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MEASUREMENTS WITH A MOVING LAMP PHOTOMETER.

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IN the following paper a modification of the ordinary photometer is described. The essential feature of the apparatus is a sliding carriage, supporting one of the lamps, which may be set in to and fro motion at uniform velocity in the photometric axis. Comparisons of equal field intensity are observed while the lamp is in motion, and recorded by a simple mechanism.

The purpose of the measurements which have been made with the apparatus was to ascertain the magnitude of errors occurring in photometric measurement in which one of the light sources is rapidly diminishing in intensity as in the photometry of phosphorescent gases and certain phosphorescent solids. The opinion was held that these errors might be of considerable magnitude, a view which has been verified by the series of measurements which are the subject of this paper. The use of the moving lamp device gives some information also on the rôle played by the fatigue of the retina of the eye in photometric measurements in general.

The paper is divided for convenience as follows:

1. The moving lamp mechanism and the method of measurement.
2. Judgment of screen equality and reaction time.
3. Retinal fatigue in the photometry of phosphorescence.
4. Use of the moving lamp apparatus in general photometry.
5. Retinal fatigue in different persons.

1. The Moving Lamp Mechanism and the Method of Measurement.

The apparatus used is shown in Fig. 1. By means of a belt carrying a metal L-shaped catch (C, Fig. 1) which engaged alternately projections E and E' on the lamp carriage, the lamp was made to approach and to recede from the photometer screen through a distance of 44 cm. respectively. The lamp carriage was equipped with a small electro-magnet with a pencil attachment controlled by a key. By this device the

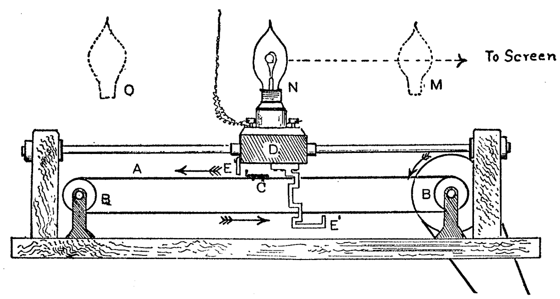

Fig. 1.

Essential Parts of Mechanism for Motion of the Lamp: A belt A moving on pulleys B, B, C a metal catch on belt, D lamp carriage, EE' projections attached to the lamp carriage to engage metal catch on the belt by which the uniform advancing and receding motion of the lamp is effected.

observer recorded the position of the moving lamp on a fixed strip of paper at the moment that the two sides of the comparison screen appeared uniformly illuminated. The lamp carriage was also equipped with a contact point, which entering a narrow trough of mercury, could be used to light a signal lamp for a moment in each advance and each recession of the light. The comparison screen employed was of the Conroy type (reflection at 60° incidence) and was viewed through an oval diaphragm and through a collimator about six feet in length. This type of screen and method of observation is not essential in the moving lamp mechanism, however. The left half of the oval collimator field was illuminated by the moving light, while the illumination of the right half was due to the standard lamp. In Fig. 2, M shows the field when the moving light is closest to the comparison screen; N shows the equality obtained as the moving light recedes; while O shows the contrast when the moving light is 44 cm. farther from the screen than in M. The investigation having been undertaken primarily to ascertain the errors in the photometry of phosphorescence; the conditions of the experiments were adjusted to correspond to the rate of the decay; that is the rapidity of fading of the light after stimulation of the substance. Accordingly the lamp was run at 13 cm. per second as this velocity produced a diminution of intensity which corresponded to the average rate of fading of the phosphorescent nitrogen gas found in previous experiments.[1] At this velocity the comparison screen changed from M (Fig. 2) through apparent equality, N,

[1] C. C. Trowbridge, Phys. Rev., XXVI., 6 June, 1908, and XXXII., 2 Feb., 1911.

to O so quickly as to produce the effect of a flash of reversal. An instant judgment was therefore possible. An explanation of the use of a uniform velocity to correspond to a phosphorescent decay is given in a later section.

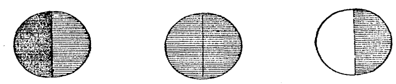

Fig. 2.

Photometric Fields of View. The Comparison Screen Corresponding to Three Positions of Lamp; M, moving light at least distance from comparison screen; N, moving light at position for apparent equality of fields; O, moving light at greatest distance from comparison screen.

