Reports

Low-Level Irradiation and Threshold Shift in the Visual Receptor

Abstract. Customary methods of stimulating and recording were used to examine threshold shifts of the single visual receptor in the lateral eye of *Limulus* in response to low-level x-irradiation. Marked visual sensitization was found and was most pronounced at the lowest dosage levels (1 to 25 r). Complete light adaptation apparently cancelled the effects of the irradiation.

Since World War II, a large number of investigations of the effects or ionizing irradiations on various kinds of behavior have been carried out. The behavior associated with the visual mechanism, however, has not been investigated to any great extent and generally has been studied with respect to relatively high doses of irradiation.

Cibis *et al.* (*1*) concluded that irradiations of 1700 r will destroy the rod cells of some mammals and that doses upward of 10,000 r will cause the destruction of the cone cells. Kektcheew (*2*) reported that doses of lower intensity produce a drop of visual sensitivity which maintains itself for several days. Lenior (*3*) used the Birch-Hirschfeld adaptometer to investigate the course of dark adaptation before and after x-ray treatment. He noted a decrease in facility of adaptation after the administration of the x-rays. Furchtgott (*4*) found that a total body dose of 369 r of x-irradiation caused a decrement in a brightness discrimination by rats.

The purpose of the present program of research (*5*) is to study further the effects of x-irradiation on the visual mechanism by using the *Limulus polyphemus* (L) or "horseshoe crab," an animal whose visual functions have been thoroughly studied (*6*). The experiment reported here was designed to examine the cumulative effects of low doses of x-irradiation on the dark-adapted threshold of the eye of *Limulus*.

Nineteen single optic nerve fiber preparations were made from the lateral eye of *Limulus*. Sixteen of these were used for the collection of experimental data, and three were used for control. The methodology utilized in securing the single unit, or single functional unit, was similar to that of Hartline (*6*), with the following exceptions: The constant-temperature solution used to bathe the excised eye was fresh sea water held at 15° ± 0.1°C, to which 4 percent reagent quality ethyl alcohol had been added. This addition was made as a precaution against possible lateral inhibition (*7*).

Once a single unit had been secured, a plastic top, whose interior contained a flat sponge saturated with sea water, was placed over the preparation to maintain a high moisture level. At this point a stimulus spot 1 mm in diameter was used to locate the corresponding ommatidium, and the preparation was allowed to dark-adapt for 30 minutes.

At the end of the dark-adaptation period, the threshold of response to a 1-second presentation of the stimulus spot from a ribbon-filament, 6-volt incandescent bulb was determined by the ascending series of the method of limits (*8*). The intensity of the stimulus spot was controlled by a circular, neutral-density optical wedge previously calibrated in tenths of a log unit. Threshold checks were accomplished at 10-minute intervals, and the response to each presentation of the stimulus was recorded photographically. The results of the analysis of the control data are shown in Fig. 1 (top) and are similar to those found by Hartline (*9*).

The thresholds of the 16 experimental preparations were recorded in like manner. Immediately following dark-adaptation, three consecutive threshold determinations were made; these are shown to the left of time zero in Fig. 1 (top). On completion of these determinations, five irradiations (*10*) of 5 r each were delivered. The threshold was redetermined after each irradiation. Further irradiation was delivered in increments of 25 r, each increment being followed by a measurement of the threshold. The mean results of these determinations are shown in Fig. 1 (top), in which the time scales for the experimental preparations and for the controls are comparable.

Five of the 16 experimental preparations were adapted to light at room intensity for 15 minutes at the end of the 200-r dose and then dark-adapted once more. The recorded threshold to this adaptation level is shown in Fig. 1 (bottom).

Apparent sensitization of some portion of the visual mechanism occurs as the dosage of irradiation accumulates. The course of sensitization is negatively accelerated. Probably of greatest interest is the pronounced shift of threshold at low dose levels. The locus of this effect may be in any or all of three systems: the photochemical system of the retinula cells, the eccentric cell, or, possibly, the axon itself.

