T H E S I S

THE FLICKER PHOTOMETER

For the Degree of

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THE FLICKER PHOTOMETER.

Almost any physical quantity may be measured by instruments, either directly or in such a manner as to allow comparisons to be made without trusting to human judgement. In the measurement of light, however, we still have to trust to certain processes of the mind which are very uncertain at times, since all measurements must be taken through the eye, which is unable to determine the relative power of two sources, although it can tell when they are equal. To help the eye judge when two illuminations are equal, use is made of photometers, which are merely arrangements of the sources to be compared so that, after the eye has judged the illuminations to be equal, the relative powers may easily be found by applying fundamental laws to the readings of the instrument.

Where the lights from the two sources are of the same quality or spectral composition the relative powers may be determined very accurately, but when the lights to be compared are of different colors, as for instance an ordinary carbon lamp (yellow) and a tungsten lamp (white), the eye is unable to get consistent results, and the greater the color difference the less accurate are the results obtained.

Many different theories have been advanced as to the reason for the inability of the eye to assign proper relative values to lights of different color composition - all agreeing that the cause is physiological rather than physical. Not only do we have the various effects which are explained by the theory of Von Kries as to the rod and cone structure of the retina, of which more will be said later, but also the Purkinje effect, an apparent shift in the color composition with changes of intensity - the luminosity curve shifting from red towards the violet as the illumination is decreased. Recently Dr. Louis Bell found that when two lights of different colors were compared there was an apparent change in the color composition. The experiments reported showed that the two contrasting colors when viewed simultaneously appeared to be spectrally separated greater than was actually the case. For example in comparing a red and a green, the former appears redder and the latter greener than they should. Such an apparent change in color composition would naturally be accompanied by an apparent change in intensity which would affect detrimentally any readings taken on an equality - of - brightness photometer but would have no effect on the flicker photometer, since the contrast necessary for this effect is absent.

With small color differences, good results may be obtained with either type of photometer although the Lummer-Brodhun head is generally used. For a zero color difference the flicker photometer degenerates into the equality - of -brightness type. A series of experiments by Mr. Ives showing that it was most sensitive when used in this manner. With a noticeable color difference the results obtained on an equality type may vary 20% in successive readings and results obtained one day will not agree with those obtained on another day. This makes it necessary in accurate work to take the mean of many readings. When the flicker type is used the results of successive readings will usually agree within 1 - 2% and are always the same. I made quite a number of experiments which seem to indicate that the error was not increased with an increase of color difference.

Another argument in favor of the flicker type could be found in the comparative readings of different observers. Persons whose results vary widely on the equality type will get very closely the same thing when the flicker type is used. It was even claimed by some that the flicker type gave the same results with a person who was color blind as with one of normal vision. The results of a great number of experiments by different people seem to indicate that this is not true.

The question naturally arises as to whether the flicker photometer will give the same results as the equality type when the same sources are compared by each. Whether the results agree or not and if not, the extent of their disagreement will depend upon several factors:

(1) The degree of color difference. With slight color differences the agreement is very satisfactory, but with larger color differences the readings are consistently separated.

(2) The conditions of the comparison. It is evident that such details as the sensitiveness of the instruments, care taken by the observer, etc. must affect the agreement. The intensity of illumination is important bringing in the Purkinje effect at low values when the equality type is used and a reversed Purkinje effect with the flicker type.

(3) The portion of the Retina used, size of field, etc. according to the theory of Von Kries, by which we are able to solve many of the problems of color-physiology,- though the theory is not

given the credence by physiologists now that was accorded it when first propounded - the percepient structure of the retina involves two kinds of sensitive elements - the rods and cones. The rods are found in the greatest numbers in the peripheral region where there are few cones. In the central portion of clearest vision the cones alone are present and in the intermediate zone both rods and cones are found. The rods can perceive light of insufficient intensity to stimulate the cones, but they appear to be a primative type of sense organ as there is only one sensation whatever the color of the light falling on them. The cones on the other hand enable one to see in a light bright enough to keep the rods in a state of exhaustion. They are also able to differentiate the the various colors. According to the Young-Helmholtz theory, there are three kinds of the cones specially sensitive to red, green, and violet respectively since all other colors are capable of being represented in terms of these three. If the theory of Von Kries is true, comparisons are not true if the photometers do not use the same portions of the retina. In this connection Mr. Ives found that the results were affected by the size of the field and suggests that a field of standard size be chosen.

