

THE REACTIONS OF CERIANTHUS TO LIGHT

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It has long been known that direct sunlight (1) will cause *Cerianthus membranaceus* to withdraw its tentacles and body within the sheath which in nature lies beneath the sandy bottom of the sea. On the other hand, a relatively weak light causes prompt heliotropic turning toward the source of light. Since light increases the muscle tone of these animals it is apparent that light as strong as sunlight would operate to draw the animal within its burrow by causing all its muscles to contract. Weak diffuse light causes the muscle tension to increase and the animal to assume a more turgid appearance, while weak directed light causes one side of the animal to contract more than the other, and the oral disk and tentacles to turn toward the light. If, however, the directed rays of light are not of sufficient intensity to cause turning of the oral disk within about 20 seconds, then the animal becomes adapted to the light and does not turn toward it. These very weak intensities of light act like indirect light, since they do not cause orientation of the anterior part of *Cerianthus*, but merely an increase in muscle tone. In such a light, the animal's orientation depends upon stereotropism and geotropism (2).

I.

In former work (3) I made the observation that when *Cerianthus* is illuminated upon one side by an effective light intensity the angle turned by this animal is in some way dependent upon the intensity of the illumination. In order to find the exact nature of this relation, series of experiments were done to measure the angles turned under varying degrees of illumination. The experiments were carried out in

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the dark room, animals being dark-adapted for at least an hour between measurements. The animal to be tested was placed in a rectangular glass dish with parallel sides. The sides except that side nearest the source of light were lined inside with dull black paper, to prevent reflections. The sea water for filling the dish was brought directly from the Bay of Naples and the animal in its natural sheath (mucus with adhering grains of sand) was placed in the dish at right angles to the source of light. The light came from an incandescent concentrated filament electric lamp of known candle power enclosed within a black box and the distance of the lamp from the animal was varied to alter

TABLE I.

Effect of Light Intensity upon the Number of Degrees Cerianthus Turns toward a Source of Light.

Intensity.*	$\log_{10} I$	Angles in degrees. x	Angles calculated. x
2.5	0.397	0.0	[6.8]
4.4	0.643	16.6	17.3
10.0	1.000	31.0	32.3
15.8	1.198	44.0	40.7
36.0	1.556	60.0	55.8
144.0	2.158	75.0	81.2
900.0	2.954	90.0	[114.8]

* 100 candle power at 1 meter is taken equal to 10.0 in the scale of intensities used. The angles were calculated by using the equation $\log_{10} I = \log_{10} b + (m \log_{10} e) x$, where $m = 0.0545$ and $\log_{10} b = 0.2344$.

the intensity. The number of degrees through which the animal turned was measured in the following way. A meter stick was laid across the top of the dish, so that the edge of the stick was parallel with the anterior oriented portion of the animal. With a second ruler this line was reproduced in chalk on the table, and the angle measured with a protractor. Using such a rough method no attempt was made to measure more accurately than to within 5° . Three animals were used, each showing a different sensitivity. Two specimens were large, about 25 cm. in length, while the third was only about 8 cm. The sensitivity of different specimens seemed to be independent of the animal's size or amount of pigmentation. A given series of experi-

ments was always finished in 1 day, since the sensitivity varied slightly from day to day. A certain weak intensity of light is unable to cause heliotropic bending, but stronger and stronger intensities cause the animal to turn through a larger and larger number of degrees until 90° is reached. Obviously it cannot turn more than 90° even if the intensity be still further increased.

If the light intensities are plotted as abscissæ, and the observed number of degrees turned as ordinates, the resulting curves appear to belong to the general group whose equation is $I = be^{mx}$. I represents the intensity of the light, b the y -intercept (the intensity of light which is too weak to produce any response), e the Napierian base of logarithms, m a constant, and x the number of degrees turned by the animal. That the curves may be expressed in this way is proved in the following manner:

If

$$I = be^{mx}.$$

then

$$\frac{I}{b} = e^{mx}.$$

Taking logs,

$$\log_e I - \log_e b = mx,$$

$$\log_e I = mx + \log_e b$$

changing to common logs,

$$\log_{10} I = (m \log_{10} e) x + \log_{10} b.$$

Since $\log_{10} I$ is an independent variable and $\log_{10} b$ a constant, it follows that this equation is of the form $y = mx + b$, which expresses a straight line whose slope is the coefficient of x . Indeed, if $\log_{10} I$ is plotted against the experimental values of x the result is an approximate straight line whose theoretical constants may be easily calculated. Since the experimental values so plotted result in a straight line we have proved the original relationship to be a simple exponential one. In other words, the effect, or number of degrees turned is proportional to the logarithm of the intensity of the light.

