

PHOTOROPISMS WITH MONOCHROMATIC LIGHT IN FUCUS AND VOLVOX.

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ANNIE MAY HURD.

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Submitted am partial fulfillment of the requirements for the degree of Doctor of Philosophy.

University of California

April 26, 1918.

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ORIENTATIONS AND PHOTOTROPISMS IN FUCUS AND VOLVOX WITH MONOCHROMATIC LIGHT OF EQUAL INTENSITIES.

Mrs. Annie May Hurd-Karrer

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I Introduction

The power of light stimuli to produce orientations and tropisms is a phenomenon which has been widely demonstrated in both the plant and animal kingdoms. Not only cannounlateral illumenate direct movements and growth but in some species of plants, namely Equisetum, Fucus, Puccinia, and related forms, it can establish the direction of the first cleavage plane of the gereminating spore. Since in such cases the cell on the shaded side of the spore becomes the rhizoidal cell, the polarity of the plant is determined irrespective of gravity.

In any attempt to discover the mechanics of such tropistic reactions, the first problem is to find what wave lengths of light are responsible, and to what extent they are a function of the quality of the stimulus apart from its quantity or intensity. This, then, is the purpose of the present investigation.

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The reviewing the literature appropriately of and by Wolves of the with monochromatic light one is struck by the absence of quantity of the intensity of the illumination. It is a well known fact that The ordinary light filters used to obtain monochromatic light transmit not only those wave lengths which predominate and give the color to the screen, but also other parts of the spectrum, theoresence of which

wave lengths other than the predominating ones were acting.

Another source of inaccuracy has been the neglect or oversight of the great variation in the intensity or quantity of radiant energy transmitted by the color screens. Biological ex-

can be detected only by a spectroscopic analysis. For example,

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experimenters have for the most part failed to take into consideration the fact that the quantity as well as the quality of the light stimulus varies with the different colors and that the former variable must be eliminated before results can be attributed to differences in wave length alone. Quite recently (1914) such work has been done and published with the statement that results are qualitative only because there is their no way of comparing lights of different colors as to amounts of radiant energy. However there have been several methods devised by means of which the relative intensity of monochromatic lights van be measured.

The first exact work of this nature was done by kniep and Minder (1909). They used a blue and a red color screen and a green solution, with sunlight as the source of light.

The wave lengths to which each, were transparent were known; and the energy behind each was determined by means of a thermopile and a d'Arsonval galvanometer. The interference of the to long heat rays was prevented by inserting a water layer in a parallel sided container between the thermopile and the source pf light.

Day (1911)) obtained light of known wave length by means of a spectfum from Nernt Glower's formed by a carbon bisulfide prism and cut down by a diaphragm with narrow vertical alits which could be adjusted so as to permit any desired region of the spectrum to be used. In this adjustment a spectroscope was used to determine the exact range of wavelengths passing through the slittin each of the four illuminations used, --- red, yellow, gfeen, and blue. He measured the intensity of each with a Boys radiomicrometer, and balanced them by varying the number of glowers employed in the lamps. Thus there was one glower for the red light light, two for the yellow, and three for the green and blue.

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Laurens in an investigation of the reactions of amphibians used these same methods and the same apparatus for the quantitave analysis of the monochromatic light he used, and for balancing them with respect to their relative intensity.

Gross(1913) also used these same methods in determining the reactions of Arthropods to monochromatic light.

An instrument has been devised by MacDougal and Spoehr () which measures the total radiant energy of any light in terms of t its dissociation effect on a photosensitive substance. This is measured by a galvanometer. The advantages in the use of this "photoelectric cell" are said to be its extreme sensitiveness to the wave lengths of the blue end of the spectrum, and the fact that its action in light is more nearly that of the organism than that of any other light measuring instruments available."

There have been therefore three different methods worked on out for biological experiments for the quantitaive analysis of light stimuli; viz., those of Kniep and Minder, Day, and of

MacDougal and Spoehr. The interesting apparatus of Patten (1914) and of Loeb and Northrup whereby quantitave measurement of the resction of organisms subjected to two beams of light of different intensity, is obtained. The measurement is in terms of the angular deflections from an initial path of locomotion. The same methods might be applied to work with colored lights. A quantitative measurement of the greater effectiveness of one spectral region over another of equal intensity might be measured by the angular deviation of the path of a motile organism from a line perpendicular to a line connecting the two sources.

