference being observed between the calculated and observed value of the light that passed through the sectored disc. This experiment shows that the error introduced by the disc is not a function of the absolute illumination of the photometer screen.

Two incandescent lamps giving nominally 150 C.P. and 16 C.P., respectively, were then mounted on the photometer bar. They

were connected to separate circuits, and the included resistances varied till they were of the same color. Again, little or no error was observed, even when the disc was nearly closed, but if the lamp at the disc end of the bar was made to burn at a voltage much greater than normal, the error again appeared. This showed that the error of the disc is not dependent upon the luminosity ratio of the two lights and suggested the possibility that the color of the light might be the cause of the discrepancy. It is to be noticed that in the above four cases where a marked error occurred, the light at the disc end of the bar was of a bluer quality than the standard.

If, after the two lights have been brought to the same color, a sheet of glass slightly tinted with blue be interposed in the path of the ray from the disc end of the bar, error values are obtained similar to those shown in Fig. 2. This seems to prove that the error of the disc is dependent upon the color of the light that it interrupts.

The phenomena described in these experiments can probably be explained from considerations of retinal inertia. The luminosity of ordinary light is the integral of the luminosity of all the wave lengths that affect the retina. The distribution of luminosity in the spectra of ordinary illuminants proceeds from a maximum in the orange or yellow, to zero at the ends of the spectrum. Both the intensity of the retinal sensation<sup>1</sup> and the time light must act upon the retina in order that it may be seen<sup>2</sup> are direct functions of the luminosity. Hence, if the light acts upon the retina for but a very short time, the elements of low luminosity — *i.e.* at the ends of the spectrum — will not produce their maximum impression. Therefore the value of the candle power deduced from the observation with the disc will be less than the total luminosity of the light. If the curve of luminosity with respect to wave length of any light be known, and also the curve of time necessary to receive a retinal impression with respect to the same range of luminosity, the error of the disc can be prophesied for any aperture.

<sup>1</sup> Fechner, *Revision der Hauptpunkte der Psychophysik*, p. 184.

<sup>2</sup> J. M. Cattell, *The Inertia of the Eye and Brain*, "Brain," Part XXXI.

After the disc has attained a speed sufficient to cause an unflickering illumination of the screen, any increase of speed produces no difference in the photometer reading. But it was noticed that if the disc did not revolve rapidly enough to produce a perfectly steady illumination of the photometer screen, *more* light appeared to go through the sectored disc than theoretically should. This can possibly be explained, as has been an analogous phenomenon by Ernst Brücke<sup>1</sup> from the consideration of a building up of the separate impressions upon the retina.

#### *Conclusions.*

I. While it is physically true that the proportion of light transmitted by a rapidly rotating sectored disc to the total incident illumination is equal to the ratio of the total aperture of the disc to the entire disc, yet the effect of this light upon the retina will not always be proportional to the ratio of the total aperture of the disc to the entire disc.

II. With mixed light containing elements of different luminosity shining upon the retina, a rotating sectored disc will appear to not cut off all the elements in equal proportion, but will intercept most strongly the elements of low luminosity.

III. With any given light, the error introduced by the use of the rotating sectored disc increases as the aperture of the disc diminishes.

IV. With ordinary illuminants, the error is negligible when the total aperture of the disc is more than one-half the entire disc, but rapidly increases as this aperture is diminished.

#### NOTE UPON THE ACTION OF INTERMITTENT LIGHT UPON THE RETINA.

From the study of rotating cardboard discs painted black and white in sectors, von Helmholtz deduced the law "if a point of the retina is excited by a light which undergoes regular and periodic

<sup>1</sup> "Ueber den Nutzeffect intermitterenden Netzhautreizungen," *Sitzungsberichte, Wiener Akademie*, 1864, Vol. 49, II. p. 128.

variations, and which has the duration of its period sufficiently short, it produces a continuous impression, equal to that produced if the light emitted during each period were distributed uniformly throughout the duration of the period."<sup>1</sup> Plateau, Fick, and Dove have repeated the experiments of von Helmholtz and confirmed this law; and yet it was thought useful to test the law by using monochromatic light throughout a wide range of luminosity and wave length.

The method employed was to compare photometrically, color for color, two spectra seen side by side in the eye-piece of a spectrometer, one spectrum being produced by a ray coming directly from the source of light, and the other by a ray from the same source, but made rapidly intermittent by a revolving sectored disc. Sunlight, daylight, and the incandescent electric were used to produce the spectra. A very accurate double slit with micrometer adjustments at the object end of the collimator gave the means of varying the luminosity of the two spectra. The method of transmitting the two rays into the collimator is shown in the figure. Observations were taken throughout the entire spectrum and of luminosities varying 1000 per cent. A difference of luminosity of 2 per cent could have been detected by this method, but no deviation from the law of von Helmholtz was observed.

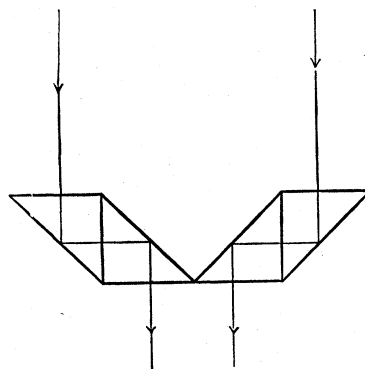


Fig. 3.

<sup>1</sup> *Physiologische Optik*, 2d ed., p. 483.