With a velocity of 13 cm. per second, the moving lamp remained at each end of its run (shown by M and O in Fig. 1) for 1.2 sec. The distance from M to O was 44 cm.; hence $44 \div 13 = 3.4$ sec.; the time of the circuit of the lamp was therefore $(2 \times 3.4) + (2 \times 1.2) = 9.2$ sec. Thus, under the above conditions, five points of judgment of screen equality, *as the light receded*, were taken within 37 sec. while if readings in both directions were desired they could be taken within 42 seconds. On the other hand, ten settings of the screen by hand adjustment without an elaborate recording device could scarcely be accomplished in less than several minutes. The moving light thus eliminates the slowness of hand settings. It is possible, of course, that new errors enter, but the convenience is undoubted.

The method of using the instrument was as follows: The "movable lamp," set at the middle point of its run, was adjusted at a distance of 80.3 cm. from the screen, this being the calculated distance for .75 of an arbitrary standard intensity, I, used in the phosphorescent work referred to above. The comparison lamp on the opposite side was then adjusted for approximate screen equality. A mean position was obtained by using long cords attached to the "movable lamp" carriage so that the observer could make a series of adjustments free from the effects of muscular coördination. The muscular control of the instrument which one has with his eye at the eyepiece and his hands upon the carriage of a Lummer-Brodhun or Bunsen screen was lacking since the cords were somewhat elastic. The judgments were therefore eye decisions, but were made after various shiftings as is usual.

Each of a series of ten hand settings were made and recorded by means of the magnetic device. The record strip was then replaced by a blank, the light set in motion at $v = 13$ cm. per second and 5 observations of apparent equality were taken. The record blank was then replaced, since more than 5 observations tended to destroy the clearness of the record. After fifteen to fifty had been secured, the apparatus was adjusted for .50 I and later for .375 I and the procedure described was repeated for each position.

The first series of observations taken cover the period from January 25, 1912, to March 16, 1912, and were 1,200 to 1,500 in number. Those shown in the tables were taken March 15 and 16, and are given merely because the measurements of the three intensities were repeated on two successive days under similar conditions and with the apparatus unchanged by any modifications during that time.

TABLE I.

Distances from Moving Lamp to Screen in Centimeters.					
Hand Settings .75I.	Readings of Position of Light Receding from Screen at v=13 Cm. per Sec.				
77.5	77.9	78.6	76.1	77.0	
79.7	81.3	79.5	77.3	78.5	
80.6	81.4	80.1	80.1	78.8	
81.5	82.6	82.9	81.3	82.1	
81.6	85.5	83.4	84.4	83.6	
82.3	79.1	75.4	77.8	77.7	
83.3	79.4	78.0	78.0	81.0	
84.2	80.2	80.3	79.4	81.7	
84.6	82.3	80.7	80.5	84.2	
85.2	78.6	81.0	84.8	86.8	
82.0	80.8	81.3	80.0	81.0	Means
1.87	1.79	2.08	2.25	2.53	Av. dev.

TABLE II.

Distances from Moving Lamp to Screen in Centimeters.				
Hand Settings .50I.	Readings of Position of Light Receding from Screen at v=13 Cm. per Sec.			
92.8	93.8	91.5		
93.9	94.5	92.3		
94.5	95.5	93.5		
95.1	96.7	94.6		
95.3	97.8	97.5		
96.4	90.8	92.8		
96.8	93.0	93.1		
97.0	95.4	95.5		
99.1	95.7	98.7		
100.8	100.0	102.9		
96.2	95.3	95.2	Means	
1.85	1.84	2.72	Av. Dev.	

TABLE III.

Distances from Moving Lamp to Screen in Centimeters.					
Hand Settings. .375I.		Readings of Positions of Light Receding from Screen at v=13 Cm. per Sec.			
108.1	104.9	109.0	107.0	106.4	
109.0	105.7	109.3	110.2	106.5	
109.1	108.3	110.1	110.4	111.9	
109.5	108.4	111.0	110.6	112.6	
113.2	108.6	113.6	112.0	115.7	
113.4	109.1	108.7	104.3	107.1	
113.6	110.8	109.7	104.9	107.2	
115.7	111.5	111.3	108.2	108.0	
116.3	111.8	112.7	111.8	115.5	
117.1	113.1	113.5	114.3	116.8	
110.8		110.9	109.4	110.8	Means
2.46		1.52	2.61	3.74	Av. dev.

Tables I., II. and III. contain the data just referred to. It will be seen by inspection that the sets of observations on screen equality for the light receding at 13 cm. per second differ among themselves to about the same extent that the hand settings differ among themselves. The average deviations for hand settings are: – 1.87, 1.85, 2.46 cm., and for the motion readings, 2.1, 2.28, and 2.62 cm. It is to be especially noted that the averages of the receding sets are in very close agreement, namely: 80.8, 81.3, 80., 81.0; Table I.; 95.3, 95.2, Table II.; and 110.9, 109.4, 110.8 cm., Table III.

