SOME SPECTRAL LUMINOSITY CURVES OBTAINED BY FLICKER AND EQUALITY OF BRIGHTNESS PHOTOMETERS.[1]

BY HERBERT E. IVES.

It is probably not necessary to discuss at any length before the Illuminating Engineering Society the difficulties of heterochromatic photometry nor the importance of a solution of the problem. Considerable work has been done in the past by numerous observers, among whom may be mentioned Dow, Abney, Tufts, Wild, Stuhr and Millar. Mr. Millar in an excellent paper before the Society's convention last year summarized the difficulties besetting this problem. It will, therefore, be assumed here that the importance of more knowledge of photometric methods applicable to our many-hued illuminants is appreciated and the difficulties in some measure understood.

In the present paper are given some results obtained in the progress of an extended investigation upon methods of heterochromatic photometry. The investigation is as yet far from completed and the results here presented form only a part of the work already done, and a smaller part of that yet to do. They form, however, a fairly complete investigation as they stand, and as they illustrate satisfactorily some of the chief phenomena appearing from the investigation in progress they are thought to be of sufficient interest to be presented now.

From the standpoint of accurate photometry, the most important problem at present is a comparison of the methods of equality-of-brightness and flicker photometry. Of the several methods of photometry of differently colored lights, these alone possess the quality of sensibility to a sufficient degree to warrant their use for measurement. Experiment has shown the criteria of these two methods to be different under certain conditions. The first problem undertaken in this investigation has been a study of the effect, on each method, of varying those conditions which affect brightness comparisons where color difference exists. The principal conditions in questions are: ab-

[1] A paper presented at the Fourth Annual Convention of the Illuminating Engineering Society, Baltimore, October 24 and 25, 1910.

solute illumination, size of photometric field, and differences in color vision in different observers.

The apparatus employed was designed with four objects especially in view. First, the scale of color should be of a standard character. Second, the flicker and equality-of-brightness measurements should be obtainable in the same apparatus without disturbing any of the critical conditions. Third, it should be possible to vary the illumination widely. Fourth, arrangements should be made to use several sizes of photometric field.

These objects were all attained by the use of a prism spec-

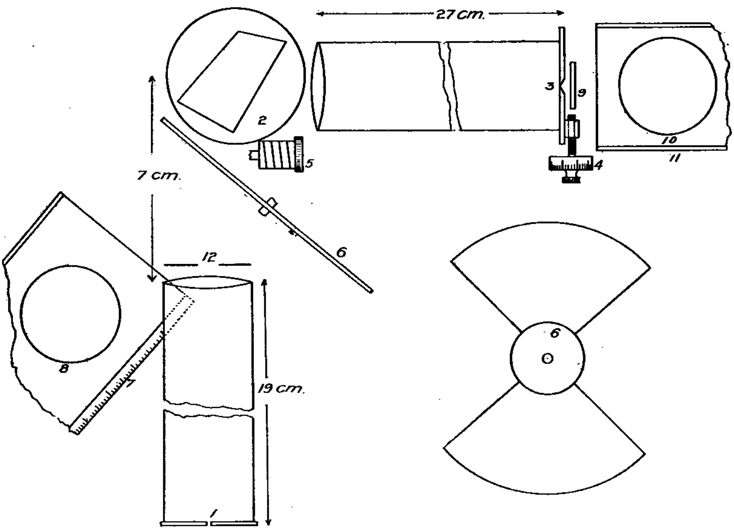


Fig. 1.—Arrangement of apparatus.

1, Observing slit; 2, prism table; 3, collimator slit; 4, divided drum; 5, wave-length drum; 6, white sector desk; 7, photometer bench; 8, standard lamp; 9, diffusing glass; 10, light source; 11, photometer bench; 12, diaphragm.

trometer in conjunction with a white sector disc, which in rotation formed a Whitman flicker photometer. With this instrument the spectrum of a normally operated tungsten lamp is formed upon an observing slit. The eye placed here sees the whole face of the prism illuminated by a narrow portion of the spectrum. The Whitman disc is situated between the prism and the observing telescope lens and is illuminated by a standard

4-watt carbon lamp mounted upon a photometer bar. When stationary the disc may be placed so that one of its edges bisects the field of view, thus permitting equality-of-brightness comparisons between the white surface and the spectrum color. The brightness of the spectrum field is altered by changing the width of the spectrometer slit. During the measurement of a "spectral luminosity curve" corresponding to one illumination, the position of the standard lamp remains unaltered, so that all of the measurements are made at that one fixed illumination. The spectral luminosity curves are then obtained by taking the reciprocals of the slit widths, correcting the values for the dispersion of the prism.

