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THE PRACTICAL MEASUREMENT OF
COLOUR AND THE SENSITIVENESS OF THE
EYE TO SMALL CHANGES IN HUE.

BY MR. F. STANLEY.

Read June, 1913.

ONE of the most difficult problems in the practical application of optics is the accurate analysis or specification of colour for the precision necessary in such that any colour may be specified within the limits of visual chromatic sensibility, and these, as we shall see later, are extremely small.

Many instruments have been designed with more or less success for the measurement of colour, but until we can obtain a light source more nearly approaching daylight, and more constant in character, the values obtained for colour standards will vary considerably. All artificial sources are deficient in violet compared with sunlight, and if we attempt to rectify this by employing a screen, the amount of light left is hardly sufficient to illuminate the apparatus, unless of course we employ the arc lamp, which has several disadvantages.

Existing colour measuring instruments can be arranged in four groups, *i.e.*—(1) Tricolour analysers, (2) Monochromatic analysers, (3) Interference instruments, (4) Instruments involving the use of comparison standards.

Of these groups, perhaps the tricolour analysers present the most difficulties, although under the trichromatic theory of vision they should be the most reliable and satisfactory. In spectral instruments of this type the greatest diffi-

culty lies in ensuring that the three entrance or illuminating slits receive the same amount of light. If sunlight is available it is not difficult to arrange this, but care must be taken to see that clouds are not focused on the slits.

Another difficulty comes in mixing the three beams after they have been dispersed by the prism. Several ingenious devices have been used for this, as for instance in the Ives colorimeter, where a rotating wheel is employed round the periphery on which are mounted a number of lenses, each lens deviating the light in two directions as the wheel revolves and thus effectively mixing the beams. The wheel must revolve at a sufficiently high speed to prevent flicker, which is in itself a source of possible error.

The three primary colours can also be mixed by using a series of half-silvered surfaces, but care must be taken to protect them, to prevent tarnish; and all three beams must suffer the same number of reflections. Tricolour analysers can also be used in which coloured screens take the place of the prism. Such instruments have the advantage of giving more light, and the screens are not very liable to change in time, although if very accurate measurements are desired the screens can be checked by a spectrophotometer.

A tricolour instrument in which only one entrance slit is employed was suggested several months back by Mr. F. Twyman, and a diagram is shown in fig. 1. The light entered through the slit A and passed through the optical train P, O, D, R₁, and O₁, to the concave mirror M, which was of exactly the same radius of curvature as the focal length of the object glass. The light was dispersed by the well known form of constant deviation prism D, and a spectrum in correct focus was formed on the surface of the concave mirror. The light forming the spectrum was allowed to return through three apertures placed in the correct positions rela-

tive to the spectrum, and the amount of light passing these apertures could be controlled by altering a series of neutral tint wedges.

Now as the concave mirror is of the same radius of curvature as the focal length of the object glass, the light passing the three apertures returns over exactly the same path as the incident light, and consequently would illuminate the back of the entrance slit and pass through it; but the reflecting cube P is composed of two right-angled prisms placed together with their

FIG. 1.

hypotenuse in contact after lightly silvering them, and thus about half the light passes direct through to the eye at E. The reflecting light from the sample under examination is passed into the apparatus by a total reflecting prism R placed immediately behind the object glass O. This instrument gave quite satisfactory results, and is possibly the most satisfactory form of spectral tricolour analysers.

Monochromatic analysers have only recently

received much attention. Abney carried out exhaustive experiments in this direction, as did also König, but it remained to Prof. Nutting, of the Bureau of Standards in Washington, to design an efficient colorimeter on these lines. Colorimeters of this type depend on the fact that all colours with the exception of the purples can be formed from a definite spectral hue diluted with the necessary amount of white light. Purples can be matched by mixing a definite spectral hue with the purple to form white. The instrument designed by Prof. Nutting is exhibited here this evening; and it is proposed in America to base a legal standard of colour by the aid of such an instrument. The general design of the instrument can be best explained by the aid of fig. 2.

The Nutting Colorimeter.

Light from the source S illuminates the three slits or apertures S_1 , S_2 and S_3 by reflexion from three nickel-steel mirrors M_1 , M_2 , M_3 . The light from the slit S is dispersed by the prism D , and a spectrum is formed by the lens O_4 at the position S_4 , where it can be observed by the aid of an eyepiece.

