published in Italy in the course of the last fifty years," by Mario Vecchi; "Mathematical methods in physics" (review of Volterra's Sur quelques Progrès récents de la Physique mathématique, Drei Vorlesungen über neuere Fortschritte der mathematischen Physik, and Leçons sur l'Intégration des Equations aux Dérivées partielles), by J. B. Shaw; Shorter notices: Berkeley's Mysticism in Mathematics, by C. J. Keyser; Aubert and Papelier's Exercices de Géométrie analytique, by F. M. Morgan; Hardy's Orders of Infinity, by W. A. Hurwitz; Smith and Karpinski's Hindu-Arabic Numerals, by J. V. McKelvey; Dalwigk's Darstellende Geometrie, by J. V. McKelvey; Schmid's Darstellende Geometrie, by Virgil Snyder; Auerbach's Graphische Darstellung, by Virgil Snyder; Meyer's Differential- und Integralrechnung, by Virgil Snyder; Note on "The discovery of inversion," by Arnold Emch; Correction; "Notes"; and "New Publications."

SPECIAL ARTICLES

THE IDENTITY OF HELIOTROPISM IN ANIMALS AND PLANTS. SECOND NOTE [1]

Paul Bert had shown in 1869 that if the small fresh-water crustacean *Daphnia* is exposed to a solar spectrum it goes towards the source of light in all parts of the visible spectrum, but most rapidly in the yellow or green.

> Il fut facile de remarquer qu'elles accouraient beaucoup plus rapidement au jaune ou au vert qu'à toute autre couleur.[2]

The fact of the predominance of the heliotropic efficiency of the yellowish-green in these and some other animals led the ophthalmologist Hess to two assumptions, first that they are totally color-blind (since the yellowish-green part of the spectrum is the brightest for the eye of the totally color-blind human) and second, that the sensation of brightness is the cause of the heliotropic reaction of animals. It is obvious that these conclusions go beyond the facts, since we have no proof for the assumption that the heliotropic effects of light in lower animals are accompanied or determined by any sensations of brightness and since totally color-blind humans do not show any positive heliotropism. In consequence of his two arbitrary assumptions, Hess is forced to the further conclusion that the heliotropic reactions in animals and plants can not be identical, since he does not seem ready to discuss the light and color sensations of plants, and he tries to support this conclusion by the statement that heliotropic plants and animals are sensitive to different parts of the spectrum, all animals to the yellowish-green, all plants to the blue. We have already pointed out in our previous note[3] that this latter statement is not correct, since we were able to show that for the positively heliotropic animal, *Eudendrium*, the most efficient part of the spectrum lies in a carbon arc spectrum in the blue near the region $\lambda = 474\ \mu\mu$, where it also lies, according to Blaauw, for the seedlings of oats.

It seemed of interest to find out whether for different motile unicellular organisms which contain chlorophyll and which are on the border line between plants and animals the most efficient part of the spectrum for the production of heliotropic reaction lies always in the same region. We investigated the reactions of *Chlamydomonas pisiformis* and of *Euglena viridis* in a carbon arc spectrum. The investigation of the behavior of these organisms in the spectrum showed a marked difference. *Euglena* gather in the blue part of the spectrum, usually in the region between $\lambda = 438$ and $\lambda = 510\ \mu\mu$. The densest gathering was generally in the region of $\lambda = 475\ \mu\mu$. In the case of *Chlamydomonas* the gathering always went much farther towards the yellow, usually having its limit in the region of about $\lambda = 560$ or $\lambda = 570\ \mu\mu$. It was in most cases not easy, however, to ascertain the region of maximal gathering, though in many cases it seemed to be about $\lambda = 520\ \mu\mu$. The most remarkable difference between the behavior of the two forms in the spectrum was therefore the fact that *Chlamydomonas* was sensitive to longer waves than *Euglena*.

It soon became obvious that this method of procedure does not permit the decision of the

[1] Loeb and Wasteneys, *Proc. Nat. Acad. Sc.*, I., p. 44, 1915.

[2] Paul Bert, *Arch. de Physiol.*, II., p. 547, 1869.

[3] Loeb and Wasteneys, *Proc. Nat. Acad. Sc.*, I., p. 44, 1915.

question of the relative efficiency of the different parts of the spectrum for both forms with sufficient accuracy. We selected, therefore, a different method which allowed us to compare the relative efficiency of two narrow parts of the spectrum. A carbon arc spectrum, 23 cm. wide, was thrown on a black screen *SS* (see

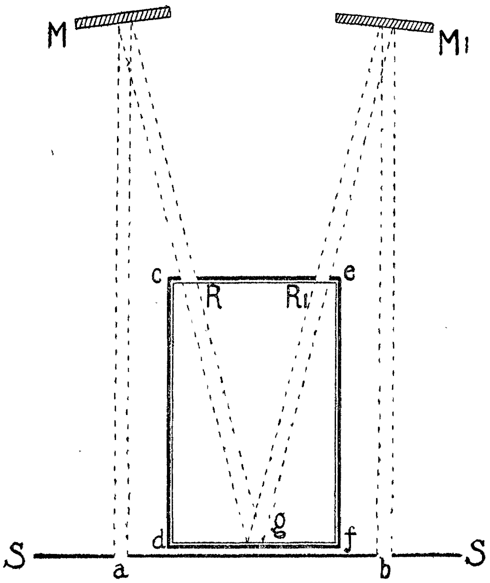

FIG. 1.

