THE REACTIONS OF CERTAIN CLADOCERA TO COLORED LIGHTS OF EQUAL INTENSITY.

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I. INTRODUCTION.

It is well known that cladocera are, at most times, sensitive to light. This fact has given rise to a number of investigations on the relative sensitivity of these animals to light of different wave-lengths.

Experiments of this nature were first performed by Bert (1869). He exposed Daphnia to light from different portions of an electric light spectrum, and found that the animals gathered most rapidly in the green and yellow-green, although they were positive to all colors. Similar results were obtained by Lubbock (1881), Hess (1910), Loeb and Maxwell (1910), Ewald (1914), and Borowski (1927). All these investigators used colored lights produced by a prismatic spectrum, although Lubbock and Ewald also employed colored filters.

Yerkes (1900) found that *Simocephalus vetulus* gathered in the yellow of a Welsbach burner prismatic spectrum, but that when a triangular prism containing India ink was placed between the source of light and the animals, so that the intensity of the red end of the spectrum was cut down to a much greater extent than that of the violet, they tended to aggregate in the blue and violet.

v. Frisch and Kupelweiser (1913), working with Daphnia, found that the animals, which became negative when the light intensity was decreased, and positive when it was increased, were positive to green, yellow, and red, although the intensity was raised, and negative to violet, blue, and blue-green, although the intensity was decreased. Similarly, Becher (1921), using colored solutions, found that *Daphnia magna* was positive to green, yellow, and red, and negative to blue and violet. Koehler (1921) obtained similar results with isolated portions of a prismatic spectrum.

Peters (1926), using a method similar to that of Becher, carried out investigations on a number of species of cladocera. For most of the species he obtained results similar to Becher's.

Scapholeberis mucronata and *Peracantha truncata*, on the other hand, were found to be positive to blue and negative to other colors.

The results obtained by these investigators agree fairly well, but their methods are, in certain respects, subject to criticism. In most cases the apparatus was neither standardized nor calibrated. Various sources of light were used. Often the wave-length transmissions of the colors used were not known. The most common fault was that of ignoring the effect of intensity, and ascribing the effects of colors to wave-length alone.

In order to ascertain quantitatively the relative stimulating effect of different wave-lengths on an organism, it is necessary to eliminate any effects which may be due to differences in intensity, either by making a correction in the results for such differences (Mast, 1917), or by using colors of equal intensity (Visscher and Luce, 1928). In none of the experiments on cladocera were either of these methods used.

The present investigation was undertaken with the object of making a comparative study of the stimulating effect of colored lights of equal intensity on certain species of cladocera.

The author is indebted to Dr. J. P. Visscher, who suggested this investigation, for his helpful suggestions and advice during the course of the work.

II. MATERIALS AND METHODS.

1. *Selections of animals for experiments:*

Investigations were carried out on the following four species: *Daphnia pulex*, *Daphnia magna*, *Moina brachiata* and *Leptodora kindtii*.

Daphnia pulex and *Moina brachiata* were collected in ponds in the vicinity of Cleveland. They were raised in the laboratory in a culture medium made up of unicellular forms of algae growing in Moore's solution, which was made up according to the following formula:

Distilled water	1 liter
NH_4NO_3	0.5 gms.
$KH_2\ PO_4$	0.2 "
$Mg\ SO_4$	0.2 "
$Ca\ C_{12}$	0.1 "
$Fe\ SO_4$ (1% soln.)	10 minims

The formula for this culture medium was taken, with some modification, from one originally used by Klugh (1927).

It is well known that the cladocera normally reproduce parthenogenetically. The eggs are laid in a brood chamber situated between the carapace and dorsal body wall. Here they remain until they are released, producing young animals which are like the adults in appearance. Consequently, it was an easy matter to obtain animals which were not only of the same age, but also alike in genetic constitution. The proceedure was as follows: The individuals of a single brood of young were isolated. When these reached maturity, and produced young, the successive broods were separated. These were used in experiments within twenty-four hours after the first brood had been released. Only females were used, the males being discarded in the few instances in which they occurred.

