A NOTE ON THE RELATIVE PHOTOSENSORY EFFECT OF POLARIZED LIGHT.

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I.

Although several considerations lead to the suspicion that an investigation of the stimulating power of polarized light may give useful results, the question seems not to have been put to test. Such a test was planned some years ago when it was realized that in devices employed for study of animal responses controlled by light there is often opportunity for polarization by reflection. The matter is of interest also in connection with the action of moonlight (Semmens, 1923). But that the polarization of moonlight, often slight, is responsible for any pronounced biological effect is still distinctly an open matter (for comment on this point compare Fox, 1923-24). The same must be said for a not inconceivable effect of polarization in diffused light under the surface of ocean water as noted by Brooks (1922). The light produced by such luminous animals as *Mnemiopsis* is unpolarized.

The question is more significant in relation to the possible rôle in photic stimulation of fluorescent substances in the definitely oriented photoreceptive cells of arthropods. Weigert (1920) discovered the polarization of fluorescent light from dyestuffs dissolved in a viscous medium (gelatin). Subsequent investigation (Carelli and Pringsheim, 1923) has shown that dyestuffs devoid of photoluminescence when dissolved in non-viscous media may in a viscous medium show polarized fluorescence when excited by polarized light. This may be understood as resulting from the definite and constrained orientation of anisotropic fluorescing molecules. It may be suggested that a constrained

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orientation should be conceivable in surface films (Langmuir, 1917; Adam, 1922) of one kind or another, as well as in an extremely viscous solvent.

We have made three groups of experiments designed to compare (1) the activating effects of light with different planes of polarization and (2) the relative stimulating efficiencies of polarized and non-polarized lights. The general method in the first two experiments was to record the trail pursued by an organism when illuminated from either side by lights of equal intensity. As shown by Patten (1914) this method is one of very considerable accuracy, with a suitable animal. It is to be expected that a bilaterally symmetrical and negatively phototropic organism, unless its receptor surfaces are effectively parallel (Crozier, 1917), will move in a line perpendicular to the opposed paths of two equally intense beams of light; under certain conditions positively phototropic organisms may also exhibit this behavior. A series of unpublished results obtained by one of us in collaboration with Dr. W. H. Cole shows that the observed mean angular deflection of blow-fly larvæ under a given condition of bilateral illumination is subject to a probable error of about 6 per cent of the mean.

II.

Preliminary trials with blow-fly larvæ at about the age of their maximum sensitivity to light (4 days; Patten, 1916) showed no obvious difference between the effects of polarized and of non-polarized lights of equal intensities (35 m.c.).

We then employed the negatively phototropic land isopod *Cylisticus convexus*. After about 2 hours dark adaptation individual isopods were allowed to creep in a field of opposed beams of polarized light of equal intensity, the plane of polarization of one beam being vertical and of the other beam, horizontal. Polarization was secured by means of two large Nicol prisms. The sources of light were two similar 100 watt tungsten filaments in nitrogen filled bulbs. The intensities (about 45 m.c.) were equalized by means of a Lummer-Brodhun photometer. The isopods crept upon moist filter paper spread upon a large sheet of glass which had been ruled with dark blue coordinate lines. These lines, visible through the moist filter paper, formed a reference grid permitting accurate mapping of the path followed by each isopod upon similarly marked paper.

As found by Patten (1914) with the blow-fly larva and as has been observed with other animals, there is often evidenced a more or less pronounced asymmetry of response. This might be due either to asymmetrical fluctuating variations of peripheral sensitivity, to central conditions affecting crossed transmission tracts, or to differences in the musculature. At all events, its effects upon the trail pursued under bilateral illumination are readily discounted by means of two trails measured for each individual creeping in respectively reversed directions. The isopods were first headed (in the dark) toward source A, then in second trial toward source B. Light from both sources being admitted simultaneously, the organism swung about to a path almost perpendicular to the line connecting the two lights of equal intensity. Light from source A had vertical plane of polarization; that from B, horizontal.

The angle of orientation was measured by means of a 9 cm. protractor. The mean deflection, in forty-four trails of twenty-two isopods, was 68.13°. The failure to assume a path at right angles to the line connecting the sources of light is probably determined by the convexity of the receptive surfaces of the eyes, their obtuse angle with respect to one another, and the shading effect of the carapace. This view is supported by the fact that with lights of higher intensity an angle of more nearly 90° is observed.

If deflections toward light A be termed $+$, those toward B, $-$, a superior stimulating effect of light with one particular plane of polarization should result in a difference between the two mean deflections. But the mean $+$ deflection was $68.02° \pm 2.40°$, the mean $-$ deflection $68.28° \pm 2.92°$. Calculating the ratios between $+$ and $-$ deflections for each isopod, and averaging the deflections, we find that the mean ratio is as 1 to 1.034, the probable error of the mean ratio being $\pm$ 0.035.

A second set of experiments with intensity about 90 m.c. gave the following result.