Different sizes of photometric field are obtained by diaphragms over the lens of the observing telescope. Three sizes are being used, and these, combined with about ten different illuminations, make thirty or more combinations of conditions under which comparisons of the two methods are being made.

The results of these will be reported upon later. The present report is upon a set of comparative measurements made by five different observers at two illuminations, for one field size. The five observers were all in some degree experienced in making observations and possessed no marked abnormalities of color vision. The two given by the initials H. E. I. and M. L. have made numerous observations with the apparatus and therefore were the most experienced. F. E. C. has had long experience in photometric work; C. F. L., considerable experience in photometric and other observations; P. W. C., the least experience in ordinary photometry, but is accustomed to visual observations in various optical instruments. The illuminations used were chosen in the light of the previous work by the two more experienced observers. The lowest is one at which it is still possible to make flicker measurements without too great difficulty; the highest is one beyond which from previous experience little change in the curves is to be expected. Both higher and lower illumination measurements with larger and smaller photometric fields have been made by the two most experienced observers, and their results will to some extent be drawn upon in interpreting the results from the measurements here given.

The two illuminations used were 250 and 10 units, where a unit is an illumination of 1 meter-candle (0.0929 foot-candle) on a surface of magnesium oxide, as viewed through an artificial pupil of 1 sq. mm. (0.00155 sq. in.) area. Owing to the small size of this artificial pupil the effective illumination is much less than 10 or 250 meter-candles as ordinarily understood, probably about one-tenth as great. The field size here used is given by a circle 16 mm. (0.63 in.) in diameter at a distance of 20 cm. (0.78 in.) from the eye, therefore subtending an angle of 4½°, approximately the size of the yellow spot of the retina.

DETAILS OF THE MEASUREMENTS.

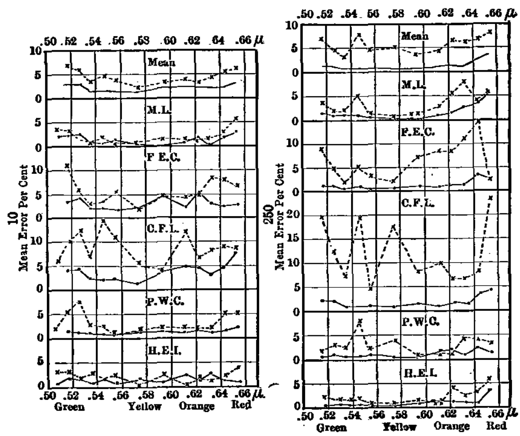
Measurements were made in the following manner: The spectrometer was adjusted to give a certain mean wave-length on the observing slit, the sector disc was placed so that half the field was "white," the other colored, and six readings made; the disc was then set into rotation, the speed adjusted by variable resistance in series with the motor, and six flicker readings made. This was done for twelve points in the spectrum, alternating on the red and blue sides. The slit openings, speeds, etc., were read by an assistant, except in the case of the two observers H. E. I. and M. L. who read their own observations.

The results of the measurements are given largely in the form of curves plotting the observations in certain combinations with each other. The chief phenomena illustrated are: (1) Relative sensibility of the equality of brightness and flicker methods. (2) Effect of changing illumination with each method. (3) Relative position of luminosity curves given by each method at both illuminations. (4) Relative positions of luminosity curves derived by all observers, with their mean values.

RELATIVE SENSIBILITY OF THE EQUALITY OF BRIGHTNESS AND FLICKER METHODS.