Specimens of *Daphnia magna* were obtained from a clone derived from a stock kept by Banta at Brown University, and were grown in a manure infusion, made by steeping manure in tap water for a few days, and then straining through several layers of cheesecloth (Banta, 1921). Animals were selected for use in experiments in the same manner as with *Daphnia pulex* and *Moina brachiata*.

The work on *Leptodora kindtii* was done at Franz Theodore Stone Laboratory, at Put-in-Bay, Ohio, in the first week of August, 1931. This species was fairly numerous in bottom tows made in the lake with a number twelve mesh tow net. It was found that the animals could not be kept in the laboratory for more than two or three days, so collections were made every morning, and the animals used the same day. Only adult females were used; these could be readily distinguished by the presence of a brood chamber.

It is desirable, during the course of experiments with colored lights, to keep the animals in a colorless culture medium. Since the medium used for *Daphnia pulex* and *Moina brachiata* was slightly green in color, and that used for *Daphnia magna* was brown, it was necessary to transfer the animals to another medium. A satisfactory one was obtained by filtering the original algal medium, so that practically all the algae were removed. To this the animals were transferred several hours before the experiment. For Leptodora, filtered lake water was used.

Although the animals grown in the laboratory were not kept at a constant temperature, their growth-rate was fairly constant. *Daphnia pulex* released the first brood of young in seven to eight days, *Moina brachiata* in five to six days, and *Daphnia magna* in twelve to thirteen days. The temperature at which the experiments were performed varied between 19.5° C. and 21.5° C. The temperature of the dark room used in the work with *Leptodora kindtii* was somewhat higher, varying between 25.5° C. and 26.5° C.

2. *Apparatus:*

The apparatus used in these experiments is essentially the same as that used by Visscher and Luce (1928). In fact, the lamps and filters used in this work, which were generously loaned to me by Dr. J. P. Visscher, are the identical ones used in their investigations. Since these are fully described in their paper, only a brief description will be given here.

Thirteen filters were used, of which eight were Corning glass filters, and five Wratten filters. They are listed in Table I, together with their spectral transmissions, dominant wave-lengths, and relative energy transmissions, as given by the distance at which the lamp must be placed for each filter to make the energies equal.

It will be noted that the first three filters in the series transmit some red. It is impossible to obtain a filter for the ultra-violet end of the spectrum, which does not transmit some red. There is no way of blocking out this red, without also blocking out some of the blue or ultra-violet. Since the amount of red transmitted is relatively small, it was decided best to use the filters as they were, and attempt a correction for the red later. This correction was made by determining the percentage of red transmitted, and deducting that from the total value obtained in the experiments.

The lamp used was a 100 watt, 115 volt, gas filled Mazda lamp, which carried, during experiments, the regular city current of 110 volts. The infra-red rays were absorbed by a copper sulfate filter two centimeters thick, and filled with a solution consisting of 57 grams of copper sulfate in two liters of water.

The apparatus was set up as shown in Figure 1. The lamp was enclosed in a light-proof box, with an opening about 5 centimeters in diameter. A copper sulfate cell was placed in front of the opening. The box was movable, and mounted on a track. The aquarium in which the animals were placed was 40 millimeters square, and 20 millimeters deep, and made of a high grade of slide glass, cemented together with De-Khotinsky cement. A line was marked across the bottom, dividing it into halves, one half toward the source of light, the other away from it. The aquarium was mounted on a stand containing a small microscope lamp, which could be used to light the aquarium from below, thus facilitating the counting of the animals. Between the lamp and the aquarium was