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All of these methods with the exception of those of Knien and inder involve special apparatus often not easily available. It was necessary for the purposes of this investigation to find a simpler method of accomplishing the same results. This report therefore is concerned with two problems; first, a means of making the intensity of the monochromatic light obtained with a set of light filters equal; and second, a comparative study of the tropisms obtained with different wave lengths when the intensity variable is eliminated. The particular phenomena chosen for this study are the power of monochromatic lights to (1) establish the polarity of Fucus sporelines and the origin and consequent direction of the rhizoids; (2) to proince the negative phototropism of the rhizoid; (3) to direct the movements of Volvox.

II. Apparatus and Methods for Exposure to Monochromatic Light of Equal Intensity.

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As biologocal science becomes more exact with the tendto reduce the expression of natural phenomena to mathematical formplace it is obviously essential to define stimule of all sorts quantlitatively. Indefimate or incomplete records of light stimuli can
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them by vrying the number of glowers employed in the lemps.

There are two methods for obtaining monochromatic light for biological experiments - -- the projection of a spectrum upon the organisms, or of filtered light passed through a color screen. The former is theoretically the best for exact work but techmical difficulties such as the limited dispersion low intensity make it impractical for many investigations. Light filters of glass are the most convenient means of securing approximately monochromatic light when unilateral illumination is desired. Ordinary color screens transmit too wide a range of wave lengths for exact work and at present there ex are very few whose light is of sufficient homogeneity. The best is the Wratten filter screen, made in London, which consists o of a dyed gelatine film between two glass plates Vac Dougal and Spoehr (1917) have described some colored glass screens designed by them for biological work, but the range of wave lengths to which they are transparent is considerably greater than for the Wratten filter:

In the experiments to be described, seven Wratten light filters were used, each of which was fitted as a window in the end of a dak box. Each transmitted only a narrow range of wave lengths but all together they embraced the whole of the visible spectrum. The wave lengths to which each screen was transparent were determined by testing the light transmitted by each with a direct vision spectroscope with a wave length scale attached. Thus the quality of the light stimulus acting in each box is accurately known.

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which all the wave lengths of the visible spectrum are required; is the electric arc. The advantages of its use are, that all the filters can be used in each exposure, insuring identical conditions of temperature, constancy of illumination, etc. The disadvantages are several. In the first place, the intensity is constantly changing as the carbons burn and the arc gets longer. Worse, the lessening of the intensity may not be the same for all the wave lengths. In the second place, fluctuations in the current cause large variations in the intensity. In the third place, unless an the automatically adjusted arc is available, it is necessary to adjust the carbons by hand every five to fifteen minutes; and when an eight hour illumination is desired, the entails considerable inconvenience.

The dark boxes were 10x13 cm.and 8 cm.high, in one end of each of which a hole was cut so that one of the light filters, 6 x 6 cm.

might be fitted into it. The boxes were made light tight with

tightly fitting covers, and were painted black inside to guard again for the cultures against reflections within the box. The dishes used were made of microscope slides cemented together with zinc sement so as to make shallow oblong dishes 7.5x2.5 cm. and 1 cm. deep. It was deemed necessary to use such flat sided dishes in order to prevent possible complications from reflected and refracted light in the

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The dark boxes were 10x15 cm.and 8 cm.high, is one end of cached which a hote was cut so that one of the light filters, 6 x 6 cm. might be fitted into it. The boxes were made light tight with tightly fitting covers, and were painted black inside to guard against reflections within the box. The dishes used were made of microscope alides comented together with sine sement so as to make shallow oblong dishes 7.5x2.5 cm. and 1 cm. deep. It was deemed necessary to use such flat sided dishes in order to prevent possible complications from reflected and refracted light in the

than one dish effects behind each screen so that none would be shaded by another, a rack was made to fit inside the box with cleats projecting inward from the bends so that three dishes equal be slipped into it one above the other. The light, entering through the screen at the end of the box, fell equally on the one exposed side of each of the three dishes. The rack containing the dishes could be easily lifted out and charried to the microscope for examination without disturbing the server and charried under nurstication.