The light from the slit S_2 is reflected by a glass plate or off the face of the prism, and an achromatic image of the slit S_2 is formed superimposed on the spectral image at S_4 . The slit S_3 is the comparison slit, before which is placed the sample under test, and is placed almost perpendicular to the axis of the slit to prevent direct reflected light from passing into the slit.

The cube P is constructed from two right-angled prisms P_1 and P_2 , one of which is silvered over half of the hypotenuse, and is so arranged that the light from the sample piece from S_3 fills this half of the cube.

In practice the eyepiece at S_4 is replaced by a pinhole, and the eye therefore observes direct the cube P . In front of each of the three slits S_1 , S_2 and S_3 are arranged a pair of Nicols, so

that either the spectrum colour white light or the light from the sample can be diminished to any desired extent and the amount of light can be determined.

The dispersing prism D is turned by means of the lever and a micrometer screw on the end of which is fitted a helical drum graduated to read wave-lengths direct. The instrument is

FIG. 2.

extremely easy to manipulate, and it is not difficult to arrange for all instruments to give the same results, which, of course, is of the greatest importance.

Of instruments employing the principles of interference of light the best one is that perfected by Arons, which although not in the final state is capable of fairly good measurements.

By this instrument colour is specified in terms of a thickness of quartz and on the angle between crossed Nicols. Six standard quartz plates are used and a white comparison surface is illuminated by the light passing the optical system.

When designing instruments for accurately recording colour values or arranging standard colour scales, it is necessary to remember the high sensitiveness of the eye to small changes in spectrum hue or wave-length. Being particularly interested in this subject some few years

FIG. 3.

back, I designed a simple instrument for finding the smallest change in wave-length which can be detected by the eye under the most favourable conditions. The results obtained are interesting, and I afterwards found were in agreement with results obtained previously by other observers. A diagram of the instrument is shown in fig. 3.

Light from the slit S is collimated by the lens O, and is diffracted by a grating, the orders on the right and left being reflected by the mirrors M_1 and M_2 through the lenses O_2 and O_3 . A neutral tint glass of the required thickness is

interposed in the beam from the brighter order to make the two beams of equal intensity. A biprism is placed at B to receive the two beams of light, and they are seen divided only by a fine line by the eyepiece E. The mirror M_2 can be rotated by means of a screw motion to which is fitted a helical drum calibrated directly in wave-lengths. The mirror M_1 can also be turned to bring on to the dividing line of the biprism light of any desired wave-length. With this instrument any desired portions of the spectrum can be brought into actual juxta-position for comparison.

FIG. 4.

In practice the mirror M_1 is first set to give light of required wave-length on the dividing line of the biprism. This light is matched by rotating the mirror M_2 by the screw motion and successive readings are recorded of the wave-length reading on the helical drum of what is thought to be an exact match in colour on the two fields in the neighbourhood of the dividing line on the prism.

In the case of my own eye I took about 30

readings at intervals of about 50 units throughout the spectrum and the mean error of observation was recorded. If the values thus obtained are plotted, a curve can be drawn passing through most of the points. Such a curve is shown in diagram 4, and it will be noticed that there are two regions in the spectrum where the eye is most sensitive. These regions or maxima are at 5,050 and 5,890, the latter being at the position of the sodium lines. At wave-lengths 5,050 matches can be made to within three Angstrom units, or half the distance apart of the sodium lines. At 5,890 the eye is only slightly less sensitive, and matches can be estimated to within 4 or 5 units, slightly less than the distance of the sodium lines. This agrees exactly with results found by Lord Rayleigh and clearly shows that the difference in colour of the sodium lines can be detected, but as these lines are not of the same intensity it is difficult to detect the colour differences when using the ordinary spectrometer.

As will be seen, the results agree fairly well with those obtained by König, but his measurements were taken in a different manner. I have not, however, been able to detect with certainty the maxima at 4,500. These curves are of course of the greatest importance in detecting colour blindness, and they lend great support to the trichromatic theory of vision for the maxima in the curve; 5,890 is where the red and green sensations of the eye overlaps, and at 5,050, where the blue, green and red sensations overlap.

This instrument is not entirely suitable for colour blindness tests, as a large number of readings are necessary to obtain consistent results, and for this reason the instrument designed by Dr. Edridge Green is more generally useful. With this instrument much more rapid determinations of the monochromatic patches can be made.