The figures in Table III. seem to indicate that low luminations give the best conditions for the use of the instrument. If we are to regard the hand adjustment as necessary to standardize, the mean position of the light receding at v = 13 cm. per second expressed in per cent., Table III. is found to be less than the mean hand adjustment by only .0036, while in Table II. the difference is .01+ and in Table I. it is .02.

2. Judgment of Screen Equality and Reaction Time.

Before proceeding to the calculation of data relating to the errors in the photometry of phosphorescence, the sources of error affecting the readings of the moving lamp photometer must be examined and the necessary corrections determined and applied. In the uncorrected readings of the photometric comparisons, four sources of error seem to be important—(X_1) the judgment of screen equality; (X_2), the effect of the diminishing intensity of the receding light upon the eyes of the observer; (X_3), the reaction time of the observer; and (X_4) the reaction time of the electrical recording device.

By means of the momentary circuit closing device which could be instantly adjusted to throw a flash from the signal lamp into the illuminated collimator field, it was possible to ascertain the values of (X_3+X_4), namely, the combined reaction times of the observer and the recording instrument.

With a given velocity of the lamp carriage, the recording mechanism was used with the automatic signal lamp to determine the reaction time. Readings taken indicated a lag in the record behind the actual time of the signal in direct proportion to the velocity. For $v = 13$ cm. per second, which corresponds to the mean rate of phosphorescent decay of intensity at the values tested in this investigation, the lag (d) was 3.6 cm. Then $3.6 \div 13 = .28$ sec. which indicates that for the same observations upon the phosphorescent problems the decay at the values of intensity tested ($.75\,I$, $.50\,I$ and $.375\,I$), was .28 sec. later than the photometric judgment, assuming the observer to have this reaction time.

The data on this lag (denoted hereafter $X_3 + X_4$) are given in Table IV. Each number tabulated is the mean (taken by inspection from the nearly overlapping strokes of the recording pencil) of five successive observations. It will be noted that the figures for the three later dates are in close agreement. The values have been applied as a correction to the photometric observations during the corresponding periods of time.

TABLE IV.

Personal and Instrumental Reaction Time $(X_3 + X_4)$.

Feb. 13, 1912.	Feb. 23.	Feb. 24.	Mar. 15.
3.1 cm.	3.7	4.0	3.7
3.2	3.7	3.7	3.8
3.0	3.7	3.8	4.0
3.1	4.2	3.6	3.6
3.4	3.7	3.7	3.7
3.3			4.0
3.6			
3.5			
3.5			
Av. 3.3 cm.	3.8 cm.	3.8 cm.	3.8 cm.

3. RETINAL FATIGUE IN THE PHOTOMETRY OF PHOSPHORESCENCE.

A curve is shown in Fig. 3 (A and A'), which gives the relation between the luminous intensity of phosphorescent nitrogen gas and the time. This gas in the phosphorescent state has been shown to be chemically active by R. J. Strutt and has been called "active nitrogen" by him. The equation of the curve is

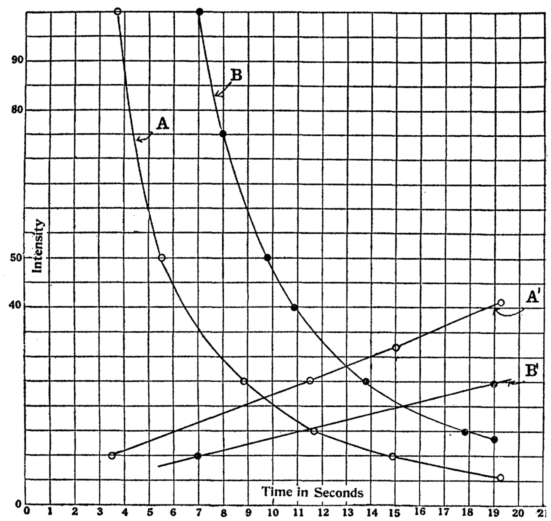

Fig. 3.

