FLICKER PHOTOMETER MEASUREMENTS BY A LARGE GROUP OF OBSERVERS ON A MONOCHROMATIC GREEN SOLUTION.

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A DETERMINATION of the mechanical equivalent of light, now in progress, demanded the photometric evaluation of the monochromatic green radiation of the mercury arc, wave-length .5461 μ. Since in measuring the luminous intensity of a colored light in terms of the present yellowish white standards it is always necessary, no matter what method of visual photometry is employed, to use a large number of observers, some means was necessary to determine that value by a separate experiment. It is well known that the current-intensity relation in the mercury arc is not nearly reliable enough to permit of holding the radiation constant by maintaining the current at a fixed value. It was therefore necessary that our measurements be made on some auxiliary standard which would possess maintainable and reproducible characteristics. For this standard we decided upon an absorbing solution, which should be used over the standard "4-watt" carbon lamp, to be of such constitution that the transmitted light would be a visual match with the green mercury light. Such a solution was developed and used. The details of its use and the results of its measurement have points of interest apart from the question of the mechanical equivalent of light and are, therefore, presented here separately.

THE ABSORBING SOLUTION.

The solution, which transmits light exactly matching the green line .5461 μ when used over a standard carbon lamp, is a mixture of potassium dichromate and cupric chloride, together with a sufficient amount of nitric acid to hold the two in solution. The composition for 25 millimeters thickness is:

Potassium dichromate	2.5 grams.
Cupric chloride	265.0 grams.
Nitric acid (sp. gr. 1.05)	26.5 cu. cms.
Water to one liter.	

The cupric chloride before weighing is dried by being raised to a temperature of 50° centigrade. When mixed the solution is filtered through a triple paper filter.

Careful photometric tests have shown that with these precautions the solution is absolutely reproducible and, certainly over periods of several weeks and probably much longer, shows no detectable fading or other change.

In the use of the solution it is necessary to know its change of trans-

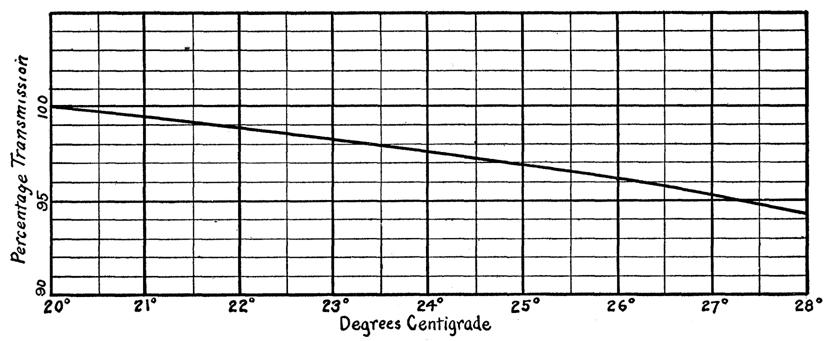

Fig. 1.

Temperature Coefficient of Transmission of Green Solution.

mission with change of temperature. This has been determined by comparison on the photometer of the light through a solution at the standard temperature of 20 degrees centigrade with that through another at various higher and lower temperatures. The values are shown in Fig. 1.

The Absorption Cells.

Great emphasis must be placed on the importance of using a reliable type of absorption cell. In a recent investigation we have found differences of as much as five per cent. in the transmission of supposedly similar clear glass tanks. As a result of our study we have come to the use of a special type of tank, shown in Fig. 2. The solid glass frame is exactly 25 millimeters thick, in this case, and can be obtained without difficulty from a good glass worker. The two removable faces must be selected with the greatest care, for upon them depends the value of the

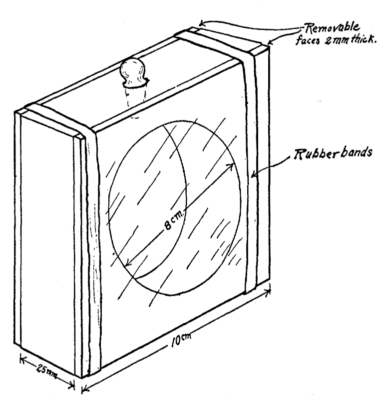

Fig. 2.

Type of Absorption Cell Used.

cells' transmission. We are using plates two millimeters thick, of special clear white glass which shows no color when viewed edgewise. In addition, we have tested these glasses through the spectrum by means of approximately monochromatic color screens on an ordinary Lummer-Brodhun contrast photometer, finding no selective absorption.

The cleaning and handling of these faces is also of importance. Whenever removed they are washed with hot water and soap, rinsed thoroughly with hot water and wiped carefully with a clean soft towel free from grit. After cleaning they are laid against the glass frame, held in place with rubber bands, and a seal of paraffine run around the edges with a hot metal spoon to prevent the cell from leaking. The solution, or the clear water as the case may be, is introduced through the stoppered opening at the top.

In order that the necessary cleaning and the inevitable process of surface decay shall not introduce progressive and unnoticed differences between the cells used they should be periodically compared for their total transmission when filled with clear water, and if it becomes necessary, new faces should be obtained.

The Method and Details of the Measurement.