There have been quite a number of people who claimed that the flicker photometer did not measure the illumination as did the equality type. Mr. Ives in a series of articles in the Philosopical Magazine during 1912 shows conclusively that the flicker photometer, while not measuring the true illumination, measures it so closely that it may be called the same. His experiments were so thorough and so carefully performed that there can hardly be any doubt of the accuracy of his conclusions.

In order to obtain good results with the flicker photometer there are several factors which must be carefully watched, for instance:

1. The dividing line between the two fields should be a line of zero width - such as is obtained in the Lummer prism. If there is a visible line between the fields a certain frequency will be required to remove it alone regardless of color difference and illumination, which tends to make the instrument less sensitive.
2. The method of altering the speed of the flicker should be simple and should cover a wide range.
3. The correct speed must be used - just enough to eliminate the color flicker. The greater the color difference the higher the speed required to fuse the colors. With no color difference the best speed is zero.
4. Movements of the body, eye, or any surrounding objects should be avoided while making the readings. The arrangement should be such that a setting can be made with a minimum of effort.
5. The flicker photometer must not be used with A. C. arcs, Moore tubes or any light source with an inherent flicker.

The Construction and Tests of a Flicker Photometer.

An old Lummer-Brodhun head was converted into a flicker head by inserting into the sight tube a bushing which contained a small prism revolved by a small shunt motor. The speed of the motor was varied by changing the impressed voltage. When the Lummer Prism is viewed thru the sight tube with the small prism revolving the effect is the same as if first one and then the other side of the Lummer Prism is seen alone, the light from the source to the eye being literally whirled around the dividing line of the fields, producing a flicker unless the two illuminations are equal. This is shown in drawings elsewhere.

Five series of tests were made to determine the sensitiveness and accuracy of the above photometer. The first test was made with an ordinary Lummer-Brudhun head and using tinted lights. The test consisted in measuring the illumination of a red and a blue tinted light, separately and then together, the check being that the sum of the illuminations was equal to the illumination of the sum. The results were satisfactory when the mean of a large number of readings was taken, agreeing within about one or two per cent and with single readings off from two to five per cent (see table No. 1.)

The second series was a repetition of the first in method, but using the flicker head instead of the equality head. After the instrument had been adjusted, results were obtained which were very similar to those of the first series (see table No. 2 and compare with No. 1.) From the results of this test I would say that there was little choice between the two types.

In the third series the real value of the flicker photometer became apparent. In these tests deep colors of red, green and blue were first compared with another lamp to get their relative power and then compared directly with each other as a check. The results, which were very satisfactory, showed that the color difference had little effect on the readings - the settings with red and green or with green and blue could be made just as quickly and accurately with the flicker type as ordinary settings on the equality type. This was the most valuable of all of the tests in point of results, showing as it did, very clearly, the accuracy of the flicker photometer on colors. (see table No. 3).

With the intention of making the fourth series of tests supplementary to the third, an attempt was made to use the equality photometer on colored lights. The results obtained were not at all satisfactory for settings made at one time could not, as a rule, be duplicated and moreover did not check at any time. However, it is said that, with experience, good work may be done in this line. It would be interesting to compare the results obtained by an experienced operator on each type. Due no doubt to my lack of experience, the data taken in this series is not representative of anything and will not be included in the tables.

In the fifth and last series of tests readings were taken to determine how closely the readings made on the two types checked with each other. Unfortunately this test could not be carried far enough to find out anything definite, although enough readings were taken to see that the agreement was some function of the color difference, being good with small color difference and poor with large color difference. This last series took me back into the fourth and brought up some new problems concerning my conception of equality of colors which might have been answered had not a fault been discovered in the flicker head. Only two sets of readings are included in the tables - that is enough to show how the readings ran. (see table 4.)

From the foregoing study I would conclude that the equality type is best for tints, owing to the size of the field, but when the color is pronounced or even noticeable, the flicker type is best. While working on the fourth and fifth series of tests I was able to see clearly what prompted Helmholtz to say that the best he could do in comparing two colors was to make one so bright that there was no doubt that it was the brighter of the two. However, I think the flicker photometer has solved this problem and makes the comparison of colored lights as simple as the comparison of white lights, and in using it, if care is taken to secure the factors of safety, the readings will be satisfactory under almost all conditions of color and illumination.

Results of Tests.

Table No. 1.