This relationship between intensity of stimulus and effect upon the sensory-motor mechanism is a common one among animals (4).

Average figures from seven series of experiments with seven intensities of light are given in Table I. The plots are shown in Fig. 1. The theoretical curve follows the calculated constants.

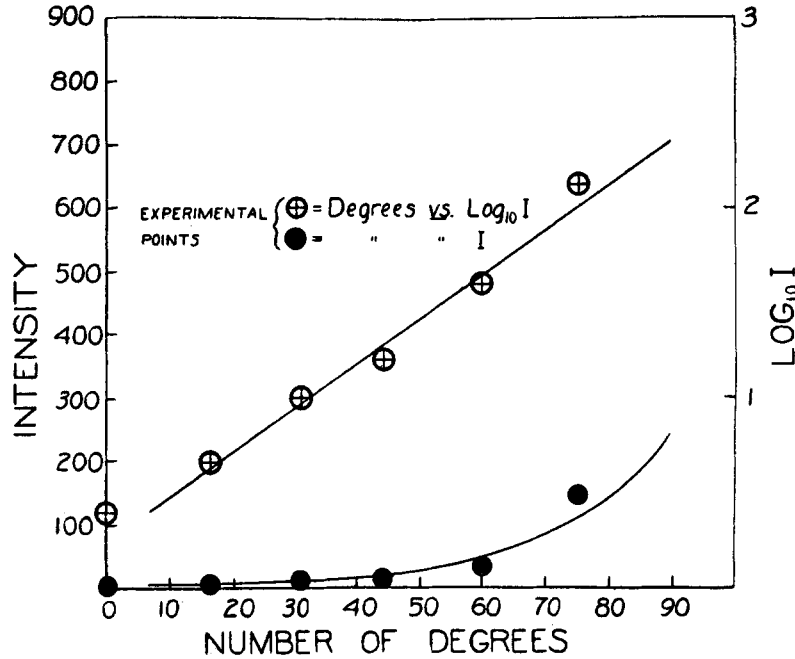


FIG. 1.

II.

If the intensity of the light be still further increased the positive heliotropic bending of the animal is interfered with by the sudden contraction of all its muscle and consequent withdrawal within its sheath. This retraction is the same as that caused by sunlight. Experiments with animals fresh from the sea showed that retraction may be caused by an intensity of between 250 meter candles, for a sensitive specimen, to 4000 m.c. for a less sensitive one. After *Cerianthus* has been kept in the laboratory for some time, however, it becomes adapted to higher intensities so that as high as 10,000 or 15,000 m.c.

may be necessary to cause retraction in such a specimen. When a strong light is thrown upon *Cerianthus*, the edge of the animal's oral disk is first curled over toward the light. This edge carries the rows of tentacles so that by watching them the exact second when motion begins can be observed. Then several seconds elapse before the whole animal begins to retract as a result of the strong light. The positive heliotropic bending is therefore interrupted by the sudden contraction of muscles which reduces the animal's size and draws it within its mucoïd sheath. One sensitive animal gave these relations: At 1000 m.c. the average number of seconds between the first turning of the side of the disk and retraction was 7.5; at 4000 m.c., 6.0 seconds. This relationship makes it clear how positive turning is the only effect at weaker intensities since the time between positive turning and retraction grows longer, *i.e.* approaches infinity as a limit; while at higher intensities the time approaches zero. Thus, the only effect of direct sunlight is a prompt retraction.

III.

C. Hess (5) stated that experiments with colored lights which he repeated with different modifications were without results; that he obtained no movements of these animals after putting red or blue glasses between the aquarium and a strong Nernst lamp. I repeated his experiment, using a set of Wratten filters (numbered 70 to 76) and a small concentrated filament lamp of approximately 100 candle power and obtained a definite bending of the oral disk and movement of tentacles on the lighted side under blue (76), blue-green (75), green (74), and yellow (73) light, but no movement under orange or red light (72, 71A, 70). It occurred to me that with a stronger light I might obtain responses to other parts of the spectrum, and this was indeed the case. But before reporting the experiments I must discuss the means used for gaining a fair estimate of the intensity of the colored light which was absorbed by the animal.

When *Cerianthus* is exposed to different intensities of white light with suitable periods for dark adaptation between exposures, the animal reacts to the light in less and less time as the intensity of the light is increased. This relationship between reaction time and light intensity has been investigated for *Cerianthus* (2) and found to be

expressed by the well known Bunsen-Roscoe law. Data obtained this season from six small specimens of *Cerianthus* about 8 cm. long are given in Table II. Fig. 2 also shows the resulting straight line when $\log_{10} I$ is plotted against $\log_{10} t$. This proves that $I \times t = k$ where I represents intensity, t the reaction time of *Cerianthus*, and k is a constant.

