Second Series. *December, 1914* *Vol. IV., No. 6.*

THE

PHYSICAL REVIEW.

A CONTRAST EQUALITY PHOTOMETER.

By A. H. Pfund.

SEVERAL years ago the writer described a simple equality-photometer[1] which has been used with success by several investigators. Recently it was found possible to modify the design of the instrument so as to introduce also the principle of contrast and thus to attain (theoretically) double the sensibility of the perfect equality-photometer.

The plan of the photometer-head is shown in Fig. 1 where AA represents a plate of brass set diagonally in a small wooden box, $3 \times 3 \times 3$ cm. An elliptically shaped hole is cut in the center of the brass plate, the axes being 10 and 7 mm. A mirror, consisting of a piece of platinized plate-glass (B), covers one half of the opening, the vertical edge of the glass coinciding with the mirror axis. By viewing this system through a tube T containing a lens which magnifies 3 diameters, a circular field, divided centrally by a perfect edge, is seen. This arrangement constitutes the equality-photometer previously described.

In order to increase the sensibility of the instrument, a piece of smoked or neutral-tint glass was ground down to a very thin optical wedge whose transmission near the thin edge was greater by about 2 per cent. than at the thick edge. After cutting the glass in two so as to procure two identical wedges, the ground surfaces were cemented to pieces of clear glass by means of Canada balsam—thus avoiding the necessity of polishing. These wedges were then mounted at C and C' and were so adjusted that their density gradients, though vertical, were reversed. Upon mounting this photometer-head and establishing a photometric balance an appearance, similar to that shown in Fig. 2, was presented. In this illustration the density gradient was made large purposely so as to bring out the principle involved. It is evident that photometric balance has been established when equality exists at the center of the

[1] Johns Hopkins University Circular (1906), p. 20.

field and equal contrast in the upper and lower portions. Without going into details it may be shown that if (for example) the eye is capable of detecting a minimum intensity difference of 2 per cent. and if the excess of transmission through the thin part of the wedge be 1 per cent., then the accuracy of setting will be double that obtainable by means of an equality photometer.[1]

Before discussing the results obtained, it may not be out of place to describe the method employed in preparing the mirror *B*. A piece of plate-glass of the approximate dimensions 25 × 15 × 1 mm. is scratched, as shown in Fig. 3, by means of a steel-wheel glass-cutter, and is then broken in two along the dotted line. The portions not touched by the steel-wheel present perfect edges. These plates are subsequently covered cathodically by a hard, highly reflecting layer of platinum and thus two plates, either of which may be used as mirror *B*, are obtained. It is needless to add that subsequent polishing is liable to destroy the perfection of the edge.

A typical series of measurements is recorded below. The comparison of a 50-watt tungsten lamp against a carbon lamp of almost equal candle-power was carried out. It will be pointed out later that a striking feature of this type of photometer is that the eye depends upon difference of contrast and disregards, to a very marked extent, differences of color. In order to accentuate the contrast in color between the tungsten and carbon lamps, a sheet of clear glass of slightly greenish hue was placed between the tungsten lamp and the photometer head. The lamps were about 200 cm. apart and the photometer head, when in position of balance, was nearly half-way between them.

Distance from Tungsten Lamp to Photometer.	Residuals.	
102.08 cm.	+.02 cm.	
102.26	+.20	
102.00	−.04	
102.13	+.07	
101.96	−.10	
102.11	+.05	Average deviation from mean setting 9.4 parts in 10,000 or < .01 per cent.
101.91	−.15	
101.98	−.08	
101.95	−.11	
102.20	+.14	
Mean 102.06		

In view of the circumstance that the lamps were permanently separated by a distance of 2 meters the error of setting the movable photometer-head is but one fourth of the error in candle-power measurement—hence,

[1] After the completion of this work (Jan., 1914) the writer was told by Dr. E. P. Hyde that he had constructed a photometer involving a similar principle. He placed opposed wedges in front of a Lummer-Brodhun contrast photometer and made final settings by obtaining equality of contrast at the edge of one of the trapezoids.—The work was never published.

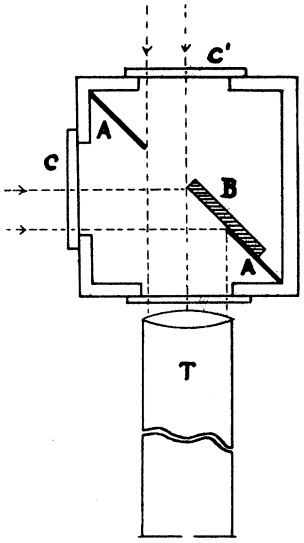

Fig. 1.

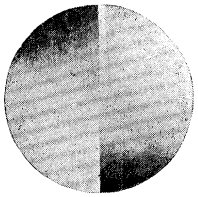

Fig. 2.

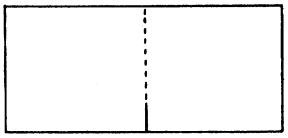

Fig. 3.