Lummer-Brodhun head -red and blue tints

set	Dist. of stand. from Head - cms. red a	blue b	combined c	$\frac{1}{a^2}+\frac{1}{b^2}$	$\frac{1}{c^2}$	Variation %	Greatest Variation
1	40.70	41.2	29.2	1191	1175	1.4	5
2	48.1	48.9	34.5	850	840	1.2	4.5
3	41.2	40.5	29.05	1185	1199	1.2	2
4	42.5	41.30	29.05	1140	1190	4.3	3

Colored light and head stationary - 50 cms. apart.

Table No. 2.

Flicker head - red and blue tints(same as above)

	a	b	c				
1	38.7	41.7	28.0	1242	1275	2.4	2
2	33.8	48.3	27.8	1302	1290	0.9	0.6
3	48.9	51.0	35.3	800	805	0.6	2
4	38.5	41.1	28.0	1263	1275	1.0	1.5

In tables No. 1 and 2, each set is the mean of ten readings

Table No. 3

Flicker head - colors

Distances given are of head from standard

Set	Direct R	G	$\frac{R}{G}$	Indirect R	G	$\frac{R}{G}$	Variation %
1	50.0	64.6	1.66	38.1	49.2	1.67	0.6
2	39.2	50.6	1.67	50.0	65.4	1.71	2.5
3	50.0	66.7	1.77	39.2	52.0	1.76	0.6
4	50.0	66.7	1.77	38.3	50.2	1.73	2.3
5	50.0	66.4	1.76	39.8	53.0	1.78	1.2
6	50.0	66.0	1.76	39.0	51.5	1.75	0.6

The blue colored glass was found to be spotted in such a manner as to cause results gotten with it count for nothing, these results will not be given.

Table No. 4.

A comparison of readings taken on same lights - a tungsten and a carbon filament using each head.

Flicker head $\frac{T}{C} = \left(\frac{50}{32.5}\right)^2 = 2.37$

Equality head $\frac{T}{C} = \left(\frac{50.0}{33.2}\right)^2 = 2.27$

Variation 4.3 %

Using the dark colors:

	Red and white	Blue and white
Flicker head	$\frac{R}{W} = \left(\frac{50.0}{71.9}\right)^2 = 0.485$	$\frac{B}{W} = \left(\frac{50}{71.2}\right)^2 = 0.494$
Equality head	$\frac{R}{W} = \left(\frac{50.0}{81.8}\right)^2 = 0.374$	$\frac{B}{W} = \left(\frac{50}{80.1}\right)^2 = 0.379$

Articles on the Flicker Photometer

Mr. Herbert E. Ives

"Studies in the Photometry of lights of different colors."

Philosophical Magazine 1912.

"A New Design of Flicker Photometer."

Physical Review sept. 1914.

Dr. Louis Bell

"Some Factors in Heterochromatic Photometry"

Electrical World, Jan. 27, 1912.

D. E. Rice

"Heterochromatic Photometry"

Electrical World Feb. 24, 1910.

M. Luckiesh

"Comparison of Flicker and Equality-of-Brightness Photometers"

Electrical World, March 22, 1913.