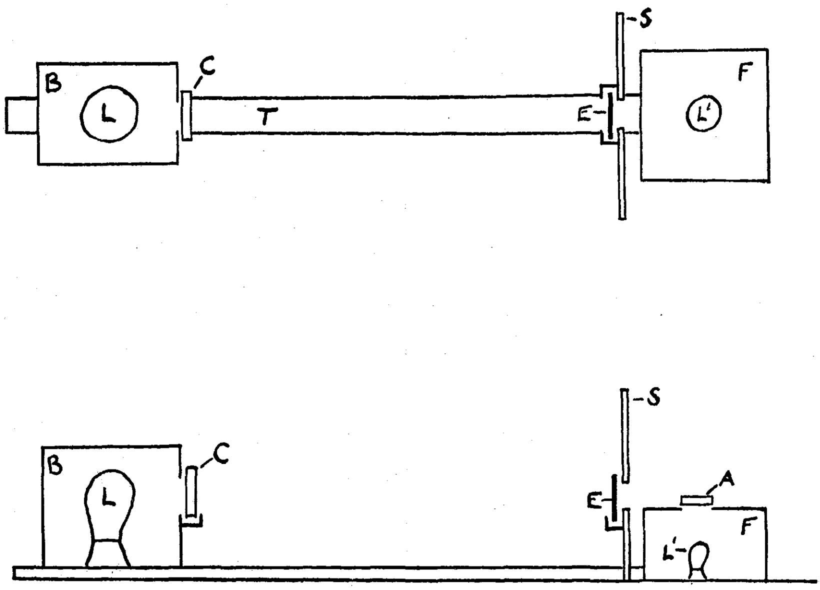

FIGURE 1. Diagrams to illustrate the apparatus used in the experiments. T, track for box (B) containing lamp (L). C, copper sulphate filter in front of opening in box. S, screen holding filters (E). F, aquarium stand containing microscope lamp (L′). A, aquarium.

placed a screen, containing an opening 5 centimeters in diameter, and a slot for the filters. The screen, stand, and lamp box were covered with heavy black paper, and the entire apparatus set up in a dark room.

3. *Method:*

When exposed to white light, *Daphnia pulex* and *Moina brachiata* were found to be neutral, and *Daphnia magna* and *Leptodora kindtii* negative. It was found, however, that they became positive when exposed to certain monochromatic lights. The method used in the experiments is based on this observation.

In carrying out an experiment, a number of animals from a single brood, usually about ten, were placed in the aquarium, and left for several hours in the dark room, to allow them to become dark adapted. They were then exposed to light. They were given three exposures of one minute each (two minutes in the case of *Daphnia pulex*) to each filter, with the

TABLE I.*

LIST OF FILTERS USED, SHOWING THEIR TOTAL SPECTRAL TRANSMISSION, DOMINANT WAVE-LENGTHS, AND THE DISTANCE OF LAMP FROM AQUARIUM FOR EACH.

Filter	Total Transmission	Dominant Wave-Length	Distance of Lamp from Aquarium
Ultra C83	315–428 μμ 609–Red End	355 μμ	24.9 cm.
Purple C69	310–485 μμ 690–Red End	370 μμ	42.4 cm.
Purple W35	300–475 μμ 650–700 μμ	420 μμ	44.4 cm.
Blue W49	400–510 μμ	440 μμ	52.6 cm.
Blue C60	335–640 μμ	460 μμ	81.5 cm.
Blue C59	335–690 μμ	480 μμ	93.2 cm.
Blue-green C56	340–700 μμ	505 μμ	100 cm.
Green C52	425–670 μμ	530 μμ	65.6 cm.
Green W58	485–635 μμ	540 μμ	63.2 cm.
Yellow W15	500–700 μμ	590 μμ	102.3 cm.
Orange W22	545–700 μμ	620 μμ	83.0 cm.
Orange C38	540–Red End	640 μμ	77.3 cm.
Red C19	620–Red End	700 μμ	49.2 cm.
White Light	....	....	119.2 cm.