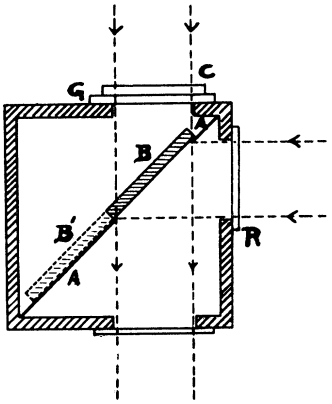

Fig. 4.

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while the error of setting was about 0.1 per cent. the error in c. p. measurement is 0.38 per cent.—The optical wedges used possessed too high a density gradient, hence the ideal conditions, which may be realized with care, were not fulfilled. It is shown, nevertheless, that even though an appreciable color difference exist between the sources, a very fair degree of accuracy is attainable by means of this photometer.

In the course of the work it became evident that the instrument could be used in the comparison of the intensities of colored light-sources. For a successful comparison of such sources it is necessary to increase the density gradient as the difference in color between the light-sources increases for the eye depends largely upon the equality of contrast and not upon a judgment of equality of luminosity. If a red and a green source are to be compared and equality of contrast has been established it is found that the eye has introduced a second (rather diffuse) line into the field of view. This subjective line intersects with the permanent vertical edge at an angle, the point of intersection being at the center of the field of view when a balance is established. By viewing Fig. 1 this subjective line, which divides the field of view into four sectors, may be readily observed. The two criteria of balance, *i. e.*, equality of contrast and central intersection of the two lines, supplement one another and thus increase the accuracy of setting.

This arrangement was tested by inserting a plate of glass covered with green-stained gelatine in front of the tungsten lamp and a similar red-stained plate in front of the carbon lamp. The distance from each source to the usual plaster of paris diffusing screen was very nearly 51 cm. A typical series of settings is given below:

Distance from Lamp to Diffusing Screen.	Residuals.	
Mean 102.06		
51.4 cm.	+0.00	
51.5	+0.1	
50.7	−0.7	
51.3	−0.1	
51.5	+0.1	
50.7	−0.7	
51.2	−0.2	
51.4*	0.0	Average deviation from mean setting 4.8 parts in 1,000.
51.6	+0.2	
51.5	+0.1	
51.2	−0.2	
51.7	+0.3	
51.3	−0.1	
51.7*	+0.3	
51.8	+0.4	
51.1	−0.3	
Mean 51.4		

The stars opposite the 8th and 14th setting indicate that 10 minutes were allowed to elapse before making the next setting in order to determine whether or not fatigue had much influence on the accuracy of setting. It will be noted that even under these extreme conditions of color difference the average deviation from the mean setting is but 4.8 parts in 1,000, whereas the average deviation from the mean candle-power is 1.9 parts in 100 or nearly 2 per cent.

After the completion of this series, Mr. Enoch Karrer, who had had no experience with this instrument, was called in. He succeeded at once in making settings which agreed, within the limits of accuracy, with those previously obtained by the writer. The wedges were then removed and a comparison of the same (red and green) light sources was attempted. The task seemed hopeless as all criteria had disappeared and recourse had to be taken to a very questionable "judgment" of equality.

An attempt was next made to use the optical wedge also in the construction of a flicker-photometer. This instrument, as shown in Fig. 4, consists of the usual brass plate AA' with elliptical aperture behind which a platinized mirror is caused to oscillate. The former red and green plates are attached to the photometer-head at R and G. When the mirror is in the position B, the entire field of view appears green and conversely, when the mirror is in the position B', the entire field of view appears red. A single optical wedge with its density gradient vertical was inserted at C. It is evident that the criterion for equal intensity is no longer disappearance of flicker over the entire field, but equality of flicker in the upper and lower portions and disappearance of flicker in the center. Surprisingly accurate settings could be made with this device—in fact, when red and green sources were compared, the average deviation from the mean candle-power was but 0.6 per cent.

In order to determine whether or not the flicker could actually be made to disappear over the entire field of view when the wedge was removed, further experiments were carried out on this point. It was noted that, with this arrangement, the flicker could not be made to disappear. As one of the sources was slowly moved up toward the position of equality the flicker first disappeared in (say) the right portion of the field of view but persisted in the left. A still closer approach of the source brought about equality of flicker on the right and left and absence of flicker in the middle—a condition which has been considered as the criterion for photometric balance. Thus it is evident that, even without the use of an optical wedge, the condition of equality of flicker may be realized. The writer assured himself that there was no asymmetry in the instru-

ment capable of accounting for the above effect—and, up to the present, no satisfactory explanation has been found.

The preceding is to be looked upon as a preliminary publication, for much remains to be done in defining the various conditions of maximum sensibility of the several photometric appliances. This work is to be taken up and extended in the near future.

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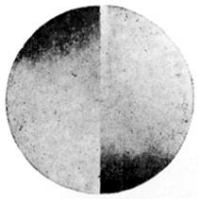

Fig. 2.