it should be noted that in this material there is no further formation of rods. The coarsely granular precipitate is well marked in the second and third divisions, but no rods are formed.

It is evident that my conclusion from a study of the material described is that the basophilic bodies found are not in the nature of chromidia, but are the result of indirect nuclear activity. As to the applicability of these results to cases in which basophilic inclusions occur normally, it is impossible to say more than that such cases should be considered in the light of the evidence here given. The explanation offered for the formation of the basophilic extra nuclear bodies described is intended to be suggestive rather than conclusive. It brings together facts which have not hitherto been associated.

A more detailed paper with illustratons is forthcoming.

Beckwith, Cora J., The Genesis of the plasma-structure in the egg of Hydractinia echinata, *J. Morph.*, **25**, 1914.

Chambers, Robert, Microdissection Studies I, *Amer. J. Physiol.*, **43**, 1917; and Microdissection Studies II, *J. Exper. Zool.*, **23**, 1917.

Dantchakoff, Vera, Studies in cell division and cell differentiation I, *J. Morph.*, **27**, 1916.

Gatenby, J. Bronte, The Cytoplasmic Inclusions of the Germ Cells, Part V, *Quar. Jour. Mic. Sci.*, **63**, 1919.

Schaxel, Julius, Das Zusammenwirken der Zellbestandteile bei Eireifung, Furchung, und ersten Organbilung der Echinodermen, *Arch. Micr. Anat.*, **76**, 1911; Plasmastructuren, Chondriosomen und Chromidien, *Anat. Anz.*, **39**, 1911.

Wilson, E. B., Archoplasm, Centrosome, and Chromatin in the Sea-Urchin Egg, *J. Morph.*, **11**, 1895.

## *A STUDY OF THE PERSISTENCE OF VISION*

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*Introduction.*—It was observed by Allen,[1] while investigating the effect of the color of the light on the persistence of vision, that there seemed to be portions of the retina where the persistence of the retinal impression was less than on the fovea. That is, when no flickering of the color under observation was perceptible in the center of the retina, a slight movement of the eye in any direction which allowed the light to fall upon the peripheral portions of the retina was sufficient to destroy the apparent continuity of the light. Allen attempted to measure the persistence for regions on the temperal side of the retina at 10 and 20 degrees from the axis of the eye but found that the results were "too uncertain to be of any use." The writer has measured the persistence of vision for several colors within the cone whose semi-vertical angle is nearly 40 degrees. More than one hundred points on the retina within this area were observed for each color used. From these data, it is possible to construct a map of the retina showing the persistence of vision for each portion.

Results of this sort should be of interest, not only to the illumination engineer, but to the physiologist and the psychologist as well. If the number of observers were large to insure that the results represent the average eye, it would be possible to construct a map of the retina with "contour lines" to show equal values of the persistence of vision. This was done by the author using the values obtained for his own eyes. The general shape of the lines was found to coincide more or less with the shape of the color fields given by Abney.[2] The extent of the color fields is, of course, dependent upon the intensity of the light. It was not possible to show that the area of the retina covered in this investigation was greater than the color field for the blue for the intensity used. As the color field for the blue is larger in area than for any other color, it seems natural to suppose that the persistence of vision should depend only upon the intensity of the light on portions of the retina outside this area and should be independent of the wave-length.

*Description of apparatus.*—The persistence of vision was measured by observing the minimum speed at which a sectored disk could be driven without destroying the apparent continuity of the light. The source of light was a concentrated filament incandescent lamp operated at constant voltage. A lens system was used to bring the rays to focus on the sectored disk. When the position of the disk is such that the rays do not strike it, they diverge until they strike a ground-glass screen about 5 centimeters square. An iris diaphragm placed just in front of it makes the size of the illuminated area on the ground-glass adjustable without altering the brightness. The sectored disk, the necessary electric motor to drive it, the incandescent lamp and the lens system are all placed in a light tight box. The eye was then placed 1 meter in front of the ground-glass and a chin rest was provided to insure steady conditions of the retina while making the observations. Needless to say, the investigation was carried on in total darkness. A small electric lamp operated on the storage battery current and carefully shielded was used to read the instruments when necessary. The time for the recovery of the retina after this stimulus was less than the time required to place the apparatus in adjustment for the next reading.

The speed of the disk was measured by means of a small magneto and a voltmeter calibrated to read the speed directly in revolutions per minute. The persistence of vision was first determined for the fovea by causing the disk to rotate at sufficient speed so that no flicker was apparent and then slowly to lose velocity until the first flicker was observed. On the average, it was found possible to determine the critical speed so that subsequent readings would not differ by more than 2 per cent. Observations were also made with the speed of the disk increasing and the average was taken as the persistence measure. A set of filters made by the Wratten

and Wainwright Company was used one at a time when it was desired to use light of a particular color. These filters were found to be very nearly monochromatic. The use of spectrum colors would be more accurate but the intensity of the light cannot be adjusted within as wide limits.