7.

The spectroscopic analysis of the light passing the screens determines definately the quality of light entering each box. It is at once evident that the quantity or intensity of light behind filters sercons placed at different equal distances from the source, varies, both because the intensity of light transmitted by the differ ent screens is different, and because the different colors are not radiated by the arc with equal intensity. This being the case, diferences in results obtained behind the screens could not be attributed to differences in the quality of the light stimulus alone. energy of to colored lights in the thermopile and sensitive galvanometer. The thermopile is very sensitive to the energy of any ether vibrations whether they be the longer infra-red or socalled heat rays, or the shorter, actinic rays, of the spectrum. The method worked out for celiminating the intensity variable in the use of the filters employed for this investigations, consisted in finding the distance of from the light source at which each box with its colored window should be placed in order that the intensity, as indicated by the deflection of the galvanometer when the open end of the thermopile was exposed to the light behind 2 , was equal in each case.

It seems necessary, on account of the questions which have been raisedduring the course of this work, to state here that the thermopile is equally sensitive to the energy off the red and the violet ens of the spectrum, and is, therefore, an accurate measure

As already pointed out much work has been done and results interpreted as if only one factor, wave length, were concerned. That differences in the amount of radiant of energy might be partly or wholly responsibly has either been overlooked or regarded as an insurmountable obstacle to exact tropistic work. The writer, has been able to find only for accounts of apparatus planned to measure the relative intensities of colored lights. Recently Machougal and spoots have published a description of a photo- electric cell designed to measure relative intensities by their dissociation effect on a light send to measure relative intensities by their dissociation effect on a light sensitive substance.

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is true because the difference between heat and light is only a mater of wave length. It is true that the thermopile measures in terms of the electric current produced by a difference in temperature of the exposed and unexposed junctions; but it does so by virtue of the fact that the energy of whatever vibrations fall upon it, be they long and therefore heating in their physiological effect, or short and therefore only perceived as light, is converted into heat energy upon being absorbed by the exposed junction of the thermopile. In other words, the light of the blue end of the spectrum produces an electromotive force much less than that of the

infra- red but no less measurable. The instrume ints used in the enegy calibration of these lecture table thermopile with junctions of bismuth and antimony, and a moderately sensitive galvanometer (d'Arsonval). electric arc similar to the one later used in the experiments themselves was the source of light, The thermopile with the open end screened by one of the light filters, was exposed to the light until the galvanometer indicator reached a maximum deflection which took, ordinarily, about thirty seconds. The number of divisions through which the spot of light reflected from the galvanometer mirror, was noted. This was repeated six times and the average deflection recorded. The other filters were then used in turn to screen the thermopile, and thermopile and screen moved to such a destance from the arc that the displacements of the galvanometer indicator was approximately equal. This distance was also found when screened by a piece of cle nease of for the unservened thermopile, which represented the removal of the control from the source. For the experiment the quantity of light used can be varied for the whole set & of screens by multiplying or dividing these distances by the same number and the intensity in all the boxes will remain equal. The actual amount of light in candlepowers can be

of the total amount of light setting behind each color screen. Which the true received the difference between heat and light is only a mate ter of wave length. It is true that the thermopile measures in terms of the electric current produced by a difference in temperature of the exposed and unexposed functions; but it does so by virtue of the fact that the energy of whatever vibrations fall upon it, be they long and therefore heating in their physiological effect, or short and therefore only perceived as light, is converted into heat energy upon being absorbed by the exposed junction of the them produces an electromotive force much less than that of the infra- red but no less messgrable.

measured by means of a photometer. Then from the law of inverse squares, viz., that the intensety of light per unit surface varies inversely as the aquare of the distance from the source, the intensity at any distance from the arc can be computed.

