

ON SEEING IN THE DARK.¹

REMARKS ON THE EVOLUTION OF THE EYE.

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In my investigations on certain properties of illuminant substances, I have had to study to some extent the anatomy of the eye and the optical functions in colored light and in the dark (beginning of brightness). I have arrived at certain conclusions relative to distinct optical perception in the daylight and in the dark, which possibly are of interest for comparative anatomy and physiology, and also for the theory of evolution.

First of all I may mention the anatomical and physiological facts upon which my conclusions are based.

The fibers of the optic nerve end in cylindrical rods (about 120 millions) and flask-shaped cones (about 60,000). The light-rays from an object, upon which our eyes are fixed, strike upon the fovea centralis, which contains cones only and no rods. The further we go away from the yellow spot, the more rods are found, and at the circumference they are in the majority. At the place where the optic nerve enters the eyeball, neither rods nor cones are present, hence this point is entirely insensitive to light.

When we fix our eyes upon an object, its image falls upon the yellow spot (foveal vision); hence during the action of direct (foveal) vision the rods are entirely out of action, while in indirect (peripheral) vision the rods come into action together with the cones.

In 1887, H. F. Weber found² during his investigations on the relative economy of incandescent lamps, that a carbon filament emits a ghostly gray light before the red-glow starts. This first trace of a misty gray light appears to the eye as something unsteady and glimmering. As the temperature rises, the brightness of this light rapidly increases, going over from gloomy

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²See *Sitzber. d. Berliner A. d. W.*, 28, p. 491, 1887; *Wiedemann's Ann.*, 32, p. 526, 1887.

gray into ash-gray, yellowish gray and finally into fire-red. When the first trace of the red light appears, the last trace of glimmering, trembling and vibrating, which was present in all the stages of the gray-glow, disappears. According to H. F. Weber and E. Emden¹ the first emission of light is visible with gold at 423° C., with German silver at 403° C.

These observations led O. Lummer² to the following conception relative to the nature of our eye, wherein he ascribes following the theories of modern physiology, entirely different functions to the two sensible components of the retina, namely the cones and the rods, by considering same as two separate optical apparatus.

If we observe in a dark room the gradual increase of the temperature of a body, according to Lummer, our eye feels twice a sudden change, first from darkness to gray-glow and then from the latter to red-glow. In both cases this sudden change or transition corresponds to the transgression of the limit of sensibility of our optic nerve (the so-called threshold of sensibility). The arising of the gray-glow corresponds to the threshold of sensibility of the rods, the one of the red-glow however, to the threshold of sensibility of the cones. Hence the sensation of the gray-glow is effected by the rods, of the red-glow by the cones.

“Based upon the new physiological researches relative to the vision at low brightness and the influence of the purple pigment in the retina, the function of our two retina-organs was gradually separated and their separate tasks ascertained.”

J. v. Kries³ solved the still existing difficulties and contradictions by the hypothesis, that the cones form our color-capable ‘bright-apparatus’ and the rods our totally color-blind ‘dark-apparatus.’ According to this theory the cones enable us to see at great brightness and their irritations by the light-waves causes in the brain the sensation of color, while the rods which are totally color-blind, come into effect only at very low brightness and have the faculty of intensely increasing their sensi-

¹ *Wiedemann's Ann.*, 36, pp. 214-236, 1889.

² *Wiedemann's Ann.*, 62, pp. 14-29, 1897.

³ *Zeitschr. f. Psych. und Phys. d. Sinnesorgane*, 9, pp. 81-123, 1894.

bility in the dark. This property is called by Kries 'dark adaptation.' Before the cones react upon colored light, the rods cause in the brain the sensation of colorless brightness.

Hence we have at very low brightness a contest of the two optical apparatus which, at sufficiently low brightness, is settled in favor of the color-blind rods, so that then everything appears gray in gray, *i. e.*, in colorless brightness.