A measure of the relative sensibility of the two methods is obtained by taking the mean error of setting. In Fig. 2 are plotted the mean errors for each observer at 10 illumination units for various points in the spectrum, from the deep red at 0.66 μ to the bluish green at 0.51 μ The mean flicker errors are given by the full line, the mean equality-of-brightness errors by the dashed line. In Fig. 3 are given the same quantities as obtained from observations at 250 illumination units. Several facts are here brought out clearly. First, the flicker method is for all parts of the spectrum several times as sensitive as the equality-of-brightness method, the relative sensibility differing for different observers, but always favoring the flicker method. Second, the difference in sensibility between the methods is greater at high illuminations than at low. At the lower illumination the equality-of-brightness sensibility becomes greater, the flicker sensibility less. Third, the sensibility by the flicker method is less toward the ends of the spectrum, where the difference in hue between the spectrum color and the standard lamp color is greatest.

It is to be noted that while all the observers made readings



Figs. 2 and 3.—Errors of observers at illuminations of 10 and 250 units.

by the flicker method which compared very closely to the accuracy of those made by the two most experienced observers, two of the three by whom the settings were made for the first time averaged five or ten times the error by the equality-of-brightness method as by the other. This illustrates the great superiority of the flicker method as a method of measurement with observers not used to making matches between lights of widely different color.

Closely connected with the question of sensibility is the question of reproducibility at different times. Entirely satisfactory data on this point have not as yet been obtained, as it has been found extremely difficult to separate changes in the color of the light source from possible changes in the luminosity criteria. It may be said, however, that flicker sensibility curves have been obtained on several successive days showing no changes larger than the range of error in the measurements, while the equality-of-brightness curves have shown marked changes. Further, since these experiments were begun the equality-of-brightness luminosity curves obtained by the writer have experienced a shifting over from the blue side to the red side of the flicker curve, while the changes occurring in the flicker curve are probably no greater than can be explained by changes in the tungsten lamp used as a source. A change of similar nature but in the opposite direction has also occurred with the writer's assistant, Mr. Luckiesh. It may, therefore, be said with confidence that the changes which occur from time to time in the results given by the two methods are less with the flicker than with the equality of brightness method, with the evidence in favor of their being very much less.

In connection with the question of sensibility may be given the data on the speeds used with the flicker photometer. As is well known, sensibility varies with the speed, being less at high speeds. In fact, with high enough speed all flicker vanishes, no matter what the differences in illumination from the two sources under comparison. In these experiments the speed was always adjusted to the lowest value at which flicker could be made to disappear. This was then read by means of an electric tachometer and reduced to cycles per second. In Fig. 4 are given the speeds as used by the different observers from end to end of the spectrum and for the two illuminations. The data show that much lower speed is necessary for low illuminations, and that the ends of the spectrum require higher speed than the middle. These facts readily fit in with knowledge derived from other sources and with such theory as we have of the action of the flicker photometer. The eye is more sensitive to flicker at high illumination than at low, hence the greater sensitiveness of the flicker method and the higher speed necessary at high illuminations. In order to compare lights of different colors it is necessary to attain such a speed that the color flicker, due to difference in hue, disappears. It is, therefore, to be expected that the ends of the spectrum where the hue is most different from the comparison lamp, a higher speed is necessary, and with

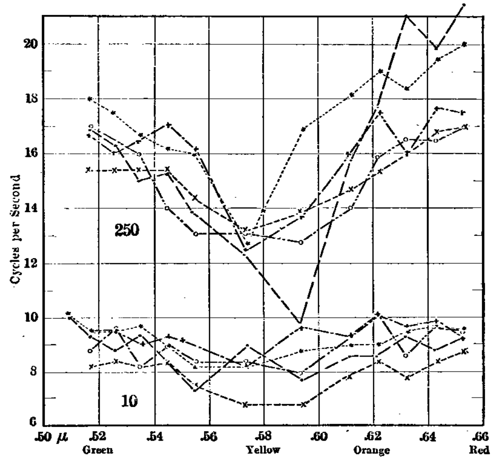


Fig. 4.—Frequency used by observers.

this higher speed goes decreased sensibility. Whether the change in sensibility is exactly what the change in speed would oc-

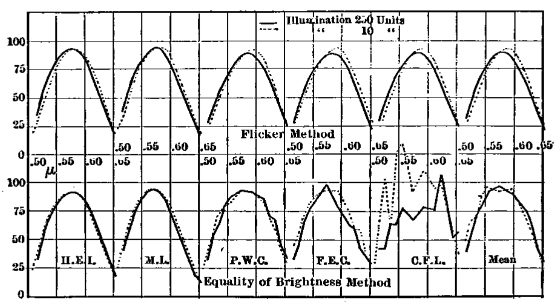


Fig. 5.—Effect of change in illumination on luminosity.

casion or whether the change in speed is conditioned by hue difference alone, are points for future study.