The calibration of the screens was repeated seven times or until satisfactory checks of the distances were obtained. With some thermopoles of less rapid action than the one used here, it is impossible to get results by waiting for the galvanometer indicator to come to a steady State. In such a case the deflections produced by exposure to the light for equal intervals of time can be compared. A series of measurements from five second exposures agreed very well with those obtained by the other megathod.

TABLE SHOWING DISTANCES OF WRATTEN LIGHT FILTERS
FROM AN ELECTRIC ARC AT WHICH THE INTENSITIES OF LIGHT
TRANSMITTED ARE EQUAL.

Filter	No.Wave-leng	ths	Color	Distance	from lig	ght
70	6600-7000	A.U.	Red	32	0 cm.	
71	6200-6800	A.U.	Red	27	5 cm.	
73	5900-6200	11	Orange	23	0 cm.	
73	5600-5900	н	Yellow	25	0 cm.	
74	5200-5600	н	Green	28	0 cm.	
75	4700-5200	11	Blue	25	0 cm.	
76	4000-4700	H	Violet	25	0 cm.	
Control			White	34	O cm.	

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one of a chemical effect; if only the red it might be assumed that

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III. TROPISTIC REACTIONS TO MONOCHROMATIC LIGHT IN FUCUS SPORELINGS.

(a) The nature of the problem

The power of external factors to determine the polarity of a germinating spore is, without doubt, the power to ortent the spindle of the first dividing nucleus, if that polarity is established by the direction of the first cleavage plane. The work on such orientations is very limited and has often resulted in negative results to pressure. The spindle parallel to the embryo by subjecting theu! flattened sides of the egg. This is consistent with Hertwig's theory that the spindle, should form parelbel to the longer axis of a divide iding cell. It is conceivable that the power of light to orient a the spindle might result from its power to cause more rapid growth result that the elongated cellin turn ' along one axis, with orients the spindle. No such effect of light has been demonstrated with animal eggs; but in certain plants, viz., Equisetum, Fucus, Dictyota, Laurencia Cystoseira, it has been found that one-sided illumination with daylight causes the first cleavage plane to be formed perpendicular to the direction of the incident light and the cell on the darker side of the spore to become the rhizoidal cell. Equal illumination on all sides retards or prevents germination.

All these experiments were conducted with natural light as the source of illumination. The first purpose of the present investigation was to determine the power of monochromatic light to establish the the polarity of germinating spores of Fucus evanescens. It was hoped that the results of such experiments might give a clue to the mechanics of such orientations. If all wave lengths should preduce the same effect it might be the result of a general intensity gradiant; if only the blue light is effective, the problem is one of a chemical effect; if only the red it might be assumed that

Gravity and contact cannot establish the polarity of these spores.

SPORELINGS.

(a) This nature of the problems.

The power of external factors to determine the polarity of a germinating spore is without doubt, the power to ordent the spindie of the first dividing nucleus, if that polarity is established by the direction of the first cleavege plane. The work on such orientations is very limitedand has often resulted in negative results Call, working on frage a cage and you by subjecting earn to presence. The spindle parallel to the flattened sides of the erg. This is consistent with Hertwig's theory that the spindle should form pereidel to the longer axis of a division iding cell. It is conceivable that the power of light to orient Q the apindle might result from the power to cause more rapid growth along one sais, with the mabult thetene elongated cellin turn ' bederiended the spindles to such effect of light has been demonstrated with animal eggs; but in centain plants, viz., Equisetum, Tuous, Dictyons, Laurencia as Cystoseirs, it has been found that one-sided illumination with daylight causes the first cleavage plane to be formed perpendicular to the direction of the incident light and the cell on the darker side of the spore to become the rhizoidal cell. Aquel illumination on all eides retards or prevente germination. Gravity and contact cannot establish the polarity of these spores. All these experiments were conducted with natural light ne the source of illumination. The first purpose of the present investi-

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the orientation is due to a metabolism gradiant. The second purpose "A" a study of the photrotropism of the young rhizoids in monochromatic light. It has been shown ("Winkly") that they are negatively heliotropic; but the apparatus designed for the polarity experiments made it very easy to answer several questions concerning the phenomenon more definitely. These questions are: (1) What wavelengths are responsible for the turning away from a source of white light? (2) What is the role of intensity of the light or is it a matter of quality alone or both? (3) Do all lights which have any effect at all produce the same negative tropism profluced by white light?