Phosphorescent Decay and the Photometric Law. *A*, curve of phosphorescent decay of nitrogen gas (active nitrogen); *A'*, same curve in which $1/\sqrt{I}$ is plotted instead of *I*; *B*, curve to show photometric decrease of intensity with distance, *or with time for uniform motion*; *B'*, same curve in which $1/\sqrt{I}$ is plotted instead of *I*.

$$I = \frac{1}{(a + bt)^2},$$

in which a and b are constants. This relation for a phosphorescent gas was first demonstrated by one of the authors of the present paper in 1907.[1] The other curve in Fig. 3, B and B' is the general photometric law,

$$I = \frac{1}{d^2}.$$

If the light I is made to recede from a screen with uniform velocity t^2 may be put in place of d^2 and under these circumstances the receding light acts as if it were a source of phosphorescence, diminishing in intensity, according to the determined law of phosphorescent decay. This circumstance affords opportunity for a study of the apparent and the real intensity in the photometry of phosphorescence. Employing the data given in the foregoing tables; first deducting the combined reaction times $(X_3 + X_4)$ from the mean positions of observed screen equality at the standard velocity of the receding light, and then calculating the intensity of the receding lamp at the corrected positions, the results shown in Table V. were secured. The figures in the last column may be

[1] C. C. Trowbridge, Astrophysical Journal, V., 26, Sept., 1907, p. 102.

considered the corrected intensity values corresponding to three different points of a decay curve of gas phosphorescence for observer *A*. The intensity value in column 4 is the corrected intensity I.

TABLE V.

Date.	No. Observations.	Standard.	Calc. Total Intensity (Moving Light).
Jan. 25 to Feb. 24	about 200	.75 *I*	.86 *I*
January 29	15	"	.85 *I*
March 9	15	"	.87 *I*
March 9	25	"	.854 *I*
March 15	45	"	.86– *I*
Jan. 25, Feb. 24	about 100	.50 *I*	.54 *I*
March 16	25	"	.55 *I*
January 25, February 24	85	.375 *I*	.41 *I*
March 16	30	"	.406 *I*

The agreement between the "corrected" intensities (last column) calculated from different experiments, is quite satisfactory, and indicates a consistent uniformity in the work done by one observer.

The time reaction of the observer[1] of the phosphorescent decays has been found to be in close agreement with the observer obtaining the results in Table V. and it seems legitimate to apply this correction for reaction time $(X_3 + X_4)$ to one of the phosphorescent curves taken by the former, but the correction X_2 for the retinal fatigue used in Fig. 4 is that of the observer of the phosphorescent decay.

In Fig. 4, *A* shows the relation between the luminous intensity of a phosphorescent source and time (the rate of decay of gas phosphorescence, —see curve *C* on page 137),[1] and *A'* is the relation between the inverse square roots of intensity and time of the same set of observations. Curve *B* is obtained by correcting the abscissae of .75 *I*, .50 *I*, and .375 *I* on the phosphorescent decay curve, by the time value of $X_3 + X_4$, the combined reaction time, and by extrapolation of a few later points. Curve *C* has been corrected for both $(X_1 + X_2)$ and $(X_3 + X_4)$ and curve *C'* is the plot of the reciprocal square roots of intensity of curve *C*. These corrections shift the curves *C* and *C'* slightly, but do not materially affect the general relation of phophorescent intensity to time of decay.

The effect of the combined reaction times $(X_3 + X_4)$ in phosphorescent measurements is to make the reading of the time nearly three tenths of a second later than it should be. The effect due to diminishing the intensity of the receding light or the decay of the phosphorescent source of

[1] C. C. Trowbridge, PHYS. REV., XXXII., 2 Feb., 1911.

light, namely, the fatigue, is to judge the intensity equal when by the law of inverse squares it must be distinctly greater. But it so happens that for the rate of decay of phosphorescent gases, these two sources of error tend to counteract each other as is shown in Tables I., II., and III. (observer A), also curve C, Fig. 4 (observer C); that is, X_2 is opposite in character and in some cases is nearly equal to $(X_3 + X_4)$.

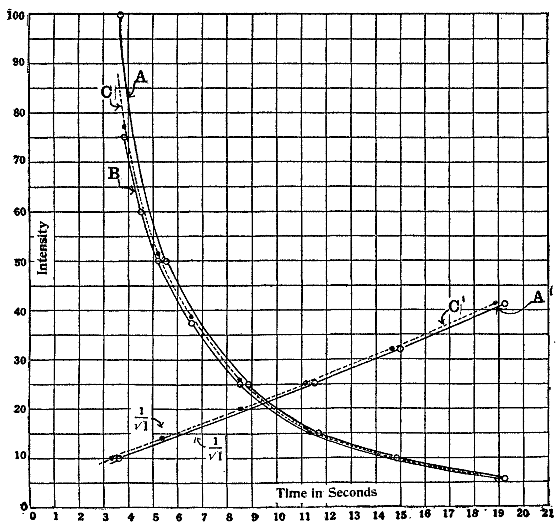

Fig. 4.