EFFECT OF CHANGING ILLUMINATION WITH EACH METHOD.

As to the effects of changing illumination on the luminosity curves; they may be described very briefly. They are illustrated in Fig. 5. With the equality-of-brightness method there occurs a shift of the luminosity curve toward the blue end of the spectrum when the illumination is decreased. With the flicker method the shift is in the opposite direction. The shift by the equality-of-brightness method is the well known Purkinje effect. The shift in the opposite direction with the flicker method has not before been observed. It is of interest to note in this connection that the results obtained by changing the size of the field of view are also different for the two methods. It appears from the investigation now in progress that a decrease in the size of the photometric field increases the red sensitiveness in equality-of-brightness comparisons, but decreases it with flicker comparisons.

These two effects are perhaps due to the same cause—a change in the relative number of retinal rods and cones acting—and bear out the conclusion that the flicker method is affected in opposite manner to the equality of brightness method by these changes of the physiological conditions. This carries our knowledge of the relationship between the two methods a step beyond the conclusion which has been reached by some, that the flicker method merely responds less to changes in illumination or field size.

RELATIVE POSITION OF LUMINOSITY CURVES GIVEN BY EACH METHOD AT BOTH ILLUMINATIONS.

In Fig. 6 are given the equality-of-brightness and flicker luminosity curves directly as obtained, showing their relative positions. At the high illumination three observers show the flicker curve with its maximum on the red side of the equality-of-brightness, one with the maximum nearly agreeing in position and one with the maximum on the blue side of the equality-of-brightness curve. None of the observers show exact agreement at every point of the two curves, but the mean of all observers shows the two curves to have maxima very nearly at the same point. At the low illumination all the flicker curves fall to the red side of the equality-of-brightness curve, as is to be expected in view of the oppositely directed shifts of the two with change of illumination.

The data shown on this plate exhibit strikingly the more satisfactory nature of the flicker method, as far as definiteness is concerned and ease of making comparisons of this sort. While with the more practiced observers the equality-of-brightness curves are comparable in smoothness with the flicker curves, with two of the less experienced the equality of brightness data are very unsatisfactory as curves. With one of the observers, in fact, it seemed next to impossible to form a decision as to a luminosity match between a bright spectrum color and the unsaturated color of the comparison lamp. This difficulty is reflected in the erratic character of the equality-of-brightness "curves."

An interesting point is that, in the case of some observers, the areas of the two curves (flicker and equality-of-brightness) are far from the same. If the total light is the sum of the separately measured parts it would follow that the total light is greater by one method than by the other. If, now, the spectrum used is