To determine the persistence of vision for off center portions of the retina, a small radiolight sight was used. This was mounted on a slider attached to a long rod and so constructed as to revolve about the center of the diaphragm. In this way it was possible to place the sight in any desired position with respect to the center of the diaphragm. Shallow grooves were placed at intervals along the rod so that it was possible to read the position of the slider in the dark. In the experimental work, readings were taken about every 3 degrees from the center and along directions which made angles with the horizontal of 45, 90, 135, 180, 225, 270 and 315 degrees. The manipulation was the same as before except that the attention was directed toward the radiolight sight and the persistence of vision measured with the light from the ground-glass screen falling on some other portion of the retina. It was, of course, necessary to cover one eye during all of the experimental work.

*Experimental results.*—Before results could be obtained which were consistent with themselves, it was found necessary to take several precautions. For example, time was given for the eye to become accustomed to the darkness. Results were obtained which showed that 5 minutes in total darkness was sufficient. It was also found that any motion of the body, however slight, would cause the interest to flag. For this reason, the motor controls had to be adjusted so that the motor would change its speed slowly as it was impossible to operate a rheostat by hand. One hand was held on a key which was pressed at the instant that the flicker was seen to appear or disappear and the critical speed noted.

The size of the diaphragm which seemed to give the best results was a circle of diameter 5.84 mm. The persistence of vision is dependent upon the size of the retinal area stimulated and also the scintillation of the light from a small aperture caused more or less uncertainty.[3] The above aperture was chosen as being the smallest that it was practicable to use. With the diaphragm placed at a distance of 1 meter from the eye, the angle subtended by the diaphragm at the eye is 3.36°.

As has already been said, the persistence of vision was determined for several colors and in each case the persistence was measured for about one hundred points on the retina lying inside a circle which is the base of a cone whose semivertical angle is 38.7°. No attempt will be made to give the results in full. They represent the persistence of an impression on the retina of the eye of the author. The eye is known to be normal for color perception but has a moderate amount of astigmatism which should not affect the persistence of vision. A few results will be given to show the nature of the inferences which may be drawn from the investigation.

For red light (6776 A°) the persistence of vision in the fovea was 0.0209 second. The persistence for points lying at equal distances from the fovea was found to be very nearly the same. That is, if lines are drawn showing equal values of the persistence of vision, they appear to approximate circles with the fovea at the center. The deviation from the circle is enough to make them resemble the limits of the color fields for the retina. The circles are in every case flattened so that the major axis of the resulting ellipse is horizontal. The persistence is less for the fovea than for any other part of the retina, and there is a steady increase in the persistence nearly proportional to the distance from the fovea. The maximum value observed occurs on the nasal side of the retina at about 38° from the fovea. The persistence is slightly greater on the nasal side than on the temporal. The maximum value is 0.109 second.

For the yellow-green (5310 A°) very similar results were obtained. The persistence of vision for the fovea is 0.0179 second and is less than any other portion of the retina. The lines of equal values of the persistence are ellipses with the major axes horizontal. The persistence is still slightly greater on the nasal side. The maximum value is observed to occur for the same region as for the red light but the maximum in this case is 0.0339 second showing that the persistence is more nearly constant over the whole retina.

For the blue-violet (4631 A°) the persistence of the fovea is 0.0346 second. There is little change in the persistence for different portions of the retina. The region which gave a maximum value for the red and the yellow-green, now gives a value of 0.0339 second or slightly less than the fovea. The maximum occurs about 7° from the fovea on the nasal side and is 0.0401 second. The minimum of 0.0305 second occurs on the temporal side at an angle of 35° from the fovea. The change between the maximum and minimum amounts only to the difference between $^1/_{25}$ second and $^1/_{35}$ second. For the blue-violet light used, the persistence is very nearly constant over the whole retina.

It will be noticed that these values for the persistence are smaller than those which are sometimes quoted. The values given here represent the time required for the impression on the retina to fade sufficiently to be noticed when compared to a fresh stimulus. They do not represent the time for the total extinction of the retinal image.

The above results were obtained at the laboratories of the Department of Physics at the University of California.

[1] *Physic. Rev.*, **28**, 1909 (48).

[2] Sir William Abney, *Researches in Color Vision*, p. 190, et. seq.

[3] See Abney, *loc. cit.*, p. 181.