Average deflection	83.20°
Average $+$ deflection	$83.75° \pm 3.37°$
Average $-$ deflection	$82.66° \pm 3.46°$

Mean ratio of $+ : -$, $1:1.031° \pm 0.052°$.

Clearly, no real difference in stimulating power is discernable in relation to the position of plane of polarization. Since the lights were equalized by visual photometry, it should be pointed out that there is no polarization effect of sensible magnitude in the human eye.

III.

The second series of experiments involved comparing the stimulating values of polarized and non-polarized lights, by the method already described. The animal used was the coral red milkweed beetle, *Tetraopes tetraopthalmus*. Freshly collected animals were allowed to creep in a field of balanced illumination, and the trails recorded.

Since these beetles are *positively* phototropic, it is necessary to consider the theory of the orientation process. It cannot be assumed that in a field of unequally stimulating opposed light beams, a positively heliotropic organism will necessarily orient itself after the fashion of a blow-fly larva. In case the two lights are of unequal effectiveness, the positively phototropic animal would be expected to move toward the more effective light; there is no opportunity to equalize illumination of the two eyes by altering the position of the body axis (Moore, 1923-24). *Vanessa* caterpillars do precisely this (von Buddenbrock, 1917). But the notion, supposedly justified by this fact, that a *negatively* phototropic organism bisects the field between opposed lights because it "seeks out the dark" (Bierens de Haan, 1921) quite fails to explain the relation between the actual angle of path and the ratio between the light intensities (Patten, 1914; Northrop and Loeb, 1922-23). Even with positively phototropic organisms, provided the rate of locomotion be sufficiently high and sideward movements of the head not pronounced, it is to be expected that in the field of almost equally intense opposed lights a path will be followed at an angle of about 90° to that connecting the two sources. Our experience with *Tetraopes* shows this to be the case for the milkweed beetle (*cf.* also Mast and Dolley, 1924).

The results of four series of tests with *Tetraopes* are summarized in the following table; in Sets 2 and 4 the lights were about 50 per cent more intense than in Sets 1 and 3.

Set.	No. of beetles (two trails each).	Mean deflection toward non-polarized light.	Plane of polarization.
1	30	5.12° ± 1.32°	Horizontal.
2	13	6.13° ± 2.52°	"
3	30	4.14° ± 2.12°	Vertical.
4	16	1.29° ± 1.05°	"

In spite of a certain suggestion of uniformity, the differences are within the limit of random error of the observations (differences from 0 angle being less than three or four times the probable error), and no definite evidence is given as to any sensible variations in stimulating power correlated with polarization. Since non-polarized radiation, not passing through a Nicol prism, might conceivably be of effectively different quality than the polarized, a real difference due to polarization would be expected to manifest itself in the relative influences of vertically and horizontally polarized beams.

IV.

A different method of contrasting the effects of horizontally and of vertically polarized light is possible with an animal in which phototropism may be made to counterbalance and to overcome another tropistic response. The larvæ of the beetle *Tenebrio* permit such an experiment (Crozier, 1923-24). Light of adequate intensity falling laterally upon a larva through a vertical glass plate with which the larva creeps in contact, forces orientation away from the glass surface. A definite amount of light (about 134 m.c.) is required to overcome positive stereotropism.

With an optical arrangement designed to give a fairly intense beam of nearly parallel polarized light, the mean critical distances from the source affording just enough light to suppress stereotropism were as follows in two sets of experiments, (*a*) and (*b*).

Experiment.	Results.	
	cm.	
(a)	158	Polarization vertical.
	152	" horizontal.
(b)	150	" vertical.
	153	" horizontal.

The differences are of no significance.

V.

The negative outcome of the experiments does not of course preclude discovery in other animals of the effect sought. Although fluorescent materials as sensitizers in sense organs have been referred to as a source of photic excitation (*cf.* Demoll, 1910; Dubois, 1914), it happens that in at least one case (Crozier, 1920–21) light passed through a fluorescing extract of a skin pigment seems unimpared in its stimulating power for a photosensitive integument. Similar relations obtain in connection with the photodynamic action of fluorescent dyestuffs (Clark, 1918-19). It may prove that in more viscous protoplasmic medium a more intense fluorescence is possible. The arrangement of retinular elements in radial symmetry in each ommatidium of the arthropod eye might be appealed to in explaining the lack of observable specific influence of the plane of polarization.

SUMMARY.

Experiments were made to compare the stimulating effectiveness of vertically and horizontally polarized lights and non-polarized lights of equal intensity upon phototropic movements of the beetle *Tetraopes tetraopthalmus*; and to compare the effectiveness of two light beams polarized at right angles to one another upon phototropic orientation of the land isopod *Cylisticus convexus*. *Tetraopes* is positively, and *Cylisticus*, negatively phototropic. Tests were also made of the intensities of horizontally and of vertically polarized light required to inhibit stereotropism in larvæ of *Tenebrio*. Under the conditions of the tests, no certain qualitative effect connected with polarization could be detected.

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