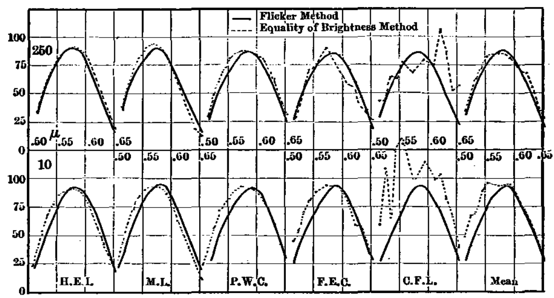
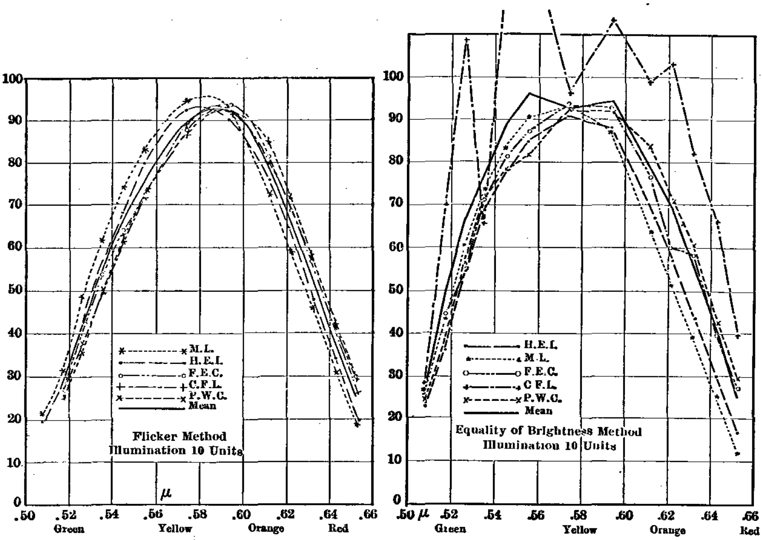


Fig. 6.—Comparison of equality of brightness and flicker methods at two illuminations.

of a lamp exactly like the standard lamp (used as comparison source) it is possible to recombine the dispersed spectrum and measure its total light against the exactly similar light of the comparison source. Under these conditions the total lights would measure the same by the flicker as by the equality-of-brightness method. This physical summation may agree with one or the other of the quantities obtained by arithmetically adding the luminosities of the component colors, but, in the case of the observers in question, cannot agree with both. This, then, offers one means of choosing between the methods, as methods of scientific measurement. Experiments on this point are now in progress.

RELATIVE POSITION OF LUMINOSITY CURVES DERIVED BY ALL OBSERVERS WITH THEIR MEAN VALUES

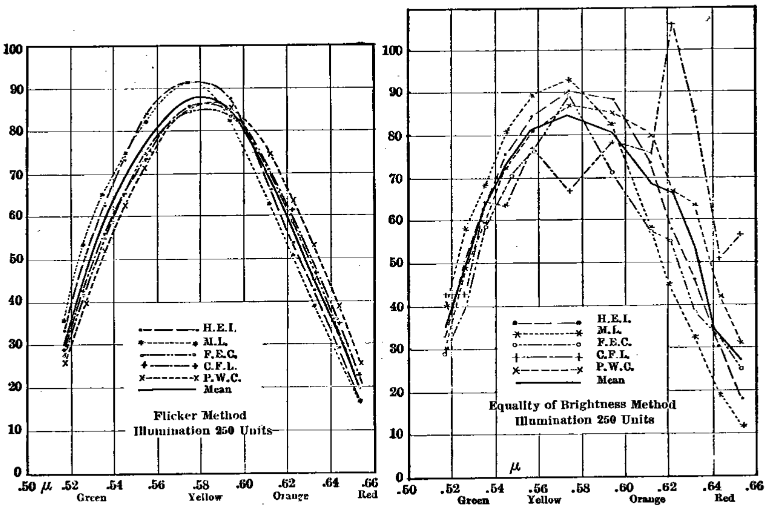
In Figs. 7, 8, 9, and 10 are shown the luminosity curves of all five observers together, for high and low illumination and both methods, with their means. These show that with observers of "normal color vision," that is, those who have no difficulty in making color matches or distinguishing colors, there exist considerable differences in the forms of the luminosity curves, both flicker and equality-of-brightness. For instance, if it were a



Figs. 7 and 8.—Luminosity curves for 10 units of illumination.

question of measuring a yellow-green at 0.55 μ against a 4-watt carbon lamp, the extreme observers would differ (by the flicker method at high illumination) by 15 per cent. Perhaps the preferable way to express the differences would be to compare the relative luminosities of the different spectral colors, thus eliminating the question of the character of the comparison lamp. This, however, would involve the assumption that the shape of these curves is independent of the color of the comparison light, and until this point is investigated, it is safer to state the results as obtained.