The letter "C" after a filter denotes a Corning glass filter. The number after the Corning Glasses refer to the transmission curves shown in Bureau of Staudards Technologic paper 148. The letter "W" denotes a Wratten filter, and the number refers to the transmission curves found in the booklet, "Wratten Filters," published by the Eastman Kodak Company.

*All but the last column of this table is taken from Visscher and Luce (1928).

lamp placed at the proper distance (see Table I). A dark period of twenty seconds was allowed between exposures. In each case, the number of animals in the half of the aquarium toward the light was counted.

It was found that the animals became more positive to light after a series of experiments than they had been at the start. The reaction to the colors, however, was the same, regardless of the order in which they were used. That is, the reaction to a given filter was the same whether it was used at the beginning or at the end of a set of experiments.

III. RESULTS.

In Table II are given the results of several series of experiments on *Moina brachiata*. Tables III, IV, and V give results similarly obtained for *Leptodora kindtii*, *Daphnia magna*, and *Daphnia pulex*. These results are shown more graphically in Figure 2. It is immediately evident from the curves in this

TABLE II.

RESULTS OF EXPERIMENTS TO DETERMINE THE DISTRIBUTION OF STIMULATING EFFICIENCY AMONG DIFFERENT PORTIONS OF THE SPECTRUM OF EQUAL ENERGY CONTENT, FOR MONIA BRACHIATA. THE FIGURES GIVEN IN EACH SET OF EXPERIMENTS ARE THE TOTAL NUMBERS OF ANIMALS POSITIVE TO EACH LIGHT IN THREE EXPOSURES.

Moina brachiata.

Average temp. = 21.0° C.

Experiments	Animals per Experiment	Filters												
		C83	C69	W35	W49	C60	C59	C56	C52	W58	W15	W22	C38	C19
1.......	7 animals	3	8	12	12	14	13	12	17	17	10	12	20	12
2.......	5 "	1	3	2	6	4	4	6	9	13	13	13	14	10
3.......	11 "	13	19	21	23	14	16	18	21	20	15	14	14	11
4.......	10 "	14	14	12	19	14	12	15	17	20	19	21	20	15
5.......	10 "	10	16	16	20	16	19	12	19	20	14	17	17	11
6.......	12 "	18	12	22	20	19	22	27	28	26	22	30	28	20
7.......	12 "	20	16	21	17	16	18	16	14	9	15	15	17	8
8.......	12 "	15	16	21	13	14	16	15	20	19	18	15	17	10
9.......	10 "	27	28	26	26	26	27	25	26	28	28	24	28	21
10.......	11 "	10	13	9	12	13	12	16	17	20	17	18	16	19
Total....	100 animals	131	145	162	168	150	159	162	188	192	171	178	191	137
Percent positive	....	43.7	48.3	54.0	56.0	50.0	53.0	54.0	62.7	64.0	57.0	59.3	63.7	46.3
Corrected for Red	....	42.5	46.8	52.4										

figure that the red end of the spectrum is greater in stimulating effect than the blue end. The maximum is in the orange, at about 640$\mu\mu$ for *Daphnia pulex* and *Leptodora kindtii*, and at about 620$\mu\mu$ for *Daphnia magna*. In the case of *Moina brachiata*, there are two maxima of equal efficiency, one in the green at about 540$\mu\mu$ and the other in the orange at about 640$\mu\mu$. There is also a secondary maximum in the blue at about 440$\mu\mu$, not very pronounced for *Leptodora kindtii*, but more definite for the other forms.