Corrections Applied to a Phosphorescent Decay Curve. A, curve of phosphorescent decay of nitrogen gas; A', straight line form of Curve A, $(1/\sqrt{I})$; B, Curve A, corrected for reaction time when making observations; C, Curve A corrected for both reaction time and retinal fatigue; C', Curve C (corrected Curve A) in straight line form showing little change from original Curve A.

In all experiments on photometry of phosphorescent sources the effect of the factor X_2 which has been assumed to be the temporary fatigue of the retina of the eye, should be ascertained. The errors due to X_2 might be of considerable importance, since failure to allow for the effect would for some persons result in photometric errors of fifteen per cent. especially with rapid phosphorescent decay.

Apparently none of the investigators who have made a study of phosphorescent decay have used this important correction; on the other hand it has required an investigation with special apparatus to determine it.

4. Use of Moving Lamp in General Photometry.

In order to determine what value the moving lamp apparatus might have for general photometry; a number of observations were taken for the equality of illumination when the moving light was *both approaching and receding from the screen* at the standard velocity, 13 centimeters per second. Here the reaction time correction cancels out and the mean position of the moving lamp is the arithmetical mean of the observed positions, subject to a correction. The three tables which follow exhibit the precision of the measurements. The observations were by three different observers, A, B and C at three distances of the moving lamp from the screen corresponding to $.75\,I$, $.50\,I$ and $.375\,I$, I being an arbitrary intensity standard.

TABLE VI.

1st Distance (80.26 Cm.), I=.75.			
Observer.	Average Deviation Cm.	Percentage Deviation.	Percentage Error of Intensity.
A	.65	.008	.016 high
A	1.38	.016	.032 "
A[1]	.27	.003	.006 low
B	.72	.009	.018 high
B	.76	.009	.018 "
C	.60	.007	.014 low
Mean......			.016

TABLE VII.

2d Distance (97.9 Cm.), I=.50.			
Observer.	Average Deviation.	Percentage Deviation.	Percentage Error of Intensity.
A	1.70	.017	.034 low
A[2]	.74	.007	.014 high
B	.95	.009	.018 "
C	.87	.009	.018 "
Mean...........			.021

TABLE VIII.

3d Distance (112.8 Cm.), I=.375.			
Observer.	Average Deviation.	Percentage Deviation.	Percentage Error of Intensity.
A	.50	.004	.008 low
A	.25	.002	.004 "
A[3]	.14	.001	.002 high
B	.10	.001	.002 low
B	.36	.003	.006 high
C	.24	.002	.004 "
Mean...........			.005

[1] Lummer-Brodhun screen.
[2] Lummer-Brodhun screen.
[3] Lummer-Brodhun screen.

The Lummer-Brodhun sight box was used in one set at each intensity in order to relate the series of measurements to a well known and standard screen.

Photometrically, the third distance used (112.8 cm. from the screen) is distinctly the best since the deviation in intensity measured falls below $\frac{1}{2}$ per cent. With the Lummer-Brodhun screen this could be reduced to $\frac{1}{5}$ per cent. and might prove useful for rapid work within the limits found. The hand-made Conroy comparison screen (60° prism) was used in most of the observations because the experiments were primarily made to correspond with a screen used in the experiments in the photometry of phosphorescence where the Lummer-Brodhun type could not be used.

Table IX. gives some information about the effect (X_2) of the diminishing intensity of the receding and advancing light upon the observer's judgment, which effect has been ascribed to what is called retinal fatigue. It shows that the intensity change is different on the two slides of the theoretically correct photometric setting, necessitating a correction if the photometer is to be used to give correct candle power.

Table IX.

Rates of Intensity Change (v = 13 Cm. Per Second).

Intensity Change. Intensities *a, b, c.*	Rate of Intensity Change.	Difference.
a. 1.42 I to .75 I Rec.	.39 I per sec	
.46 I to .75 I Adv.	.17 I per sec	.22 I
b. .83 I to .50 I Rec.	.19 I per sec	
.33 I to .50 I Adv.	.10 I per sec	.09 I
c. .58 I to .375 I Rec.	.12 I per sec	
.27 I to .375 I Adv.	.06 I per sec	.06 I

In Table IX. the intensity of the moving light is diminished from 1.42 I to .46 I in 3.4 sec. In b this decrease is from .83 I to .33 I, or a change from .83 to .50 I of .33 I in 1.7 seconds. In C the fall is from .58 I to .27 I or a change from .58 to .375 of .205 in 1.7 seconds.