Inspection of the curves shows that the relative positions of the observers are substantially the same by both methods and illuminations, therefore apparently corresponding to real differences in color sensitiveness. These differences, as shown, are quite large, when pure colors are concerned. In the measurement of illuminants whose color is far less saturated than the colors of the spectrum, the differences between observers would not show so strikingly. Nevertheless is is evident that one can hardly expect any two observers taken at random to obtain ex-



Figs. 9 and 10.—Luminosity curves for 250 units of illumination.

actly the same results in heterochromatic comparisons if such differences in color sensitiveness are the rule, as there seems no reason to doubt. Hence it becomes evident that no matter which method of photometry is used dependence must be put upon the average results of numerous observers for the standard luminosity values of differently colored illuminants.

In Fig. 11 is given the spectral energy distribution of the source used. This was obtained by spectrophotometric comparison of the light as obtained through the prism, lenses, etc. of the instrument used, with that of the tungsten lamp matched against a black body at known temperature the distribution of energy of which was calculated from the Wien equation. In the same illustration is given the mean high illumination flicker curve, reduced to a normal equal energy spectrum by taking into account the distribution of energy in the source. It shows a maximum of luminosity at 0.545 μ.

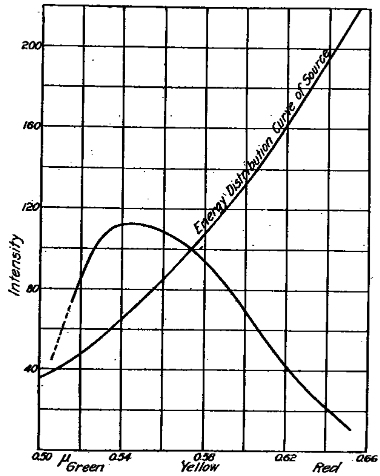


Fig. 11.—Spectral distribution of the light source.

SUMMARY AND CONCLUSION.

Spectral luminosity curves obtained by several observers using the flicker and equality-of-brightness methods do not show exact agreement between the two methods. With different observers the relative positions of the two kinds of curves are different. At low illuminations the equality-of-brightness curves shift toward the blue, the flicker toward the red. Marked differences in the color sensibility of the five observers exist, as shown by each method. The flicker method possesses much greater sensibility than the equality-of-brightness method, the difference being greatest at high illuminations.

The most important fact shown by this investigation is probably that the flicker method and the equality-of-brightness method give nearer the same values at high than at low illuminations. This result was thought probable before the investigation was undertaken, from consideration of the results of other observers. There is some reason for believing the flicker photometer to act chiefly by means of those elements of the retina called the cones, in distinction from the rods. The cones are supposed to be responsible for vision at high illuminations, the rods at low. The Purkinje effect is ascribed to the shift from cone to rod action; it becomes very small at high illuminations. Furthermore, the flicker photometer had been found to show little or no Purkinje effect. It therefore seemed possible that at high illuminations, using a size of photometric field such that the retinal area used is very largely cones, the two methods might agree.

In view of the fact that the observers in this test placed the high illumination flicker curves some one side and some the other of the equality-of-brightness, it does not seem unwarranted to expect that with a large number of observers a still closer agreement between the mean flicker and mean equality-of-brightness curves might be obtained. In addition it might be remembered that, as stated above, an observer's equality-of-brightness criterion is apt to change from time to time with respect to his flicker criterion. In the writer's own case, at one time in the course of the investigation the equality-of-brightness and flicker curves agreed exactly for the size of field here used and an illumination slightly above this; at another time they agreed exactly at a slightly lower illumination. The uncertainty as to the real position of the equality-of-brightness points precludes determining definitely how they do stand with any one observer. Only by taking numerous observations under such conditions that the observer's memory of previous settings was lost could a true curve be obtained to compare with the easily-obtained and definite flicker curve. Therefore it may be said that while the observations shown exhibit clearly only the fact that the two curves approach each other at high illuminations, there is strong evidence that at the highest illumination here used (250 units) the mean of numerous flicker and equality-of-brightness curves would very nearly if not exactly coincide.

This then would be an argument for choosing such an illumination as the standard one for making the heterochromatic comparisons necessary for the preparation of standards of different colors. For it must be clearly borne in mind that such comparisons can, from the nature of vision, hold exactly for only one illumination and size of field. The best solution to be hoped for must contain specifications of these two conditions. When the stage has been reached where one can give a definite candle-power rating to a colored illuminant for a certain illumination the first step will have been made. The second step will be when one can state also what the illuminant's candle-power will be at any other illumination, knowing it at the standard.