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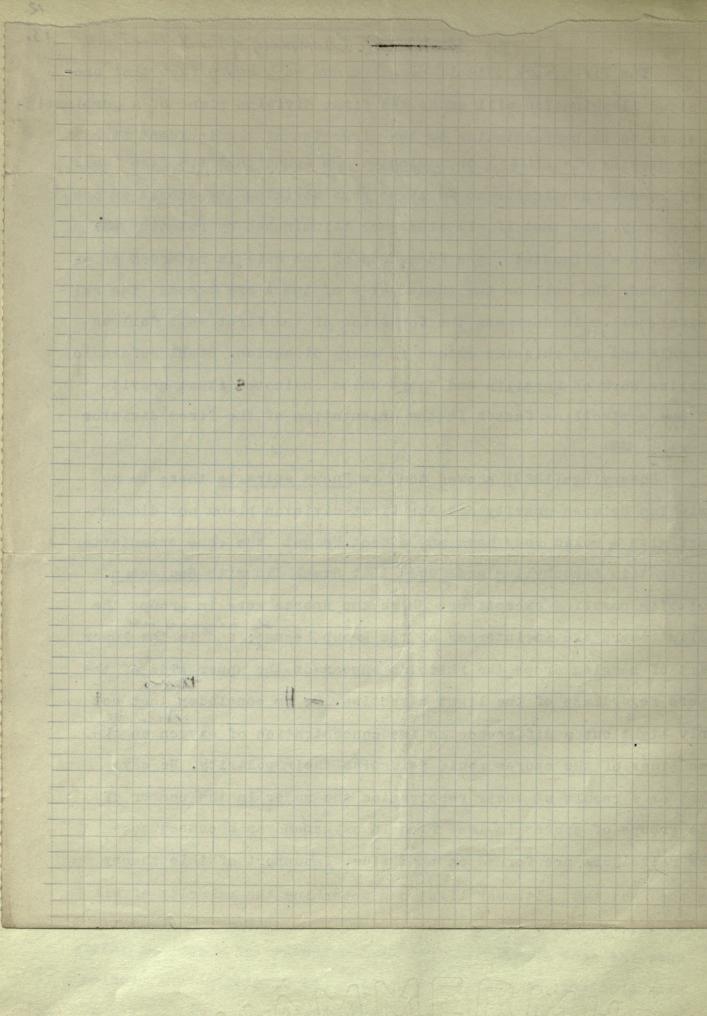
the orientation is due to a metabolism gradient. The second purpose of a study of the photrotropism of the young rhizelds in monochromatic light. It has been shown (Warks) that they are negatively heliotropic; but the apparatus designed for the polarity experiments made it very easy to answed several questions concerning that phenomenon more definitely. These questions are:(1) What wavelengths are responsible for the turning away from a source of white light? (2) What is the role of intensity of the light or is it a matter of quality elone or both? (3) Do all lights which have any effect at all produce the same negative tropism profuced by white light?

(b) Het Literature

The first work establishing the now well known fact that one -sided illumination will cause the first division plane of a germinating spore to be perpendicular to the direction of the incident light ewas done by Stahl (1885) on Equisetum. He found that the first wall is formed perpendicular to A light rays striking the spores on one side only, and that if all sides are illuminated by rotating spores on a clinostat, the formation of the wall is retarded or prevented. The cell on the shaded side of the spore becomes the rhizoidal rell. In darkness the formation of the first wall follows no rule and the rhizoids extend to every direction. Stahl refers to earlier work on Marsilia and Chara which indicates Athat gravity is the controlling factor in the otientation of the first division 1

Rosenvinge(1889) showed that in Fucus spiralis there is no relation between gravity and the first division plane nor did contacf with a solod body have any effect. He got the same orientation to light in Ascophyllum and Fucus that Stahl did with Equisetum. but with puzzling exceptions. Where the spores were in groups the celly toward the interior of the group became; and in the lower part of hanging drops the rhizoids appeared on the upper side of the spore regardless of the light direction. So the concluded that not only light but a difference in the concentration of oxygen on the two sides of the spores could determine their polarity. He says that as a result of their respiration the water in the center of the groups of spores is less rich in oxygen and as a consequence the rhizoids are formed on that side. Insupport of this theory is the fact that although light can determine the polarity of all

plane.



