ART. XXXII.—*On the Sensitiveness of the Eye to Slight Differences of Color*; by BENJAMIN OSGOOD PEIRCE, JR.

AUBERT has shown * by his experiments with revolving discs that the eye is able to detect the change produced by the addition of 1 part of white light to 360 parts of colored light, and that perceptible changes in hue can be brought about by adding to light of any color less than 1 per cent of light of a different color. He infers from this that a normal eye could distinguish at least one thousand different hues in the solar spectrum.

At the suggestion of Professor Wolcott Gibbs, I have made a few experiments to test the sensitiveness of the eyes of different people to slight changes of wave-length in different parts of the spectrum.

For this purpose, a long, thin sheet of vulcanite was inserted lengthwise into the collimator of a large spectroscope so as to divide the tube into an upper and a lower half. The lower part of the tube received light from a fixed slit, the upper part from a movable slit of the same width, which could be set exactly over the other, or displaced to the right or to the left. The amount of displacement was determined by means of a steel scale fastened to the upper slit and moving with it past a fixed zero point. The light from the collimator fell upon a Rutherford diffraction-grating of about 17,000 lines to the inch, and the resulting spectra were then thrown, one above the other, into the observing telescope. A blackened, metallic diaphragm, out of which two narrow slits had been cut in the same vertical line, was placed in the eye-piece of the telescope, so that when the two collimator slits were even the observer saw merely two narrow strips (one over the other) of the same colored light on a black field. When the movable collimator slit was displaced, the *color* of the observer's lower strip was changed without changing its *position in the field*, and the object of the experiments was to see how small a displacement could be infallibly *detected* and *named in direction* by the observer.

The width of the collimator slit was about $\cdot 25^{\text{mm}}$, and the slit in the eye-piece diaphragm was nearly of the apparent size of the collimator slits as seen through the telescope. The length of that part of the spectrum which was so bright as to be easily studied (say from Li α to G) extended over more than 12 degrees of arc as measured in the instrument, and the width of the strip seen by the observer was about 5 minutes of arc, so that not more than the $\frac{1}{150}$ part of this brighter part of the spectrum was in the field at the same time.

* "Physiologie der Netzhaut," Breslau, 1865, pp. 132-154; Rood, "Modern Chromatics," pp. 39-41.

In no case was the observer able to detect any difference between the colors of the two edges of a strip; each strip seemed to be of one color throughout.

It was necessary to regulate very carefully the Argand burner used as a source of light, for the least difference in the intensities of the two spectra made the strip of the brighter seem to the observer yellower than the corresponding strip of the other spectrum. This error, due to the "color of brightness,"* was most apparent in observations made at the extremities of the spectrum, i. e. in the red and the violet.

A displacement of the movable collimator slit amounting to 1 scale division corresponded to 4 minutes of arc, or to a difference in wave-length of $\cdot 0000013^{\text{mm}}$.

The observer sat in a darkened room and directed the telescope to that part of the spectrum in which the observations were to be made. After an assistant had placed the movable collimator slit even with the other, and the observer had seen to it that under these circumstances the strips of light in the eye-piece seemed just alike—as they should—the observer took his eye away from the instrument, and the assistant displaced the movable collimator slit and asked the observer to look into the telescope and to tell him, from the colors of the strips, in which direction the slit must be moved in order to be even again with the fixed slit. If the displacement was very large, the observer was able to tell immediately how to move the slit in order to match the colors of the strips; if in successive trials the displacements were made smaller and smaller, a place was reached where the colors of the strips did not seem well matched to the observer, but where he could no longer say with confidence *in which direction* the movable slit had been displaced.

The smallest displacements which the observer could infallibly detect and name were determined at different places in the spectrum, and it soon appeared, as was to have been expected, that the magnitude of these displacements was very different with the same person for different colors and not by any means alike with different persons for the same color.

Though the results seemed at first somewhat irregular, I found that the same series of results were invariably obtained with the same person, even though the experiments were separated by days or weeks, and that certain features were common to all the series obtained with the different observers.

The largest displacement needed (except at the ends of the spectrum) by any of the observers corresponded to a difference in wave-length of the middle of the two strips of about $\cdot 000005^{\text{mm}}$, and the smallest displacement which any observer could infal-

* C. S. Peirce, "Note on the Sensation of Colors," this Journal, April, 1877.

libly detect corresponded to a difference in wave-length of only $\cdot 0000005^{\text{mm}}$. This last is rather remarkable, for although no one could see any difference between the colors of the edges of either of the strips, a displacement which made the color of the middle of one strip the same as that of an edge of the other sometimes made the two strips distinguishable.

There was a singular uniformity in the performance of different eyes as judged by the average of these displacements for the whole visible spectrum. Perhaps smaller differences might have been detected if the strips had been narrower, but the work proved to be so trying to the eyes that I thought it best not to experiment further.

From a series of observations made by a number of different persons and extending over several months, two or three general conclusions may be drawn. To make these evident, I have plotted a curve by laying off over different places in the spectrum ordinates obtained by averaging in each case the least

displacements distinguishable by the different observers at that point. The general features of this curve appeared in the results of every observer.

In all cases the eye was most sensitive to changes in a color slightly less refrangible than that of the sodium line, though this color varied somewhat with different persons, being in some cases more orange and in others more yellow. In all cases the eye was more sensitive to changes in the color corresponding to the F line than to changes in colors lying half-way between *b* and F.

In many cases, though not in all, the eye was less sensitive to changes in a red near the C line than to a somewhat darker red beyond the Lithium line. In the darker colors at the ends of the spectrum it was, of course, very hard to distinguish small differences.

In addition to these general features there were in most of the curves obtained by plotting the results of the different observers lesser maxima and minima which showed peculiarities

in the different eyes. These peculiarities appeared unchanged in every set of observations taken by the same person.

I wish to express my obligations to Professor Gibbs for his advice and for the loan of apparatus, to Professor J. P. Cooke, who kindly placed at my service the magnificent spectroscope made for him by the Clarks, and, among others, to Professor W. E. Byerly, Professor C. R. Lanman and Messrs. F. B. Knapp, E. B. Lefavour and E. S. Sheldon for their kindness in helping me with their observations.

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