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HUMAN VISION AND THE SPECTRUM

By Professor **GEORGE WALD**[1]

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THE basic relation which describes the response of the eye to radiation is its sensitivity to the various wave-lengths of the spectrum. The limits of this function define what is meant by light. Its form expresses fundamental properties of the retinal receptors, and of the ocular structures which light must penetrate to reach them.

The human retina contains two groups of receptors: rods, which function in dim light; and cones, the organs of vision in bright light, and color vision. The rods are mainly sensitive at lower wave-lengths than the cones. Hence, in the passage from dim to bright light, the spectral sensitivity of the eye shifts toward the red. This is the Purkinje phenomenon.

A small central area of the human retina—the fovea—which subtends a visual angle of about 1.5°, contains only cones. Within this region, therefore, no Purkinje phenomenon is observed.[2] Even in the dark-adapted eye, in which all peripheral responses are dominated by rods, the fovea retains the characteristics of pure cone vision.

The intrinsic sensitivities of rods and cones are

[1] This research was supported in part by a grant from the Josiah Macy Jr. Foundation. Part of the work was reported to the Optical Society of America at its meeting in October, 1944 (*Jour. Opt. Soc. Amer.*, 34: 769, 1944). The remainder was to have been reported to the society at its meeting in April, 1945, since cancelled. Most of the experiments on aphakic eyes were performed in the summer of 1943 at the Dartmouth Eye Institute, Hanover, N. H., to whose director, Professor Adelbert Ames, Jr., and ophthalmologist-in-chief, Dr. Hermann Burian, I am most grateful. I wish to acknowledge also the technical assistance of Ruth Hubbard with some of the experiments.

[2] A. Kohlrausch and J. Teufer, *Tab. Biol.*, 1: 309, 1925; K. Gross, *Z. Sinnesphysiol.*, 59: 215, 1928; S. L. Polyak, "The Retina," Chicago, 1941, p. 202.

but it does not soften up the fundamental postulate of statistical mechanics as stated with ruthless rigor three pages further on: and when after another three pages the reader confronts the (undefined) "barrier" I suspect that he will be stopped, and this at least will save him from being burned by the (undefined) "hot molecules" and then going astray in the (undefined) "configuration-space" which he is invited to enter. Forgive me, Professor Eyring! I do not intend to imply that there is anything wrong with your fabric, but just that it is tailored for minds already molded by long study of thermodynamics and statistical physics. For such minds it is well adapted and (to depart from the metaphor) concentrated but instructive.

O. Loewi spoke under the title "Chemical Transmission of Nerve Impulses." This illustrates strikingly how the verbal usages of one science may confuse the practitioners of another. To the physicist or engineer, this title implies the passage of impulses along a nerve; but what Loewi means is what the physicist would call the "coupling" of a nerve to a muscle. This coupling or transmission is managed by a chemical substance which the nerve-ending releases and which stirs the muscle to action. With the biological meaning of "transmission" clear in mind, and with a little more knowledge of the terminology of the nervous system than the reviewer possesses, the reader should find this lecture suitably clear and notably interesting.

D. W. Bronk presents a highly readable account of "The Physical Structure and Biological Action of Nerve Cells." To a small group of physicists and engineers, part of what he says can be condensed into the phrase that the nervous system is a truly wonderful servomechanism. The electrical phenomena in calls have been studied with the aid of physical apparatus of the utmost refinement, and the story ought to stimulate some physicists to dedicate themselves to biophysics. The lecture also treats some of the physiological problems pertaining to aviation; and these in part, but the psychological problems mainly, are the topic of the longest paper in the book: "Psychological Aspects of Military Aviation," by W. R. Miles. This is packed with information about such matters as the tests applied to prospective fliers—too packed, indeed, for easy reading.

K. C. D. Hickman writes, under the title "Adventures in Vacuum Chemistry," on the recent advances in the art of distillation and the application thereof to the Vitamin A industry. The audiences may have been swamped by the flood of information ranging from physics through chemistry to biology, but the material is well presented. I think that it must be a slip (on page 212) which implies that a tea-kettle produces a vacuum of 10^{-3} mm Hg, and I do not follow the explanation (on page 223) of the persistence of the spiral pattern. The "Present Status of the Vitamin B Complex," as described by C. A. Elvehjem, is apparently that the said system is found to consist of a good many things (some of them having chemical formulae so complicated it seems a wonder that they are known) of which the properties are found largely by observing what happens to an animal which does not get them in its diet. Happy the experimental physicist who works with spectroscopes and electronic devices on nice clean inorganic matter!

E. J. Cohn's admirable "Blood and Blood Derivatives" is the 1944 Sigma Xi lecture. It is thrilling to read of the complicated nature of the blood and its exquisite adaptation to so many purposes; thrilling also to hear of the skilful ways of separating and conserving its constituents for the benefit of the injured and the sick, one of the few offsets to the horrible expense and irrevocable waste of war. Osmotic pressure proves, as usual, difficult to present; we find the strangely sounding statement that "molecules by exerting osmotic pressure pull water back into the bloodstream."

The brilliant mathematician, George Birkhoff, whose sudden death is so much deplored, contributed a lecture, "The Mathematical Nature of Physical Theories." I am sorry to be obliged to conclude that he lost his audiences, excepting the mathematicians and a few mathematical physicists, in a very few minutes. Several times he refers too sketchily to little-known work of his own. It is tantalizing, for instance, to read that "the form of relativity of motion appearing in (Einstein's) theory is really that which would be suggested naturally to an astronomer who looked out upon the stellar universe with a completely impartial view" and then be sent elsewhere for the explanation!

KARL K. DARROW

BOOKS RECEIVED

Annual Review of Physiology. Vol. VI. Pp. 630. Annual Reviews, Inc. $5.00. 1945.

CANNON, WALTER B. *The Way of an Investigator; A Scientist's Experiences in Medical Research.* Pp. 229. $3.00. 1945.

CARTER, G. W. *The Simple Calculation of Electrical Transients.* Pp. viii + 120. Illustrated. Cambridge University Press, The Macmillan Company. $1.75. 1945.

CLIFFORD, HARRY E., and others. *Transmission Lines, Antennas and Wave Guides.* Illustrated. Pp. xv + 347. McGraw-Hill Book Company. $3.50. 1945.

DIEHL, HAROLD S. *Textbook of Healthful Living.* Third edition. Illustrated. Pp. xiii + 707. McGraw-Hill Book Company. $2.50. 1945.

KEYS, THOMAS E. *The History of Surgical Anesthesia.* Illustrated. Pp. xxx + 191. Schuman's, New York. $6.00. 1945.