In this work we are concerned with the chemical effect of the light. The activity of light is considered to be proportional to its "chemical" absorption. Now "chemical" absorption is purely an abstract concept; its existence has never been proven experimentally. However, light, in order to produce a photochemical effect must be absorbed, hence the statement that "only the light which is absorbed is active

TABLE II.
Effect of Light Intensity upon Reaction Time.

Distance of light.	Intensity.*	Average reaction time.
<i>cm.</i>		<i>sec.</i>
400	1.5	11.0
300	2.7	10.0
200	6.2	9.3
150	11.1	8.6
100	25.0	8.1
75	44.4	7.5
50	100.0	6.1

* These experiments were done with a 500 watt concentrated filament lamp placed at varying distances from the animal.

in producing chemical change (6)." But the converse, that all light which is absorbed gives rise to chemical action is not proven, although the absorption spectrum of a chemical system is intimately connected with its photochemical behavior.

It is clear therefore that the degree of physical absorption of light by the animal cannot be taken as a measure of the quantity of light "chemically" absorbed by the photoreceptor substance of the animal. It is also obvious that the use of energy measurements for the purpose of comparing lights is valid only for lights of the same wave lengths. Photometer measurements of light intensity yield values which are

necessarily true only for the human retina. From these considerations it follows that in a given animal the only adequate measure of the "chemical" intensity of the light is the velocity of the photochemical reaction in that animal. And since we have shown that the Bunsen-Roscoe law holds for *Cerianthus*, we may consider reaction time as

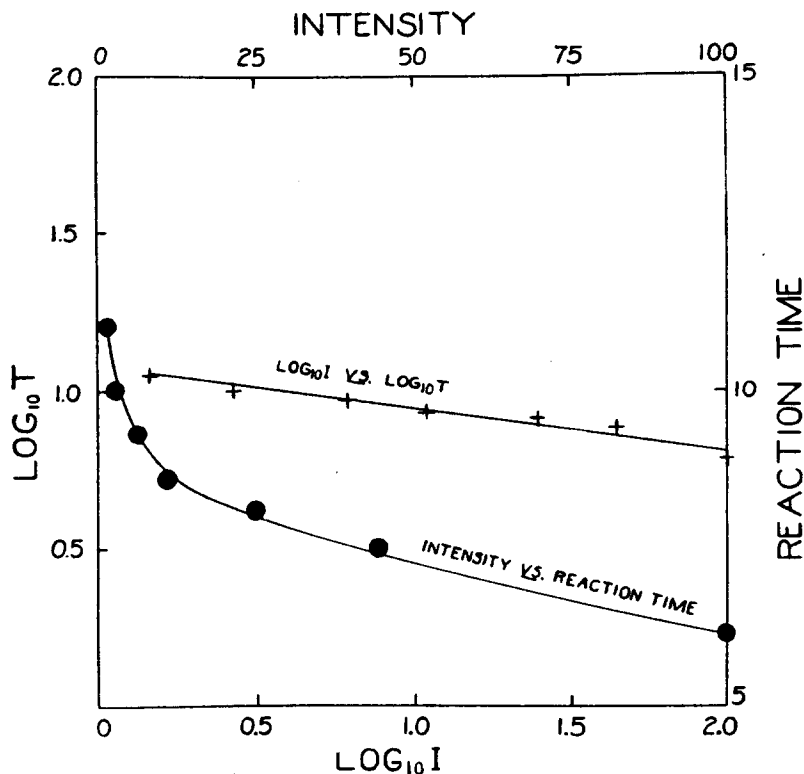


FIG. 2.

the reciprocal of the rate at which photochemical changes are brought about in the animal, and, therefore, of the photochemically effective intensity of the incident light.

The absorption curves of the Wratten filters used to obtain monochromatic light in these experiments have been carefully determined spectrophotometrically. The percentage transmissions at wave lengths 10 millimicrons apart are shown on pages 68 and 69 of Wratten

light filters (7th edition, revised), published by the Eastman Kodak Company. Total percentages transmission of these filters as found by the spectrophotometer are shown in Table III. The experiments with colored lights were carried out as follows: A 2000 watt lamp which Dr. Selig Hecht kindly loaned me was enclosed in a dark box. Light came onto the optical bench through a square opening. Between it and the Wratten filter was interposed a water screen to absorb heat, and the small aquarium containing the dark-adapted animal was set 44 cm. from the lamp. The same specimens of *Cerianthus* mentioned above were used in these experiments. They were of

TABLE III.
Effect of Wave Length upon Reaction Time.