We can now understand why we do not see distinctly in a dark gray light (at low brightness); it is because, if we fix our eyes upon an object (*i. e.*, have an image produced on the fovea centralis), we have no apparatus that is affected by such image or light; the rods which are able to receive this light are absent from the fovea centralis and thence only a glimmering restless image is produced by an object in gray light. If we would have a sufficient number of rods among the cones around the fovea centralis, we would see much better in the dark than we actually see. This enables us to explain why a large number of animals see very distinctly in the dark. The cause of this most probably is, that in their eyes, which are of nearly the same construction as the human eyes, rods and cones are uniformly intermixed. It can be proven that a horse sees very distinctly in the dark, by simply taking a ride on a very dark night over country roads. The horse will trot and gallop as safely as in daylight, while sometimes the rider will be afraid, that the horse may stumble over a root or fall into a ditch. But there are even animals in existence which we positively know see much more distinctly at very low brightness than in the daylight: owls, etc. Here we have a case where, very probably, rods and cones have exchanged locations, as compared to the human eye. The rods are around the fovea centralis and the cones at the periphery. Hence with these eyes a distinct vision is effected at very low brightness, while at a greater brightness only a restless, glimmering sensation will be produced. While we see ghostly lights in the dark, the owl probably sees ghostly lights in the daylight. For physically a ghostly apparition is nothing else but a bright point which we cannot get into the foveal vision and which whenever we try to do so, is naturally vanishing, thereby causing the impression of motion.

We can infer, that as soon as the eye of about the construction of the mammalia — or aves-eye — was developed in the course of evolution, rods and cones were uniformly intermingled, or rather became uniformly intermingled by natural selection. Thereby the animals were adapted to the light in the daylight and in the dark. In such animals that are now procuring their food mainly during the night and in the dark, the cones were gradually driven back by the rods. In the human eye the opposite process took place; the rods were driven back by the cones. We only see a restless glimmering light, a ghostly apparition, where a horse will distinctly see an object.

Another question is whether we have simply lost the faculty of seeing in the dark or whether we have exchanged same for a higher faculty; we have lost one faculty which is of no use to us now and have gained one that is extremely valuable for our development. By driving back the rods we have concentrated and increased the strength and sensitiveness of our cones; we have developed and are still further developing and refining our sense for color and for light, our capacity for distinguishing the closest shades of colors. Whether we look at it practically or symbolically, we find that the driving back of the rods makes us masters of light and colors.

We can observe the development of the human eye within the historical times. Homer does not distinguish black from blue, but his heroes find their way as well in the dark night as in daytime. And now take a modern silk-dyer or cotton-printer who clearly distinguishes thousands of different shades, though he is not able to find his way on a dark country-road.

Rivers states¹ that some Australian tribes have but three expressions for colors, one for red, purple and orange, another for white, yellow and green and the third for dark blue and indigo. Some primitive races cannot distinguish blue from green, nor blue from violet. Tintometric tests have proven that in these races the threshold of sensibility is very low for red, much higher for yellow and very high for blue. Lobsien² has found that violet is frequently taken for brown by children; he

¹ *Popular Science Monthly*, 1901, p. 44.

² *Zeitschrift f. Psych. und Phys. d. Sinnesorg.*, 1904, p. 29.

shows that at the age of thirteen to fourteen years violet, orange and indigo are still struggling for their development.

We have reason to believe that this evolutionary contest between rods and cones does not require a long period and that adaptation is effected in a comparatively short time. Generally people that have lived in the country for generations and have to use their eyes in the dark, are in this respect very much superior to the inhabitants of the cities. In a few generations of city-life, however, this faculty is lost or rather exchanged for a higher faculty, which makes our eyes, from the standpoint of evolution, superior to the eye of the eagle or owl.

If we would know as much about the work and action of the different parts of the ear as we do of the eye, we would probably be enabled to form an idea about the limits of sounds perceived by the different species of animals.