MR. T. SMITH said there were so many points of interest in Mr. Stanley's paper that he was afraid he could not cover them all, and must content himself with asking one or two questions of particular interest to himself. He had been very much struck by the ingenuity of the instruments Mr. Stanley had described. In the case of the one he had sketched on the board, he would like to ask whether he had experimented to determine whether he had noticed any different results by having the angle M_3 rotated in a different direction relatively to the slope of the sample. It was quite possible that one might get materials which reflected light differently—reflected some colours more strongly in some directions than in others—so that in order to obtain definite results it might be requisite to specify a particular standard of position for M_3 . He very much admired the instrument described by Mr. Stanley as having been used for the mixing of the three colours together. He gathered that the new instrument was much quicker in use, and more satisfactory, but he did not quite understand whether such colours as browns could be matched by the mixture of one single monochromatic object in a white light. He would like to hear what could be done in that way. With regard to the apparatus for determining the sensitiveness of the eye to different colours, he did not know whether he had been setting his instrument to determine the accuracy with which colours could be repeated, or whether he had been doing what had been done by another investigator, namely, to make his error as large as possible without being able to say decidedly the difference in colour. He would expect the results obtained by making comparisons in these two ways to be very different indeed.

MR. EVERITT wished to know whether Mr. Stanley had noticed any change in the sensitiveness of one eye as compared with the other, because some years ago, when he had had occa-

sion to make a series of spectral measurements, lasting over several months, at the end of that time he found that through using one eye at the red end, and the other at the blue or violet end, there was afterwards a distinct difference in the sensitiveness of the two eyes to colour, and, when looking at a white surface with the one eye, there was a slightly orange, or yellow, tint perceptible, while when using the other eye there was visible a bluish tint. Now, before making those observations, he had never noticed that difference, although it might have been there.

The CHAIRMAN said he was struck with the very great sensitiveness to colour differences shewn by Mr. Stanley's results. He would like to ask him how far he would consider that was due to the sort of differences obtained in reading Vernier readings, or whether he considered the effect would be much the same if one was observing only a comparatively small portion of each spectrum. He would have, he imagined, a comparatively complete spectrum on each field.

The Lecturer's Reply.

MR. STANLEY: The sensitiveness of the eye determined in the manner described, is really the mean error of observation, the match in each series of measurements being made as carefully as possible. There is in the field of view two spectra, and any desired region from each can be brought into coincidence.

The CHAIRMAN: You would use the two spectra?

MR. STANLEY: Yes.

The CHAIRMAN: And you would not exclude any except just the actual portion you were dealing with? You would be able to use the whole of the rest of the spectra to aid your comparison?

MR. STANLEY: Yes, but cutting it down to about 10 to 20 units on either side made no difference to the results.

The CHAIRMAN: That is, with 10 or 20 units in each portion of the patch, you could set the two spectra against one another with an accuracy of about 5 or 10 units?

MR. STANLEY: Yes.

The CHAIRMAN: That is quite contradictory of the results published by Dr. Edridge-Green. If you could do it with such a small patch of the field, his results would not hold. You have two things along side one another, and he has them gradually changing from one to the other, and therefore the difference may be due to the fact that as the eye travels along you get a gradual change which is not appreciated, whereas, if you got even one-tenth of that change suddenly, you would appreciate it.

MR. STANLEY: The larger values obtained in the Edridge-Green instrument are, I think, due to the gradual change which is, as you say, not so well appreciated in finding a monochromatic patch. This, of course, is of no importance in practical colour blindness tests.

The CHAIRMAN: It would be very interesting indeed if Dr. Edridge-Green's experiments could be repeated with intervals—if he were to cut out pieces of the spectrum in between. I should imagine from your results it would be much easier to find colour changes under those circumstances than with a continuous spectrum.

MR. STANLEY: That might be the case, but, on the other hand, with his instrument it is much easier to tell whether anybody is colour blind than with mine. You can take readings much more quickly with his.

The CHAIRMAN said his reason for raising the point was that it affected the question how far Dr. Edridge Green's results were of value in deciding on colour vision. It might be that those results were dependent upon a special method of observation, and were not universally applicable to observations of limited portions of the spectrum.

MR. STANLEY: Dr. Edridge-Green's results are

quite sound, and of the very greatest importance in colour blindness tests. The instrument described was used for determining only the sensitiveness of the eye to *small* changes in wavelength.