Fucus vesciculosus, F. spiralis, and Pelvetia canaliculata, their sensibility to light differe and the oxygen factor or internal causes are alwaysformed on the darker side of the spore, and this is the one species in which the egg is surrounded by an oogonial wall which might prevent any of he effects of varying oxygen concentration, which can act more potently than light on the spores of the other species. Rosenvinge quotes Kny as finding that neither light, gravity, for contact cap influence the point of origin of the pollen tube from pollen grains, but that in the neighborhood of other grains the tubewill be sent out from the side away from them, on which side the supply of owygen or nutritive elements would be greater.

are illuminated on all sides they tend to remain spherical in stead of producing a rhizoid by the elongation of one of the two cells.

Again(1898) they experimented with one-sided illumination with the usual result that most of the rhizoids originated on the shaded side of the spore and the others were turned that way. The fact that some grew out at an angle to the incident light was attributed to "the character of the egg itself".

Winkler(EXX)1900) found the same orienting effect of light on the spores of Cystoseira barbata but failed to find any effect of a difference in the oxygen content of the water. He too that gravity and contact are not factors in the establishment of the polarity of the sporelings. He found that the direction is determined before the first division takes place. Since this polarity is perestablished during the first four hours of illumination and connot be changed afterwards by any change in the direction of the incident light, he concludes that light can orient the spore only during fertilization.

the species cludied excess fucus serratus; viz., Ascoparting nodosum. Fucus vescioulosus, F. souraits, and Pervetia cancifeutats, their sensibility to light differe and the oxygen factor or internal cources at attack produce frequent exceptions in all but Pelvetia. The rhizoids of the latter species are alwaysformed on the darker side of the assers, and this is the one species in which the egg is surrounded by an occonial wall which might prevent any of he effects of varying oxygen concentration, which can act more potential than ingut as finding that neither light, gravity, for contact centification and that the point of origin of the pollen tupe from pollen grains, but that in the neighborhood of other grains the tupewill be sent out from the side sway from them, on which side the supply of

in 1955. Farmer and Williams (167) states that if Fucus spores are illuminated on all sides they tend to remain spherical in stead of producing a rhizoid by the elongation of one of the two cells. Again (1898) they experimented with one-sided illumination with the usual result that most of he rhizoids originated on the shaded side of the spore and the others were turned that way. The fact that some end at an ungue to the remainment illuminated to "the constactor of the seg itself".

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Randolph and Pacree (1905) performed the one-sided illumination experiments on <u>Dictyota</u>, <u>Dictyoteris</u>, <u>Laurencia</u>, and <u>Cystoseira</u>, and point out the certainty of the <u>Arrence</u> action of other factors because rhizoids are formed in the dark and in all-sided illumination. They say that although Winkler (1900) suggested the possibility of stopping germination by changing the direction of light every three hours, it could not be done with <u>Dictyopteris</u>. They emphasized the possibility of influences preceding the illumination affecting the polarity.

The work of Fromme (Rev. 1914) on the urediniospores of Puccinia is interesting because if that in darkness the rhamist should be mentioned here. He that in darkness the germ tube grew from any side of the spore, but that in inilateral light the tubes almost always issued from the darker side of the spore.

refutes the idea that the orientation of sporelings by light is due to the leftest of one-sided illumination of the chloroplasts to cause an aggregation of the chloroplasts.

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for eight in an otherwise darkened rous, she enrouse using al-

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Randolph and Righter (1905) performed two one-sided illumination experiments on Dictyota, Dictyonteris, Learencis, and Cystoseira, and point out the certainty of the Arkanyse action of other factors because rhizoids are formed in the dark and in all-sided illumination. They say that although Winkler (1900) suggested the possibility of stopping germination by changing the direct on of light every three hours, it could not be done with Dictyonterie. They emphasized the possibility of influences preceding the illumination affecting the polarity.