But in the last case the rise from .271 to 37.5 I is .105 I, with the light advancing. The rate of change of intensity is thus the lowest of the three cases and it is more nearly balanced by the rate of change in the opposite direction. It was also at this intensity at which the precision of the observation was found to be best.

Probably these are the conditions to be met if the instrument is to be used as a photometer.

The apparatus is to be rebuilt with various improvements and one of these is an adjustment which may be varied to secure these best conditions for any intensity to be measured and at any distance from the screen.

The error due to reaction time of the electro-magnetic recording mechanism (X_4) is very small and has so far been included with the personal reaction time. The error of judgment of screen equality (X_1) has not been separated from the effect of the diminishing intensity of the receding light. Perhaps it is not even separable.

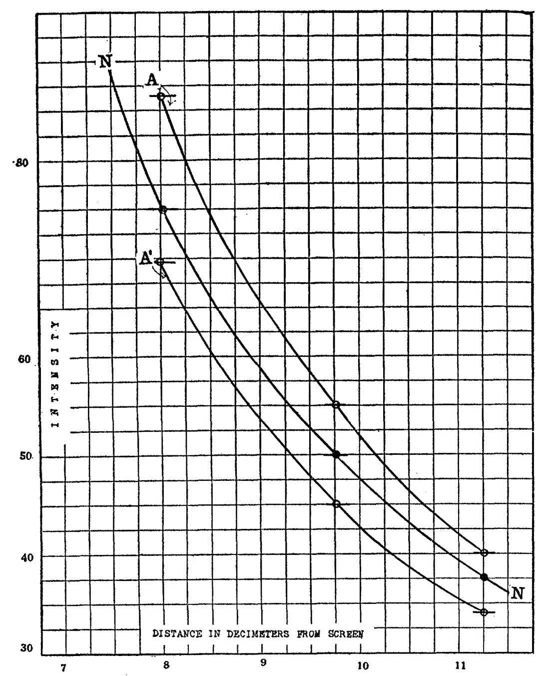

Fig. 5.

Deviations from True Intensity Curve for Both Advancing and Receding Light. *A*, three intensities receding light, *A'*, three intensities advancing light. Same observer. In obtaining these values the Lummer-Brodhun screen was used; *N*, the true intensity curve.

While these observations are only preliminary, the results nevertheless indicate that we may have there a method of photometry in which the settings are free from the trial and error method now employed. Furthermore in the latter case the movement of the screen, or of one of the lamps in the usual way when making a setting, must necessarily cause retinal fatigue effects that are confusing and which affect the photometric judgment to a certain extent at every setting, unless the movement is extremely slow.

In the moving lamp photometer the change in the retina is utilized to obtain the equality of illumination. With the method now in vogue in lamp testing laboratories, namely, that of substitution in which the lamp under test replaces the standard, and with the electric recording devices which are used, it is doubtful if the moving lamp will prove of advantage except for special purposes. On the other hand, using the substitution method with the moving lamp photometer might give the best results since the correction referred to in a previous paragraph, namely, that owing to the difference in retinal fatigue for receding and advancing light would not need to be applied.

5. Retinal Fatigue in Different Persons.

The moving light photometer affords a means of measuring the so-called fatigue of the retina of the eye by a new method.

Retinal fatigue is a difficult quantity to measure and has been chiefly studied by means of light from revolving discs. In the present method retinal fatigue is measured by a photometric comparison. The reaction time of the sensation wave from the retina to the brain appears to be included in the personal and instrumental reaction times $(X_3 + X_4)$ and hence the quantity X_2 on which the measurement of retinal fatigue with the moving light depends, is chiefly the retina effect alone. With the small range of luminosities of the experiments described in this paper the effect of the change in intensity on the size of the pupil of the eye is probably but a small part of the value of X_2; there is, however, the possibility that the pupil change is greater than is suspected.

Table X.