Fig. 1) with two slits *a* and *b* in the two different parts of the spectrum which were to be compared in regard to their heliotropic efficiency. The two beams of light passing through the slits are reflected by the two mirrors M and M_1 into the square glass trough in such a way as to strike the same region *g* of the back wall of the trough. The glass trough is surrounded by black paper except at R and R_1, where the two beams of light enter from the mirrors. Before the experiment begins, all the organisms are collected in the region *g* by a special arrangement which need not be described here. As soon as the spectrum is turned on, these organisms are simultaneously exposed to two different beams of light which come from the two mirrors M and M_1. When one type of light, *e. g.*, that from M, is much more efficient than the other coming from M_1, practically all the organisms are oriented by the light from M and move toward this mirror, collecting in the region R. When the relative efficiency of the two types of light is almost equal the organisms move in almost equal numbers to R and R_1. By using as a standard of comparison the same region of the spectrum and successively altering the position of the other slit in the spectrum we were able to ascertain with accuracy the relative efficiency of the different parts of the spectrum for the two forms of organisms. When the two parts of the spectrum which are to be compared are very close to each other it is necessary to deflect the beams with the aid of deflecting prisms, before they reach the two mirrors. It turned out in these experiments that for *Euglena* the region of maximum efficiency was in the blue between $\lambda = 462$ and $\lambda = 492\ \mu\mu$; while for *Chlamydomonas* it was in the green or greenish-yellow between $\lambda = 529$ and $\lambda = 539\ \mu\mu$. In other words, *Euglena* behaved like the seedlings of oats and like *Eudendrium,* both of which had their maximum of efficiency in the blue (in the carbon arc spectrum); while *Chlamydomonas* behaved like *Daphnia.* We may remark incidentally that earlier experiments by Loeb and Maxwell[4] on *Chlamydomonas* had led these authors to the same conclusion.

From the viewpoint of Hess, which seems to have met the approval of several German physiologists, we should be forced to conclude that the unicellular green organism, *Chlamydomonas,* has sensations of brightness, that it is totally color-blind and that it is not heliotropic; while the unicellular green organism, *Euglena,* has no sensations of brightness, is not color-blind and is heliotropic. The confusion created by this mode of reasoning is increased if we consider that *Chlamydomonas* is usually claimed by the botanist and *Euglena* by the zoologist.

We are inclined to put a different interpretation upon our observations, namely, that heliotropic reactions may be determined by two different types of photosensitive substances or by the same type of photosensitive substance in two modifications. One of these types of substances or modifications has its maximum

[4] *Univ. Calif. Publ.*, Physiology, III., p. 195, 1910.

of sensitiveness in the blue (in the neighborhood of $\lambda = 477\ \mu\mu$), the other in the yellowish-green (in the region of $\lambda = 534\ \mu\mu$). The latter type is found in *Chlamydomonas, Daphnia,* the larvæ of barnacles and other organisms; the former type exists in *Euglena, Eudendrium,* the seedlings of oats and others.

It seems of interest to call attention to the fact that according to the measurements of Trendelenburg the visual purple in the eye of the rabbit is bleached most rapidly by light of the wave-length $\lambda = 536\ \mu\mu$. As Kuehne had already shown, visual purple is not affected by red light, and only feebly by yellow light. The relative efficiency of different parts of the spectrum for the heliotropic reactions of *Chlamydomonas* coincides, therefore, approximately with the relative bleaching power of rays of different wave-lengths for visual purple. This makes it almost appear as if in the one group of organisms, namely, those which behave like *Daphnia* or *Chlamydomonas,* the heliotropic reactions were determined by a substance or by substances which behave in regard to photosensitiveness like visual purple; and which may possibly be identical with visual purple.

This assumption allows us to explain the heliotropic reactions of lower organisms without arbitrarily ascribing to them sensations of brightness the existence of which can in their case not be proved. And, furthermore, when the heliotropic effect of rays of different wave-lengths upon lower organisms is found to run parallel to their effect upon the bleaching of visual purple (as it does in *Daphnia* and *Chlamydomonas*) it seems more rational and promising to conclude that the heliotropism in these cases is caused by a substance or substances which behave photochemically like visual purple than that these lower organisms suffer from total color-blindness. We have already shown in our first note that the theory of heliotropic orientation is independent of the relative efficiency of different wave-lengths.

We may summarize the results of our experiments in the following way:

1. The validity of the Bunsen-Roscoe law for the heliotropic reactions of certain (and possibly all) plants and animals suggests that these reactions are due to a chemical action of the light.

2. There seem to exist two types of heliotropic substances, one with a maximum of sensitiveness (or absorption) in the yellowish-green (near $\lambda = 534\ \mu\mu$) and the second with a maximum of sensitiveness in the blue (near $\lambda = 477\ \mu\mu$). Visual purple is a representative of the former type.

3. The photosensitive substance of the visual purple type occurs in the protozoan *Chlamydomonas,* which is usually stated to be a plant, in *Daphnia* and many other organisms. The photosensitive substance with the maximal sensitiveness in the blue is found in *Euglena,* in many plants and in certain animals, *e. g., Eudendrium* and probably others.[5]

4. It would, therefore, be wrong to state that the one type of photosensitive substances is found exclusively in plants and the other exclusively in animals. As a matter of fact they are distributed independently of the systematic boundaries between the two groups of organisms.

5. It is immaterial for the theory of heliotropism to which of the two types the photosensitive substance in any given heliotropic organism belongs.

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AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

SECTION M, AGRICULTURE

THE first meeting of Section M, Agriculture, of the American Association for the Advancement of Science, was held in the Engineering Building of the University of Pennsylvania, Philadelphia, December 30, 1914.

The inauguration of the new section was particularly auspicious, and the large attendance was encouraging as indicating wide interest. Dr. Charles W. Eliot, president of the Association, presided at the opening of the meeting, and in a brief address called attention to the great importance of the agricultural industry, and expressed

[5] This seems to be indicated by the work of Parker and his pupils.