NOTES FROM NELA RESEARCH LABORATORY.*

NOTES ON FLICKER PHOTOMETRY: FLICKER-PHOTOMETER FREQUENCY AS A FUNCTION OF THE COLOR OF THE STANDARD, AND OF THE MEASURED, LIGHT.

By Leonard T. Troland.

THE *flicker-photometer frequency* of any two visual stimuli may be defined as the rate of alternation (cycles per second, with equal intervals) of the two in the same photometric field, which is just sufficiently rapid to eliminate flicker, when the ratio of their intensities is such as to give a minimum of flicker at a slightly lower rate.

The measurements recorded below were made with an instrument of the Whitman disk type, operated by an adjustable speed synchronous motor. The field was an annulus, of 0.23 degrees internal and 1.14 degrees external diameter, so that stimulation was strictly foveal. This was viewed in dark surroundings, and each setting was made after approximately 30 seconds' fixation of the central dark area, thus insuring fairly stable local adaptation. The artificial pupil employed was a square, 2.51 mm. on a side. Care was taken to reduce scattered light in the spectrometer system to a minimum.

Two series of measurements were taken with sixteen spectral colors, and a "physiological white" standard, of constant intensity for each series. This standard consisted of tungsten light corrected with a blue glass, so as to exhibit no chromatic tinge either when viewed directly or in the after-image reaction produced by dimming the light upon a retinal area already strongly "fatigued" by it (Hering's test for a physiological white). All of the spectral colors were equated in brightness to the standard, by the criterion of flicker, as a part of each measurement. The results for the two intensities of 1025 and 547 photons,¹ respectively, are given in the first two columns of the table below.

* Communicated by the Director.

¹ One *photon* is an illumination of the retina corresponding with a stimulus-surface brightness of one candle per square metre, and an effective pupillary area of one square millimetre.

Color	Wave-length in $\mu\mu$	Flicker-photometer frequency cycles per second							
		White standard				Plain tungsten standard, 510 photons A.D.		Over-corrected tungsten standard, 510 photons A.D.	
		1025 photons A.D.		547 photons A.D.					
Red.....	648.2-720.0	27.76	.18	24.69	.26		...		...
Red.....	693.9-720.0		...		...	23.57	.05	24.63	.14
Red.....	676.4-700.0	28.15	.08	24.79	.17	23.82	.14	24.04	.20
Red.....	658.6-680.0	27.93	.14	24.34	.09	23.88	.11	23.83	.26
Red-orange.....	640.7-660.0	27.54	.09	23.86	.05	23.22	.10	23.60	.20
Orange.....	629.4-640.0	26.70	.10	23.62	.08	22.57	.10	23.19	.23
Orange.....	610.4-620.0	24.02	.17	22.50	.26	20.68	.24	21.57	.26
Yellow.....	591.5-600.0	20.26	.40	19.54	.09	16.14	.09	18.15	.14
Yellow.....	572.3-580.0	17.10	.35	15.94	.15	17.34	.006	17.02	.23
Yellow-green.....	553.1-560.0	17.82	.14	17.83	.10	18.33	.24	16.51	.32
Yellow-green.....	533.8-540.0	19.07	.26	18.30	.05	18.03	.08	17.66	.18
Green.....	514.5-520.0	21.79	.18	18.86	.15	19.90	.20	18.67	.10
Blue-green.....	492.1-500.0	22.49	.29	21.98	.15	21.94	.10	21.93	.21
Blue.....	473.1-480.0	25.26	.14	22.46	.26	23.18	.17	23.00	.06
Blue.....	444.0-460.0	26.13	.07	23.12	.12	24.22	.11	23.88	.13
Violet.....	426.7-440.0	25.76	.15	22.99	.07	23.61	.04	23.53	.10
Violet.....	408.1-420.0	24.13	.19	21.73	.44	22.61	.21	22.02	.11

As will be seen from the table, the flicker-photometer frequency for a white standard varies radically with the spectral character of the measured light, being greater at the ends of the spectrum than in the middle, with a minimum at about $575\mu\mu$. Similar results appear in the rougher data of Ives, who used uncorrected "carbon" light. In order to test the hypothesis that the position of the minimum was determined by a subliminal chromatic factor in the standard, very careful comparative measurements were made with two standards of equal brightness—510 photons—but of different color, one being plain tungsten light at low efficiency (having a definite orange tinge) and the other being an over-corrected tungsten light (decidedly bluish, and of about the same saturation as the plain tungsten). The results are shown in the third and fourth columns of the table. They prove that the flicker-photometer frequency is determined primarily by the character of the spectral stimuli, in relation to white, although a marked color tone in the standard will shift the position of the minimum.

Each value in the first two columns represents 4 independent determinations, except in a few cases, where 8 were taken. The values in the third column are averages of at least 10 determinations, and those in the fourth column of at least 15 determinations, in each case. The deviation measures are those of the averages.

No influence of the color of the standard upon the intensity required for a match was apparent within the limits of reliability of the measurements. The photometric sensibility, however, was found to depend on the color of the standard, and also on that of the measured light. The sensibility was exceedingly low in the red, as shown by the following table:

Color	Wave-length	Average percentage deviation in photometric brightness for a match	
		Plain tungsten standard	Bluish standard
Red	693.9-720.0	4.45	6.39
Orange-Red ...	640.7-660.0	4.43	6.70
Yellow	572.3-580.0	0.89	1.83
Blue-Green	492.1-500.0	1.65	2.05
Violet	408.1-420.0	0.99	2.07

All of the above results are for the writer's right eye. The investigation is being continued, and a more detailed description of the conditions will be given in a later, extended account.

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THE LAWS OF VISUAL MINUTHESES: THE INFLUENCE OF INTENSITY ON THE EQUALITY TIME-FUNCTION.

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THE time, t_q , required for a fresh negative after-image, projected on a reacting field of light, to just fall below the threshold may be called the *equality-time*, since it is the time needed for two differentially minuthetized ("fatigued") retinal areas to reach sensibly equal degrees of adaptation. The after-image must be produced by preëxposure of the eye to a primary stimulus during an interval t_p , the preëxposure-time, which immediately precedes the interval t_q . The function, $t_q = f(t_p)$, may be called the *equality-time function*, which is shown by experiment to be representable by a curve of the saturation type.

Measurements were made to determine the influence of stimulus intensity upon this function, the primary and the reacting lights being of the same color and brightness. The field was circular, with an angular diameter of 3.38 degrees, was provided with a central fixation point, and had dark surroundings. The initial minuthesis was produced by exposure either of the right or