The transmission of this solution was measured by means of the special flicker photometer recently described in the Physical Review.[1]

The conditions of measurement were those determined upon as a result of the extended study of colored light photometry by one of the present writers, involving the maintenance of one field brightness throughout, the use of a small field and other details for which reference may be made to the work quoted.[2]

The experimental procedure was as follows: The flicker photometer was mounted at one end of a three-meter photometer bar. The carbon lamp, a 100-candle-power point source of the stereopticon type, carefully matched in color with a standard supplied by the Bureau of Standards, was upon a movable carriage. The absorption cells, one containing clear water, the other the green solution, were held in supports before the photometer. The first measurement was upon the transmission of the clear water. The lamp was set at such a distance from the photometer screen that the brightness of the photometer field was that of a white surface illuminated by 25 meter-candles. After five settings were made with the clear solution it was replaced by the green one, and the lamp moved to a nearer position so that the new measurement was carried

[1] Physical Review, October, 1914.

[2] Photometry of Lights of Different Colors, Phil. Mag., July–December, 1912.

out at approximately the same field brightness. Five settings were made on this and then the process was repeated so that each observer made ten settings. Between groups of settings the green solution was immersed in a basin of water held at 20 degrees centigrade, on removal from which it was wiped dry with a clean soft towel. From the relative distances of the lamp, correcting for the thickness of glass and water, the transmission of the solution, compared with clear water, is obtainable.

This description refers to a single observer. In order that the result may apply to the average eye, it is necessary to secure values from a large number, just how large a number being one of the points to be determined by the investigation. The measurements here recorded were on some sixty-one observers, members of our laboratory force employees of other departments of the company, and some visitors. Many of the subjects were new to photometric reading, the majority had never read a flicker photometer. The determinations extended over a period of about two months.

No other tests of color vision were made so that it is possible we have among the number some whose vision might be classed as abnormal. We are reasonably sure that none is included who would fall in the classification of "color blind," because measurements made on one known color-blind person gave a result 60 per cent. larger than the mean, falling in a class entirely apart. The observers probably constitute an "average" group of men and, as will be seen, the number is apparently large enough so that the addition or subtraction of any chance observer or any group chosen at random would leave the mean value substantially the same.

Results.

In Fig. 3 are plotted the results obtained by the observers in the order taken, together with the mean of all values up to each point. The final mean value for the transmission of this solution at 20 degrees centigrade, compared with clear water, is .0437. Individuals vary from this as much as sixteen per cent. above, and twenty-nine per cent. below (leaving out of account the color-blind observer above mentioned).

Discussion.

The question of the precision and reproducibility of measurements of this kind has been discussed quite fully in the previous papers. The present measurements merely confirm the previous findings. Repeat measurements were made on some of the observers, with results checking to about one per cent. About a third of the observers had previously taken measurements on a similar but ultimately unsatisfactory solution.

Their relative positions with respect to the mean were the same on that series and on this with only a few slight changes in order, showing that no considerable changes in an observer's criterion are to be looked for.

We have searched in vain for any connection between the position of an observer in this series and any of his physical characteristics, such as age.

A point of extreme importance in colored-light photometry is here demonstrated in very convincing form. This is that precision in reading and agreement between different observers of a small group are no

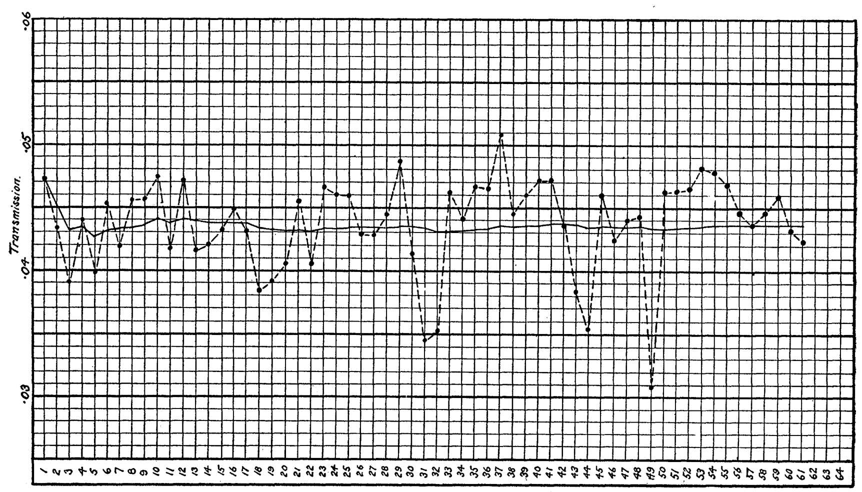

Fig. 3.

Individual Readings on Transmission of Green Solution.
Points,—observations.
Numbers,—observers.
Solid line,—mean of all observations up to and including point.

evidence whatever of accuracy. The emphasis placed upon this is prompted by the widely-found belief that if one observer reads with a small mean variation and consistently from time to time it is evidence that his readings are "right"; and the similar idea that if several observers who happen to be associated together read alike, their result must be "right." This conclusion is valid only where there is no color difference. Where there is a color difference, only some such investigation as that here reported can be established what is to be taken as correct. The correctness of an individual observer's setting has nothing whatever to do with his skill or training—it is dependent upon the color sensibility of his retina. The agreement of several observers is a matter of chance, except where, using the equality of brightness or direct comparison method, observers have consciously or unconsciously altered their criteria toward a common mean. The justice of this criticism is strikingly illustrated by the fact that observers 51, 52, 53, 54 and 55 constitute the entire group of photometrists from a laboratory in which measurements involving a considerable color difference were part of the regular routine. They agree with each other to within about three per cent. but their mean on this particular color difference is eight per cent. above the average for all.

These considerations indicate the importance of a definite scheme of selecting observers from a group of at least twenty-five or thirty where lights of different color are to be evaluated. They also emphasize the desirability of methods of colored-light photometry by which individual observers may secure the results of the average eye as established by measurements on a large group. We expect to report shortly on means for achieving this end.

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