It seems unlikely that there is an effect in the chemical systems which mediate the propagated potential. There is evidence to support the view that nervous tissue is insensitive to less than lethal dosages (*11*). It seemed possible to localize the effect to the photochemical system of the retinular cells by the light-adaptation–dark-adaptation procedure. Preliminary experiments had established

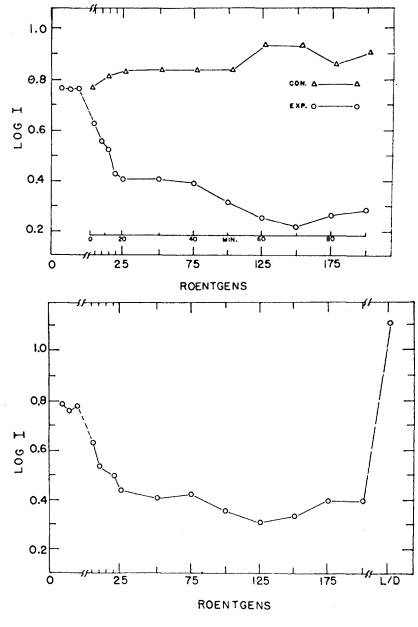

Fig. 1 (Top) Visual dark-adapted threshold measures for single-unit preparations from the lateral eye of *Limulus*. The thresholds of the experimental preparations were measured during cumulative x-irradiation; thresholds for nonirradiated controls were determined at comparable time intervals. (Bottom) Thresholds for dark-adapted preparations similar to those represented in Fig. 1 (top), as a function of cumulative irradiation. After x-irradiation of 200 r, the preparation was light-adapted and then dark-adapted, and the threshold was again determined.

Instructions for preparing reports. Begin the report with an abstract of from 45 to 55 words. The abstract should *not* repeat phrases employed in the title. It should work with the title to give the reader a summary of the results presented in the report proper.

Type manuscripts double-spaced and submit one ribbon copy and one carbon copy.

Limit the report proper to the equivalent of 1200 words. This space includes that occupied by illustrative material as well as by the references and notes.

Limit illustrative material to *one* 2-column figure (that is, a figure whose width equals two columns of text) or to *one* 2-column table or to *two* 1-column illustrations, which may consist of two figures or two tables or one of each.

For further details see "Suggestions to Contributors" [*Science* 125, 16 (1957)].

that the shift in threshold of response to irradiation was of a stable nature under dark-adapted conditions and remained constant after the final irradiation at 200 r. The threshold was determined at irregular intervals on some preparations for as many as 6 hours with no apparent return to normalcy.

Light-adaptation apparently serves to cancel the effects of irradiation on the system when the receptor is once more dark-adapted and the threshold is again measured (Fig. 1, bottom). The disparity between this sensitivity level and the terminal sensitivity of the controls is no more than might be attributed to pathological decay of the system. A similar control point may be extrapolated from the data by extension of the curve for an equivalent length of time. On this basis we may tentatively place the locus of effect in the photochemical system.

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References and Notes

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5. This work was supported in part by the Office of Naval Research and the Office of the Surgeon General, Department of the Army, contract No. 40-007-MD-683.
6. H. K. Hartline and C. H. Graham, *J. Cellular Comp. Physiol.* **1**, 277 (1932).
7. E. F. MacNichol, Jr., and R. Benolken, *Science* **124**, 682 (1956).
8. The relatively high threshold criterion of five axon discharges during the stimulus period was adopted to reduce misinterpretation of possible spontaneous discharge. However, spontaneous activity was not evident in most preparations, and discharges never exceeded ten per minute.
9. H. K. Hartline, *J. Cellular Comp. Physiol.* **5**, 231 (1934).
10. The x-ray source was a 100-kv, 30-ma Westinghouse diagnostic machine which was operated at 79 kv and 17 ma with a 0.125-in. aluminum filter. Estimated minimum lambda was approximately 0.2 A. in the far x-ray range. TSD, 4 in., 150 r/min.
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Paper Coal in Indiana

Abstract. The foliated, papery texture of the upper third of an 18-inch coal seam in a strip mine near Rockville, Indiana, is attributable to matted plant cuticle. The cuticles of pinnules, pinnae, and rachides resemble *Sphenopteris bradfordii* Arnold and thus differ from the lycopsid stem cuticles of the Russian paper coal.