J. S. Dow

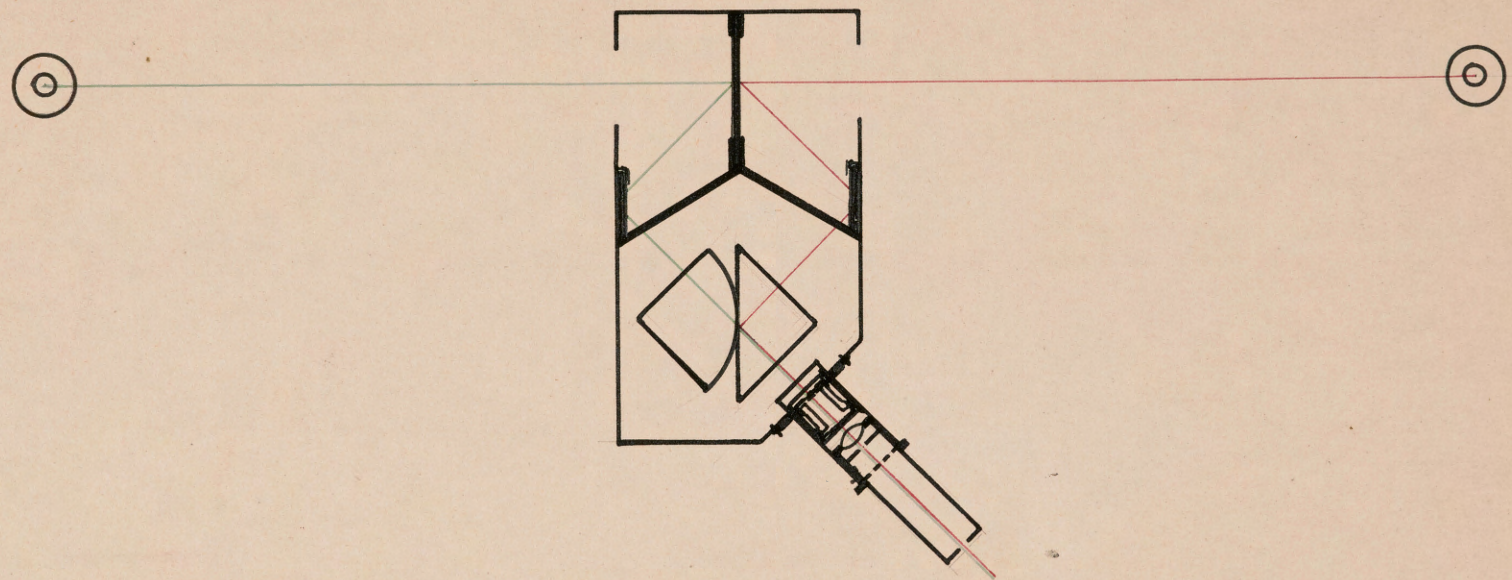
"The Problem of Color Photometry"

Electrical World, Nov. 30, 1907.