	1912.	Observer.	No. of Obs.	Mean Distance.	Reaction Distance.	Corrected Distance.	Hand Setting.	Intensity.	
1	Jan. 25	*A*	25	79.7	3.7	76.0	80.8	.85 −	.86 −
2	Jan. 29	*A*	15	79.5	3.7	75.8	80.8	.85	
3	Feb. 24	*A*	50	78.1	3.7	74.4	80.8	.88 +	
4	Mar. 9	*A*	15	78.6	3.7	44.9	80.8	.87	
5	Mar. 9	*A*	25	79.5	3.8	75.7	80.8	.85	
6	Mar. 15	*A*	45	80.4	3.8	76.6	82.0	.86 −	
7	May 14	*A*	20	80.5	4.0	76.5	82.2	.86 +	
	1913								
8	Jan. 7	*A*	70	79.9	4.6	75.3	80.0	.85 −	
	1912								
9	May 7	*B*	25	82.1	3.7	78.4	80.7	.79 +	.80 +
10	May 14	*B*	20	81.7	3.6	78.1	81.6	.82 −	
11	May 28	*C*	20	84.1	4.1	80.0	80.9	.77 −	.77 +
12	May 28	*C*	10	83.5	4.1	79.4	80.9	.78 −	

The quantity X_2 may be measured under the following conditions; brightness of the light source, the rate at which this source is diminishing in intensity, and color. Thus far, only greenish white and yellowish white light have been used. Values of X_2 have been obtained for three persons for receding light, as set forth in Tables X., XI., XII., and XIII., and show at once that X_2 is widely different for different individuals. The effect must depend on the time of recovery after some organic change in the retinal cells when they are subjected to light and may be due in part to the rate of the replacement of the visual purple, as has been suggested.

TABLE XI.

	1912.	Observer.	No. of Obs.	Mean Distance.	Reaction Distance.	Corrected Distance.	Hand Setting.	Intensity.	
1	Jan. 25	*A*	100	98.5	3.5	95.0	97.8	.53	
2	Feb. 23	*A*	20	99.6	3.8	95.8	99.9	.54	
3	Mar. 16	*A*	25	95.4	3.8	91.6	96.2	.55	.55−
	1913								
4	Jan. 10	*A*	40	96.6	4.6	92.0	97.9	.57−	
	1912								
5	May 7	*B*	20	98.0	3.7	94.3	97.5	.53+	.53+
6	May 28	*C*	30	100.0	4.1	95.9	97.5	.52−	.52+
7	May 28	*C*	10	99.7	4.1	95.6	98.4	.53−	

TABLE XII.

	1912.	Observer.	No. of Obs.	Mean Distance.	Reaction Distance.	Corrected Distance.	Hand Setting.	Intensity.	
1	Jan. 31	*A*	55	110.4	3.5	106.9	111.6	.41	
2	Feb. 23	*A*	60	111.6	3.8	107.8	112.8	.41	
3	Mar. 16	*A*	30	110.3	3.8	106.5	110.8	.40+	.40+
4	May 14	*A*	20	114.3	4.1	110.2	113.6	.40−	
	1913								
5	Jan. 17	*A*	50	112.3	4.5	107.8	113.2	.41	
	1912								
6	May 7	*B*	25	111.9	3.7	108.2	111.3	.39	
7	May 7	*B*	25	113.0	3.7	109.3	111.3	.39−	.39
8	May 14	*B*	25	113.9	3.7	110.2	113.2	.39+	
9	May 28	*C*	30	114.5	4.1	110.4	111.5	.38	.38+
10	May 28	*C*	15	112.9	4.1	108.8	111.2	.39	

In Table X. the intensity of the moving light is that which has been called .75 I. The apparent intensities, due to retinal fatigue, X_2, are for three individuals, A, B and C, .86−, .80+ and .77 respectively.

In Table XI. the results for intensity .50 I are given. These are for

A, *B* and *C*, .55, .53 and .52 respectively, in Table XII. the results for intensity .375 *I* are .40+, .39 and .38. These results are strikingly represented in Fig. 6 by three curves showing the apparent intensities as modified by retinal fatigue, and the curve showing the true intensities.

In a series of measurements extending from January 1912 to January, 1913, observer *A*'s results recur to the intensity values 86, 55 and 40 instead of true values of 75, 50 and 37.5. The prejudgment of the light value thus varies in a consistent manner at different intensities in the case of the persons tested. The effect might be explained by saying that with the receding lamp the retina is fatigued by the brightness of the light while at the near point. When the lamp is advancing there is a similar prejudgment also; for example, with the light approaching the screen, observer *A* obtained 70, 45 and 35 instead of 75, 50 and 37.5. The full significance of this effect ascribed to retinal fatigue is not understood at present; but the instrument has obvious possibilities for the study of some optical and psychological questions.