In 1860 Auerbach and Trautschold (*1*) reported the occurrence of an unusual type of coal in the Moscow Basin of central Russia. This unique *Papierkohle,* as they called it, has been the subject of several reports and numerous discussions by geologists and botanists since then. The plant cuticles which make up the Russian paper coal are the remains of twigs of arborescent lycopods, although their specific botanical affinity has been the subject of considerable controversy. Auerbach and Trautschold (*1*) named the cuticles *Lepidodendron tenerrimum.* Walton (*2*) assigned them to the genus *Bothrodendron,* Bode (*3*) to *Porodendron,* a genus belonging to the eligulate Lycopodiales. Bode distinguished two species, *Porodendron lepidodendroides* and *P. pinakodendroides.* Figure 1, *A* and *B,* shows cuticles that occur in the Russian *Papierkohle.*

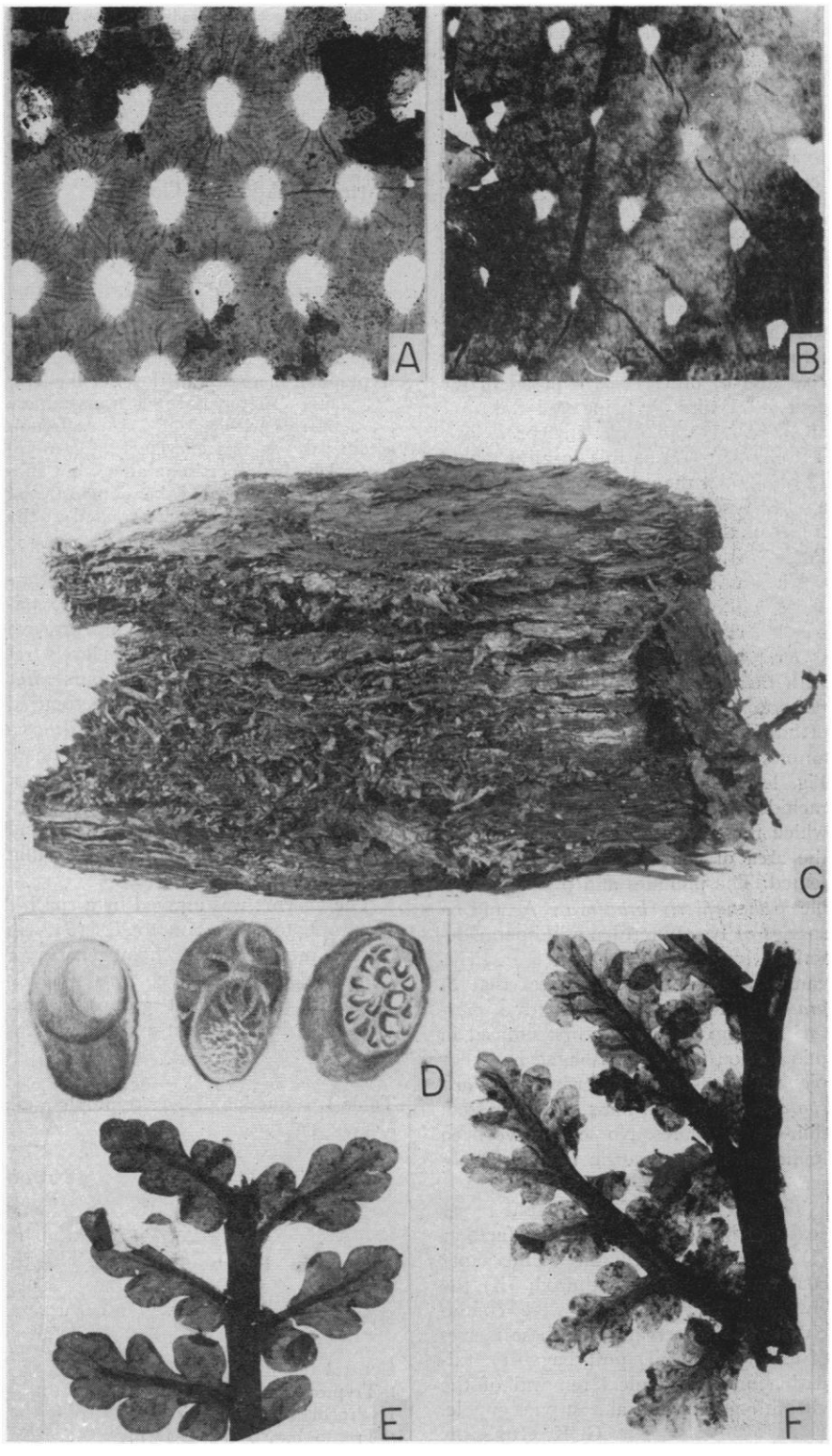

Fig. 1. *A, B,* Cuticle from the Russian paper coal (*7*) (about × 2). *C,* Block of Indiana paper coal (about × ¼). *D,* Drawings of Torispora specimens (about × 250). *E, F,* Parts of pinnae from Indiana paper coal (about × 2).