It is interesting to note that although the distribution of stimulating effect is similar in these forms, there are differences in the curves for each species. Those for *Daphnia pulex* and *Leptodora kindtii* are most alike. That for *Daphnia magna* differs from these in that the maximum is slightly different, and that the stimulating effect of green is relatively less. While

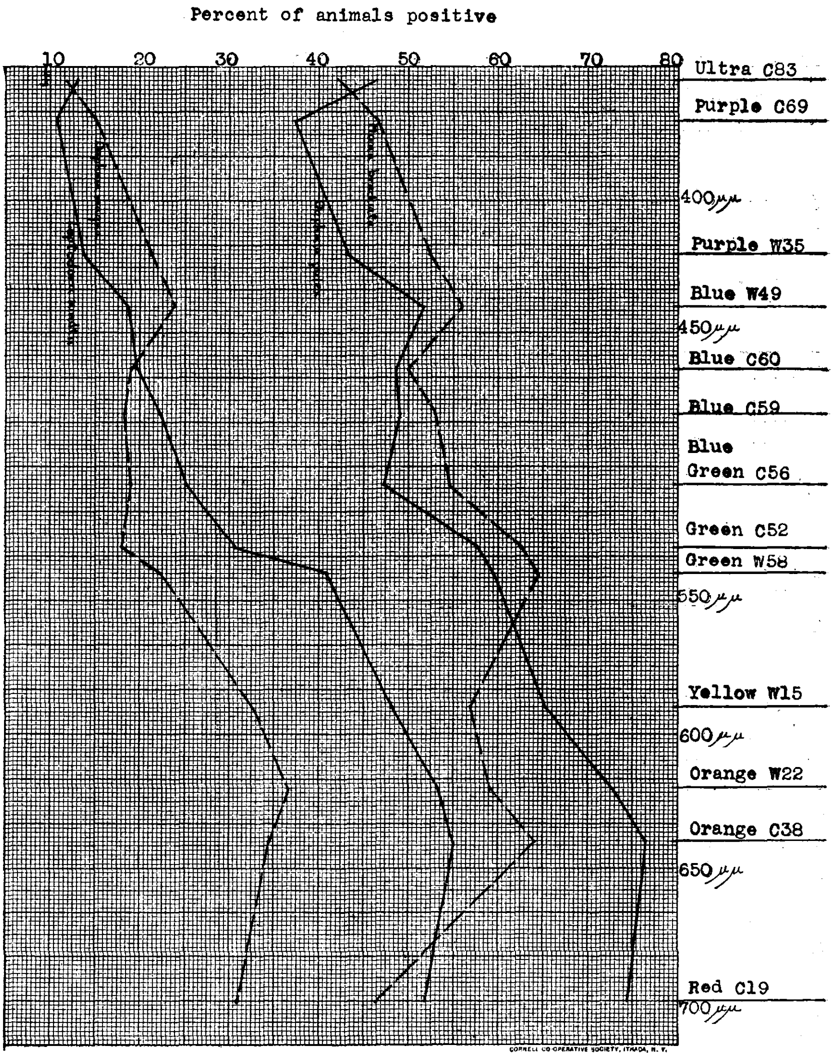

FIGURE 2. Curves showing the distribution of stimulating efficiency among colors equal in radiant energy content.

the curve for *Moina brachiata* appears markedly different from the others, it may be noted that it is quite similar to that for *Daphnia pulex* from the violet through the green; after that the effect is relatively much greater in the latter form.

There is, in the case of *Daphnia pulex* and *Leptodora kindtii*, a slight increase in effect toward the ultra-violet, while in the

TABLE III.

RESULTS OF EXPERIMENTS TO DETERMINE THE DISTRIBUTION OF STIMULATING EFFICIENCY AMONG DIFFERENT PORTIONS OF THE SPECTRUM OF EQUAL ENERGY CONTENT, FOR LEPTODORA KINDTII. THE FIGURES GIVEN IN EACH SET OF EXPERIMENTS ARE THE TOTAL NUMBERS OF ANIMALS POSITIVE TO EACH LIGHT IN THREE EXPOSURES.

Leptodora kindtii.

Average temp. = 26.0° C.