The much greater sensibility and ease of setting of the flicker method point to its decided superiority for heterochromatic photometry. However it is not the object of this paper to recommend the use of one photometer over another nor is any claim made that the results here given are in any way final. They constitute merely the preliminary steps in the investigation of the whole problem. Several important points must be investigated before the facts here brought out can be safely applied to practical photometry. Prominent among these lie the investigation of the effect of changing the color of the comparison source, and of the relative values of the physical and arithmetical summation of colored lights.

The above results show, however, as they stand several facts of scientific interest in the study of light measurement. These are expected to have important bearing on the further study of the practical side of the problem. They are given for that reason and, too, partly that the Illuminating Engineering Society may know that this problem in which it is prominently interested is being followed up.

The writer's thanks are due to Dr. P. W. Cobb, to Mr. F. E. Cady and to Dr. C. F. Lorenz for their kindness in making the readings here used, and especially to Mr. Matt Luckiesh, not only for assistance in the readings but for the preparation of the numerous drawings necessary to illustrate the paper.

DISCUSSION.

Mr. S. W. Ashe:—About three years ago at Columbia University, the speaker with others undertook an extensive investigation involving among other things the problem of color photometry. We spent 20 hours a week for one year on the problem. A considerable amount of work had been done there in the past by Prof. Rood, who was the father of the flicker photometer. The work was conducted in cooperation with the physics department and the department of psychology. Unfortunately the experiments were not entirely completed, but a great deal of pioneer work was done, and much of the investigation outlined has since been completed by others. Many of the points that we could not quite settle at the time have since been investigated. For instance, Mr. J. S. Dow in England carried on considerable work along the same lines and Mr. A. J. Sweet has also taken up certain other phases bearing on the acuity problem. Mr. P. S. Miller has also taken up the acuity end of it, and now Dr. Ives has taken up the flicker photometer. There are three methods of light comparison. One is the acuity method; another is the equality-of-brightness method, and the third is the flicker photometer method. Those who have attempted to compare lights by the acuity method realize that it is not at all satisfactory for commercial practice. Against the direct comparison method for color comparisons is the statements of Helmholtz, who was probably the greatest investigator the world has ever known on physiological objects, who said that he placed absolutely no confidence in his ability to determine equal luminosity of two different colors. On flicker work Dr. Rood probably did more than most other people. One of his convincing tests was to measure the individual intensities of two lights of complementary color on the flicker photometer. He then superimposed these lights over each other, producing white light, and the resultant intensity as measured on the flicker photometer was equal to the sum of the individual intensities of the previous colors. No one would want a stronger proof of the flicker method.

Some of the best work done with the flicker photometer has never been made public and never will be published, because the man who did it, Dr. Tufts, was accidently killed before the work was completed. The conviction is growing more and more as a result of various investigations that the flicker photometer gives a better answer than anything else to the question of the proper basis of color photometry. There is one point, however, that has not been decided as yet, and that is what is actually measured by the flicker photometer. The fact that a slightly different answer is obtained with the same colored light sources when employing equality-of-brightness and the flicker methods leads to the belief that the phenomena in the two cases are different.

Many extravagant claims have been made for the flicker photometer and these claims have given photometrists a wrong impression of the instrument. For instance, in England use was made of color-blind subjects and many unwise claims were made; consequently there was a certain amount of prejudice at the beginning of our work which ourselves and others have had to discount.

Many things that Dr. Ives has mentioned agree with our results, such as the great sensibility of the instrument and the luminosity curves obtained.

Mr. G. C. Keech:—I should like to ask if any experiments have ever been made with sensitive plates.

Mr. F. J. Pearson:—About two years ago, the speaker working with others made several determinations on arc lamps, by means of the flicker photometer, using an incandescent lamp standard. In view of the fact that there were many variations in our reading, I ask Dr. Ives if in using a standard of low intensity such as a 16-c-p. incandescent lamp, a wide range of variation readings is to be expected. We failed to get concordant results all through the entire series of observations and I have always wondered why it was that such inaccurate results were obtained from the flicker photometer observation as checked with those from the Weber photometer using color screens.