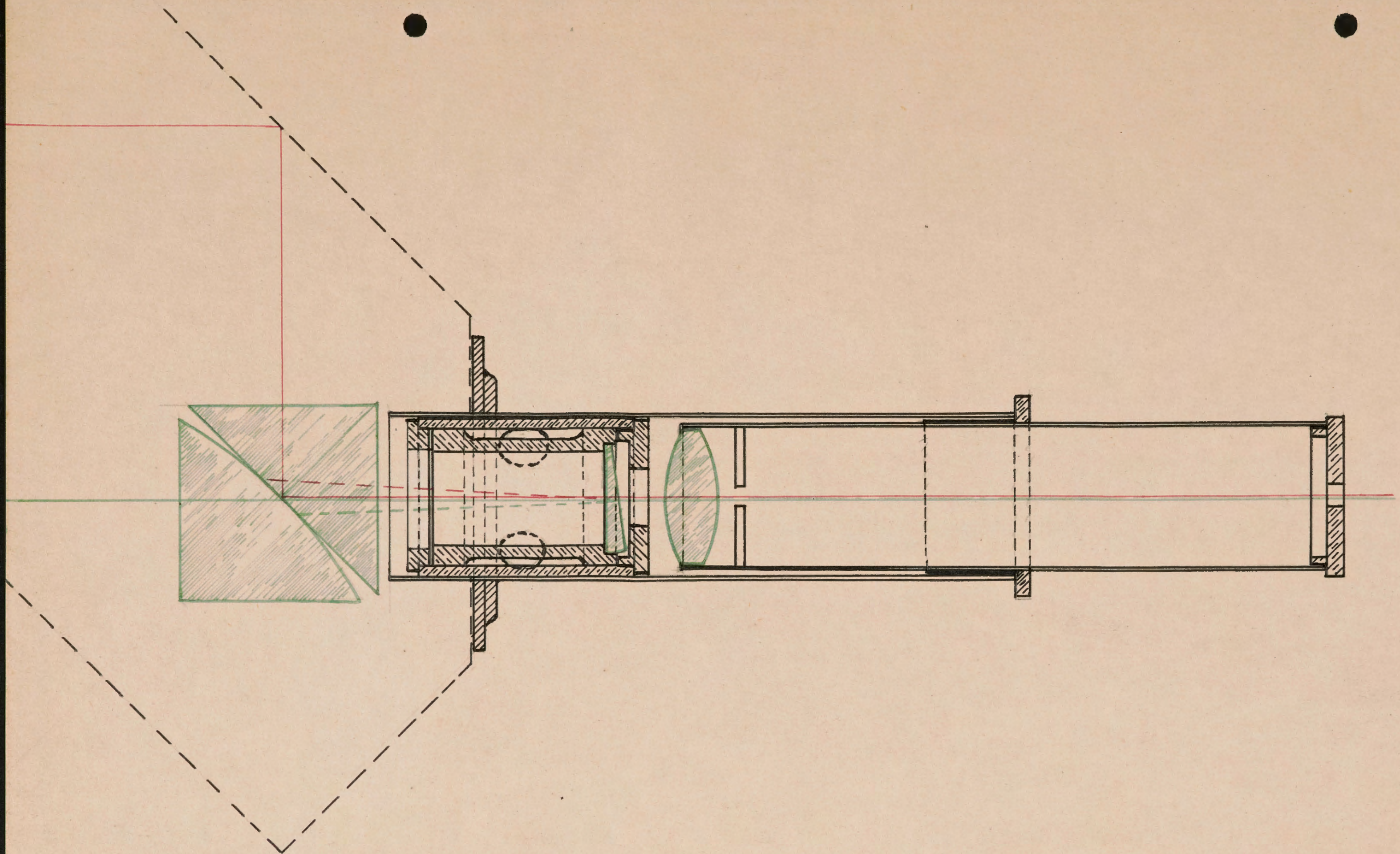
Sydney W. Ashe

"The Flicker Photometer"

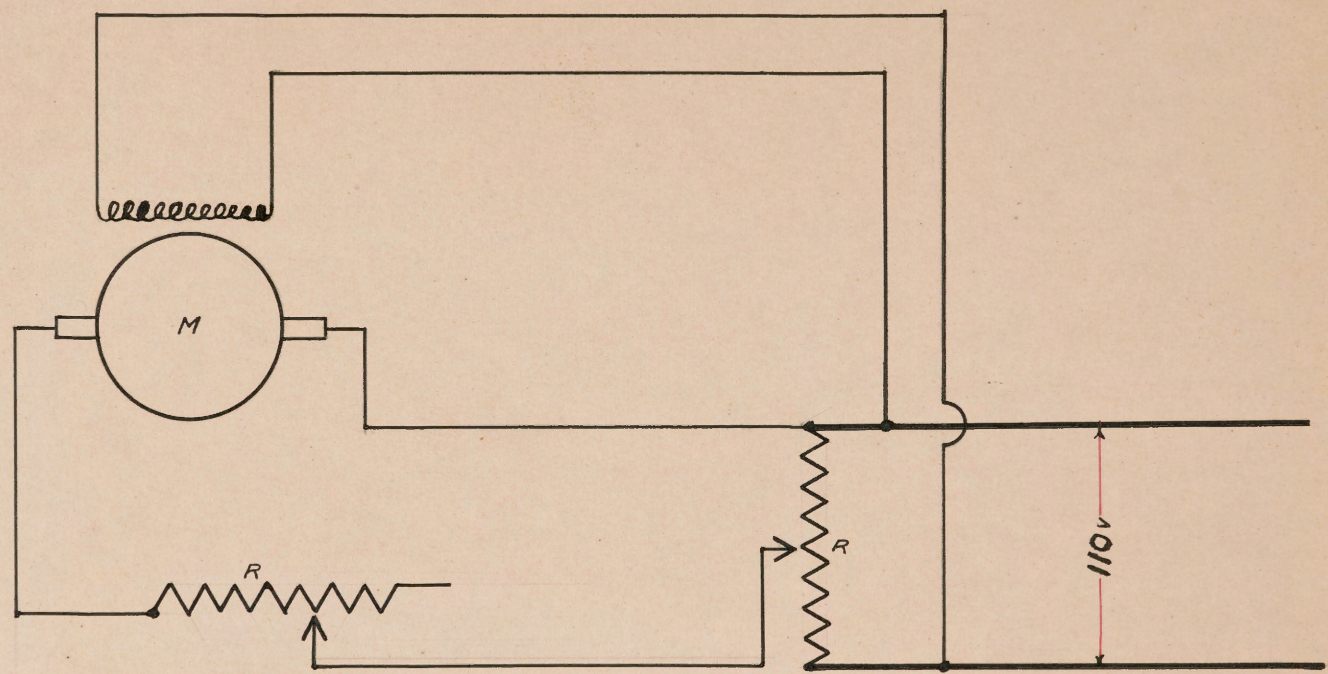
Electrical World, Nov. 25, 1909.



Showing path of light from sources to the eye.



Showing details of the flicker arrangement with prisms and lens in place.



Motor connections for variable speed.