Experiments	Animals per Experiment	FILTERS												
		C83	C69	W35	W49	C60	C59	C56	C52	W58	W15	W22	C38	C19
1.......	7 animals	5	2	3	5	6	6	5	8	9	6	10	11	8
2.......	8 "	4	5	4	6	6	4	5	7	9	13	13	14	17
3.......	10 "	11	10	9	11	11	8	11	11	12	15	12	10	13
4.......	8 "	4	1	3	6	4	6	8	11	14	14	18	17	16
5.......	10 "	3	2	2	2	3	4	6	10	16	16	20	24	22
6.......	8 "	1	0	2	5	5	6	3	9	11	12	13	15	15
7.......	9 "	4	4	7	6	13	13	12	11	15	14	17	16	18
8.......	10 "	2	2	6	3	5	5	6	9	13	21	16	19	17
9.......	10 "	4	4	2	3	3	3	4	3	6	9	11	10	7
10.......	10 "	2	4	4	4	6	6	7	11	9	11	12	14	14
11.......	10 "	3	3	4	5	6	6	6	9	12	14	18	15	8
Total....	100 animals	43	37	46	56	59	67	75	92	126	145	160	165	155
Percent positive	....	14.3	12.3	15.3	18.7	19.7	22.3	25.0	30.7	42.0	48.3	53.3	55.0	51.7
Corrected for Red	....	13.1	10.8	13.7										

other two species, the efficiency is lowest in this region. It would have been desirable to test this region further, but this was not possible with the apparatus used, since light from a tungsten filament does not penetrate far into the ultra-violet.

It is also interesting to observe that the effect of red is rather high in three of the species; in fact it is almost as great as that of orange. For *Moina brachiata*, on the other hand, it is scarcely higher than the effect of violet.

IV. DISCUSSION AND CONCLUSIONS.

It is apparent that the results of these experiments differ from those of previous investigators, first, in that here the efficiency of the orange is greater than that of the green, or at least equal to it (*Moina brachiata*), and second, in that here the efficiency of red is relatively high, being, with the exception

TABLE IV.

RESULTS OF EXPERIMENTS TO DETERMINE THE DISTRIBUTION OF STIMULATING EFFICIENCY AMONG DIFFERENT PORTIONS OF THE SPECTRUM, OF EQUAL ENERGY CONTENT, FOR DAPHNIA MAGNA. THE FIGURES GIVEN IN EACH SET OF EXPERIMENTS ARE THE TOTAL NUMBERS OF ANIMALS POSITIVE TO EACH LIGHT IN THREE EXPOSURES.

Daphnia magna.

Average temp. = 21.0° C.

Experiments	Animals per Experiment	Filters												
		C83	C69	W35	W49	C60	C59	C56	C52	W58	W15	W22	C38	C19
1.......	6 animals	1	2	1	0	5	5	2	0	1	4	3	6	9
2.......	9 "	1	3	7	3	2	1	3	5	7	6	8	5	9
3.......	14 "	2	7	6	5	2	2	7	5	7	11	16	10	10
4.......	8 "	4	1	9	5	7	8	8	8	8	13	17	17	10
5.......	7 "	7	6	7	6	5	5	6	5	6	8	8	11	9
6.......	13 "	2	3	5	6	4	3	4	4	7	6	10	0	4
7.......	8 "	7	10	11	13	9	11	9	11	11	18	16	16	13
8.......	10 "	3	5	7	12	6	3	2	1	3	8	13	9	9
9.......	12 "	3	3	7	8	6	5	7	4	5	6	5	7	12
10.......	13 "	9	10	9	13	11	12	9	11	12	18	14	14	6
Total....	100 animals	39	50	69	71	57	55	57	54	67	98	110	104	93
Percent positive	....	13.0	16.7	23.0	23.7	19.0	18.3	19.0	18.0	22.3	32.7	36.7	34.7	31.0
Corrected for Red	....	11.8	15.2	21.4										

of *Moina*, higher than that of the green. On the other hand, the results are similar to those obtained by v. Frisch and Kupelweiser, Becher, Koehler, and Peters, in that the animals are, as a rule, more positive to green, yellow, orange, and red, than to blue and violet. The only exception to this is *Daphnia magna*, which is about equally positive to green and blue.