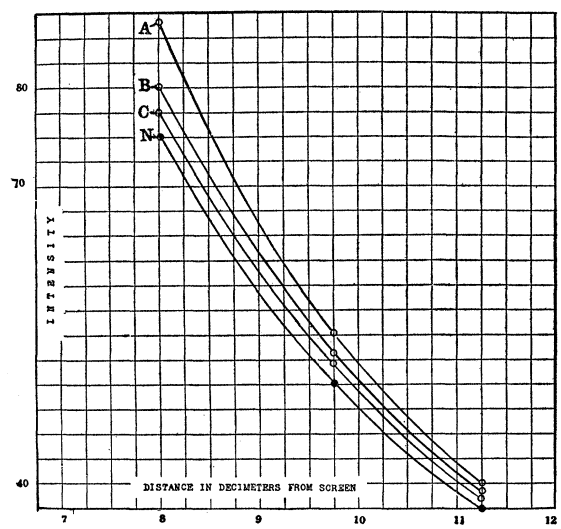

Fig. 6.

Deviations Shown by Three Observers *A*, *B* and *C*, from True Intensity Curve Due to Retinal Fatigue when Using a Light Receding with Uniform motion. *N*, true intensity curve (hand settings); *A*, *B*, and *C*, observed intensity curves (moving light).

In Table XIII. is given the percentage deviation from true intensity due to retinal fatigue for the three observers *A*, *B* and *C*. The actual rates of diminution of intensity of the stimuli producing a uniform field of light on the retina of the eye are also given. The intensity *I* taken as an arbitrary standard is equivalent to about 3.0 lux (meter candles).

The figures given are purely relative, however. If a study of retinal fatigue is undertaken by this method it would seem a simple matter to standardize the measurements; using the Lummer-Brodhun screen as the standard of comparison for all observations and expressing the rate of diminution in decrease in lux per second.

Another method would be to adopt some prism screen standard, diaphragmed to a definite size, and specify the decrease in intensity of the light in factions of a lumen per second. The field in this case might well be a meter's distance from the eye viewed through a collimator.

TABLE XIII.

Observer.	True Intensity.	Mean Rate of Change of Total Intensity.	Observed Intensity.	Difference of Observed from True Intensity.	Per Cent. Deviation from True Intensity.
A	.75 *I*	.63 *I* per sec.	.86 *I*	.11 *I*	14.6
B	.75	.63	.80 *I*	.05 *I*	6.6
C	.75	.63	.77 *I*	.02 *I*	2.6
A	.50 *I*	.39 *I* per sec.	.55 *I*	.05 *I*	10.0
B	.50	.39	.54 *I*	.04 *I*	8.0
C	.50	.39	.52 *I*	.02 *I*	4.0
A	.375 *I*	.28 *I* per sec.	.41 *I*	.035 *I*	9.3
B	.375	.28	.39 *I*	.015 *I*	4.0
C	.375	.28	.38 *I*	.005 *I*	1.3

SUMMARY.

In conclusion the paper may be summarized thus:

1. A simple mechanism for producing a uniform motion of a lamp in the photometric axis with the method of recording observations, while the lamp is in motion, is described.

2. Analysis of the following corrections that must be applied to the observations is made:

(*a*) Personal equation of the photometric judgment, X_1.

(*b*) Retinal fatigue, X_2.

(*c*) Reaction time of the observer, X_3.

(*d*) Reaction time of the recording device, X_4.

3. By means of the receding lamp moving at uniform velocity, it has been possible to investigate quantitatively the errors in photometric measurements of phosphorescent decays. These errors may run as high as fifteen per cent. or more for rapid decay, and are apparently chiefly due to fatigue of the retina of the eye.

It should be added that the corrections applied to the decay curves of

phosphorescent gases and phosphorescent solids to allow for retinal fatigue would not alter the general laws of decay which have been formulated by those who have made the subject a study, but the corrections would shift the curves to some extent.

4. The moving lamp photometer has been studied with a view to its use in general photometry and it has been shown that at least in special investigations it would be advantageous since it has the following desirable features:

(*a*) It is more rapid than hand adjustments.

(*b*) There is no possibility of muscular coördination control as in hand movements, the settings being strictly eye judgments.

(*c*) The effect called retinal fatigue is used to obtain positions of screen equality, while by hand adjustments this fatigue is usually a source of error in each setting.

(*d*) The settings appear to be more accurate than hand adjustments; yet it is doubtful if the moving lamp would prove of advantage over the methods used in lamp testing laboratories where an electric recording device is used and the substitution method of comparison of lamps is employed.

(*e*) When this moving lamp device is used for general photometry the substitution method should be employed, if a correction is to be avoided.

5. The rôle played by the fatigue at the retina of the eye in photometry is shown and figures are given for this effect in the case of three persons showing a marked difference of retinal fatigue among the three individuals tested.

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Columbia University,
June, 1914.