Mr. R. C. Ware:—What is the effect of difference of speed at which the flickers rotate? Will not the balance be secured at different points as the speed is raised or lowered?

Dr. Ives:—One point to be emphasized in connection with the use of the photographic plate in its calibration. That is to say one must know how the eye estimates the brightness of colors in order to use anything else in the place of the eye, so that the first problem to be solved is the one of a method of photometry of lights of different colors. When this problem has been solved then it will be time to discuss using photographic plates or instruments which measure radiation through a certain color screen, or the use of colored glasses or of secondary standards which will reduce the actual photometry to that of lights of the same color.

As to the question about the wide range of readings obtained by Mr. Pearson, I am at a loss to answer, because I do not understand what kind of range of readings he obtained; whether it was simply lack of sensibility or whether the readings at different times did not correspond. I should expect a greater definiteness and reproducibility with the flicker photometer. If the arc used was an alternating current lamp there would be a peculiar superposition of the flicker of the photometer with the flicker of the arc.

In regard to the difference in speed and the effect on the reading of the flicker photometer it may be said that there is simply one point at which the flicker photometer may be used for reading. If the flicker photometer is run fast enough, even when comparing light and darkness, one can set the photometer anywhere at all. If it is going about sixty cycles a second, all flicker can be eliminated. When two lights are being compared, the speed is much reduced. When it is not reduced enough, there is quite a space in the center of the photometer bar where the photometer head may be placed without flicker being noticeable. Beyond that space, there is flicker; by reducing the speed, the limits between which the photometer shows no flicker are reduced until a certain definite point is reached. The question of the effect of difference of speed simply drops out, for the reason that one cannot have different speeds when using the flicker photometer properly. There is only one correct speed.

Mr. P. S. Millar:—Does Dr. Ives advocate the use of the flicker photometer?

Dr. Ives:—I would recommend for the comparison of lights of different colors the use of no photometer. In other words, I think it extremely important—it is essential—that in ordinary photometry there should never be made a comparison of lights of different colors. All practical photometry should be reduced to the photometry of lights of the same color. Consequently, the question of which photometer is to be used for comparing lights of different colors, becomes a question for the standardizing laboratory, the Bureau of Standards the Reichsanstalt or the National Physical Laboratory. I certainly do not wish to be understood as advocating the use of any particular kind of photometer in ordinary practice. When it comes to the question of methods to be used in standardizing laboratories, I do not think the work has gone far enough to warrant recommending one photometer over another. The object of the investigations reported is to determine ultimately what method can be used with the greatest success in the standardizing laboratory for securing secondary standards or colored glasses or other means by which practical photometry may always be the photometry of lights of the same color.

Dr. C. H. Sharp:—Does Dr. Ives want to make the statement that we ought to stop trying to compare lights which differ a little bit in color, simply for the reason that we cannot do it so precisely as we can lights of the same color? His last remark seems to imply that we must stop trying to photometer arc lamps, for example because we cannot do so as well as we can incandescent lamps.

President Hyde:—I do not want to presume to answer for Dr. Ives—let him answer for himself—but if I understood correctly Dr. Ives' view on the subject, it is this: There is no reason why there should not be established some standard methods for color differences, such that in the ordinary photometry of arc lamps against incandescent lamps or other lamps of different colors, there will be no need for measurement of the extreme color differences which occur. The establishment of a standard method is a problem that perhaps is up to the Research Committee of the Illuminating Engineering Society, (which has not yet been appointed), or is one which this committee should take up with the National Laboratory. The question of standardizing some method by which the color differences can be overcome will involve the photometric difficulties to which Dr. Ives has referred in his paper.

Dr. Ives:—The President clearly expressed my position. I think Dr. Sharp entirely misunderstood me on the point. I consider that the ideal towards which we should aim,—the goal in heterochromatic photometry,—is to reach the point where the practical observer never has to face the problem of comparing two lights of different colors. Such work should be done for him in the standardizing laboratory.