The explanation of the discrepancies between these results and others may lie in one or more of the following factors; physiological condition; age; or the distribution of radiant energy in the spectrum.

The results in question were obtained with animals positive to light. The animals used in these experiments were either neutral (*Daphnia pulex*, *Moina brachiata*) or negative (*Daphnia magna*, *Leptodora kindtii*) to white light. Mast (1917) has shown that for certain organisms the distribution of stimulating effect is the same whether the organisms are positive or negative

TABLE V.

RESULTS OF EXPERIMENTS TO DETERMINE THE DISTRIBUTION OF STIMULATING EFFICIENCY AMONG DIFFERENT PORTIONS OF THE SPECTRUM, OF EQUAL ENERGY CONTENT, FOR DAPHNIA PULEX. THE FIGURES GIVEN IN EACH SET OF EXPERIMENTS ARE THE TOTAL NUMBERS OF ANIMALS POSITIVE TO EACH LIGHT IN THREE EXPOSURES.

Daphnia pulex.

Average temp. = 21.5° C.

Experiments	Animals per Experiment	Filters												
		C83	C69	W35	W49	C60	C59	C56	C52	W58	W15	W22	C38	C19
1.......	10 animals	11	8	12	8	15	13	8	10	14	17	20	24	19
2.......	10 "	16	11	10	10	14	18	20	20	22	25	23	26	23
3.......	10 "	12	9	8	12	11	10	7	15	22	20	23	22	23
4.......	10 "	15	11	12	17	15	13	16	16	23	19	21	25	25
5.......	10 "	18	17	17	24	21	20	22	24	24	19	24	23	27
6.......	10 "	17	12	13	23	22	22	21	23	18	22	22	19	17
7.......	10 "	18	16	14	16	18	16	13	20	19	19	21	23	19
8.......	10 "	14	10	19	14	8	14	10	16	10	14	14	20	21
9.......	9 "	10	10	12	16	9	7	8	9	9	15	23	22	26
10.......	6 "	5	7	11	7	6	7	10	12	9	16	16	14	12
Total....	95 animals	136	111	128	147	139	140	135	165	170	186	207	218	212
Percent positive	....	47.7	38.9	44.9	51.6	48.7	49.1	47.4	57.9	59.6	65.3	72.6	76.5	74.4
Corrected for Red	....	46.5	37.4	43.3										

to light. Although this has not been definitely shown for cladocera, it is rather to be expected, particularly if the distribution of stimulating effect depends on the presence of a fixed photosensitive substance. Consequently, the factor of physiological condition is, to a great extent, ruled out. A series of experiments on positively phototropic animals would be required, however, to settle this point definitely.

It is known that the phototropic reactions of cladocera change with age. Newly hatched animals are positive to light at all temperatures. As they grow older, however, they become neutral or negative to light, and are positive only at low temperatures, the range depending on the particular species. This indicates primarily a change in physiological condition, but there is also a possibility that the nature of the photosensitive substance may change with age. In previous work, animals in various stages of development were used; here, the animals used were as nearly as possible of the same age. However, since animals of only one age were used, nothing definite can be said here concerning this factor.

It may be noted that in practically all previous investigations with Daphnia, in which the region of maximum efficiency was found to lie in the green or yellow, the monochromatic light was produced by a prismatic spectrum. The radiant energy of a prismatic spectrum increases from the blue to the red, slowly at first, then more rapidly (Mast, 1911, p. 306; 1917, p. 490). Thus, the radiant energy of the orange and red used in such experiments is much greater than that of the green and yellow. It is quite probable that the energy of the orange and red was, in cases where a prismatic spectrum was used, too great to elicit a positive response, especially since these animals are positive only within a limited range of intensities. With colors equal in energy, however, such a probability is eliminated; here the response to color is not hidden by an opposite response to intensity. This factor is the one which most readily explains the discrepancies between the results of these and previous investigations.