No. of filter.	Mean wave length.	Reaction time.	Calculated relative intensity.	Apparent percentage intensity from reaction time.	Percentage transmission from spectrophotometer.	Intensity Transmission
		<i>sec.</i>				
White.	Control.	7.0	81.8	100.00	100.00	1.0
70	680 dark red.	No response.	—	—	6.7	0
71A	653 red.	16.3	0.219	0.26	2.3	0.11
72	612 orange.	16.9	0.302	0.37	1.0	0.37
73	578 yellow.	13.4	0.386	0.47	0.93	0.50
74	532 green.	10.9	1.621	1.98	1.2	1.65
75	492 blue-green.	11.4	1.085	1.32	2.07	0.63
76	450 blue.	13.2	0.338	0.41	1.19	0.34

varying sensitivity, but since the same animals were used for all the experiments with colored lights the averages represent true differences between the effectiveness of different parts of the spectrum. The relative effect of different colors was measured by taking the reaction time; that is, the time between exposure and the beginning of movement of the tentacles nearest the source of light. The end-point used was therefore the same in all the experiments. Not all the animals responded to every exposure to colored light, but at some time during the course of the experiments, one or another of the animals responded to every part of the spectrum except the dark red. I was never able to observe any response to this wave length.

Since the averages of reaction times determined experimentally bear a mathematical relation to the effective intensities of the light transmitted by the filters, I have calculated these intensities from the equation of the straight line shown in Fig. 2. This equation is

$$\log I - 9.3995 = - 8.86 \log t,$$

and was derived in the usual way. The intensities in per cent, taking the intensity of the white light as 100 per cent, are shown in Table III.

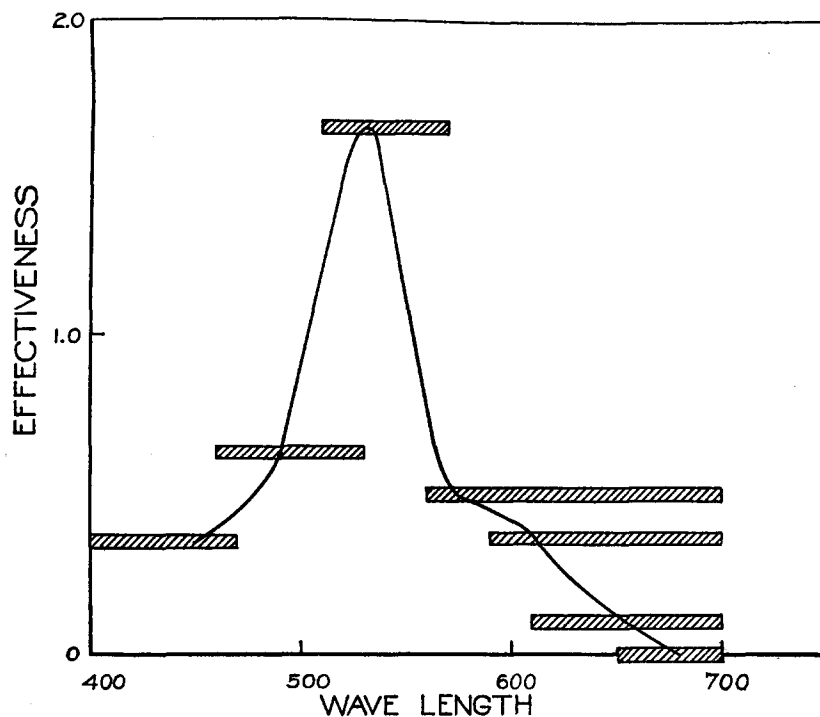


FIG. 3.

The reaction times given in Table III are averages of eighteen exposures. If we consider the percentage transmission as shown by the spectrophotometer as a measure of the actual intensity of the light which fell on the animal, and compare this with the apparent percentage intensity of the same light as measured by the reaction time of the animal, we obtain a quotient which gives us a value for

the relative effectiveness of different parts of the spectrum with respect to the animal. These values are also shown in Fig. 3, the line being drawn through points of mean wave length. From these figures it becomes apparent that for *Cerianthus* light of mean wave length $\mu\mu$ 532 (green) is the most effective part of the spectrum.

CONCLUSIONS.

1. When *Cerianthus membranaceus* is illuminated upon one side, the animal turns its anterior portion toward the source of light. The number of degrees through which the animal turns is proportional to the logarithm of the intensity of the light.
2. A light intensity of between 250 m.c. and 15,000 m.c. is necessary to cause retraction of the animal.
3. The part of the spectrum which is most effective in causing heliotropic bending of *Cerianthus* lies between $\mu\mu$ 510 and $\mu\mu$ 570.

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