It may be concluded, accordingly, that the animals investigated are more strongly stimulated by some wave-lengths than by others, when the intensity of the various wave-lengths is equal. There is a region of maximum stimulating efficiency in the orange (620–640$\mu\mu$) for all the species investigated, and also an equal maximum in the green at about 540$\mu\mu$ for *Moina brachiata.* The stimulating effect falls off greatly toward the violet end, with a secondary maximum in the blue at about 440$\mu\mu$, and very little toward the red, except in the case of *Moina brachiata.* That these reactions are specific effects of the wave-lengths involved, and are not due merely to the amount of ultra-violet transmitted by each filter, as Becher maintains, is evident from the fact that not only is little ultra-violet transmitted by any but the purple filters, but whatever is transmitted is almost completely absorbed by the three layers of glass through which the light passes.

A comparison of the curves in Figure 2 warrants the further conclusion that the photosensitive substances in these four species, although fundamentally similar, are specific for each species. It is interesting to note that the curve for *Daphnia pulex* is more similar to that for *Leptodora kindtii* than it is to that for *Daphnia magna.* This indicates, as do the results of Mast (1917) and Hecht, (1928), that distribution of stimulating effect in the spectrum is not correlated with the degree in which the species are related.

V. SUMMARY.

1. Four species of cladocera (*Moina brachiata*, *Leptodora kindtii*, *Daphnia pulex*, and *Daphnia magna*) were exposed to a series of thirteen colored lights of equal intensity, and the percentages of the total number positive to each light determined.

2. Orange light (620–640$\mu\mu$) was found to have the maximum stimulating effect for all the species investigated. For *Moina brachiata*, the efficiency of green light (about 540$\mu\mu$) was approximately equal to that of orange. The discrepancy between these results and those of previous investigators, who maintained that green light had the maximum stimulating efficiency, is most probably due to the fact that colors equal in intensity were used in these experiments.

3. The stimulating efficiency falls off greatly toward the violet, with a secondary maximum in the blue at about 440$\mu\mu$, but very little toward the red, except in the case of *Moina brachiata*, where the effect of red is very low.

4. The curves for the distribution of stimulating efficiency, although essentially similar for these forms, are nevertheless different in certain details for each species. This indicates that the photosensitive substances are specific for each species, although fundamentally similar.

5. The similarity of the curves for two species is not correlated with the degree of relationship of the species since the curve for *Daphnia pulex* is more similar to that for *Leptodora kindtii* than it is to that for *Daphnia magna*.

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The Emergence of Life.

This book is an attempt to interpret Emergent Evolution on the basis of logical and mathematical theories which have been prominent in recent scientific discussion; and also to gather up suggestions from the classic philosophers. The basic interpretation is an idealistic theory of reality. The monadology of Leibniz is given a central position, though reinterpreted in a manner deemed necessary in the light of later thought. The emergence of life is regarded as following lines capable of accurate description in terms of mathematical logic. This calls for a reduction of structure to infinitesimals of the infinite order, and for a discussion of continuity and discontinuity in the light of mathematical-logical analysis of these concepts. Contributions are drawn from a wide range of scientific literature, physical and biological.

The result is an imposing array at certain points of mathematical and logical formulae, though their connection with the thesis presented is often so briefly given that the necessity of the connection and relevance to the theory are not clearly evident. The massing of differential equations, radicals, vector analyses, theory of groups, etc., seems more like a display of elaborate erudition than a convincing straightforward argument. To the general reader it looks quite forbidding. To the specialist it might easily look over-ambitious. An effective synthesis in a single volume might well dwell longer upon fundamental principles, rather than attempt to present too much detail, fundamental as this is ultimately.

—A. E. AVEY.

The Emergence of life, by J. B. BURKE. viii+396 pp. Oxford Univ. Press, 1931. $7.50.