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related the salar that the original of aposting by light is due to the the salar than a sure or and illumination of appearance to the salar and illuminations of the color of and a sure and a sure or and a sure or and appearance of the color of local color.

All attempts to solve the groblem as to what wave lengths of light are responsible for the orientation of the first cleavage plane of Fucus spores germinated in unilateral have failed so far, and apparently cannot succeed with the apparatus described 165 in the first part of this paper. However it seems worth while to report the methods used and why they have failed. Work will be continued on this investigation at the earliest opportunity, as it is merely a matter of obtaining the right conditions of growth behind the light filters, together with a sufficiently strong illumination.

The fruiting plants of Fucus evanescens were collected at Sausilito at low tide of one day and kept over night in damp news papers. The next morning they were dried slightly by exposing them to the air for about half an hour or less. The fruiting tips were then cut off adh, submerged in the water in the culture dishes. After fifteen minutes many eggs and sperms have settled to the bottom of the dish or can be scraped off into the water. The piece of plant is then removed and the dish is placed in the rack which fits into a dark box behind a filter screen. Each box with its cultures is placed at the proper distance from the light so that each is 11luminated with equal intensity. These distances for each filter adn the method by which they were obtained, and given in pe the case might be paper Each distance given there however was divided by four or fire in order to increase the intensity of the illumination equally for all. The illumination with the electric arc was continued for eight in an otherwise darkened room, the carbons being adjusted every five minutes. This time was judged more than sufficient to produce any effect since it was found in Cystoseira (Winkley

(c) Resulted of Eletetrapium Egyminuts

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that the polarity of the egg is so firmly established by four hours exposure to daylight that it cannot be changed.

The fact that Fucus evanescens is a monoecious species makes it impossible to tell the exact time of fertilization, but it occurs soon after the eggs escape from the oogonial sac into the water. The sperms at this time can be seen escaping from the antheridia and swimming rapidly around the eggs, then scattering as, presumably, one of them succeeds in entering. The first cross-wall can be seen very plainly twenty- four hours after the cultures are started. The mucilage accompanying the eggs caused them to adhere so firmly to the dish that it is not necessary to use a solled media to keep the sporelings from being displaced when the

cultures are moved to the microscope stage for examination.

However all the eggs germinated behind the color screens, and illuminated for the first eight hours after fertilization, showed no orientation with respect to the direction of the light. They grew pormally as if in darkness with the direction of the clearage plane following no rule and the rhizoids extending in every direction. Evidently the intensity of the light was too low to have any effect, or the time or duration of the stimulation was not right.

Attempts to increase the intensity by bringing the cultures closer that is, within about seventy-five centimeters, to the arciresulted invariably in the death of the spores pefore any placed 15 cm. from the naked arc, development occured. A cooling device consisting of a layer of water

6 cm. thick between two glass plates, reduced the temperature the intensity of the light that no orientation was obtained. Attempts to use direct sunlight as the source of light also caused the rapid death of the eggs, presumably on account of the high temperature accompanying it.

Future work on this problem must therefore involve the use of stronger sources of illumination, adn cooling devices to

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keep the temperature below the death point.

Interesting results were obtained in an experiment to discover the weakest stimulus which would produce the characteristic orientations of natural illumination. Cultures were placed at intervals of 15 cm. from an east window adn exposed 8 hours on a cloudy day. Upon examination a few days later every culture was found to show strikingly the strong orienting effect of unilateral daylight. Even the one fartherest away, 350 cm. from the window were practically all oriented, with the vious wall exactly perfect to the direction of the window, 4 the rhighest originating fragment to the direction of the window, 4 the rhighest orientation has frequent exceptions to the rule. Every worker on this problem has reported such exteptions and they have been ext plained by the assumption of the existence of an inherent polarity which as a rule is overcome by the stronger light stimulus. The fact that in absolute & darkness, germination and normal growth are as rapid or more so than in light, also points to an inherent polarity. But the tendancy varies enormously in individual spores. Therefore it is easy to understand that soight vareations in the quantity and quality of illumination might easily produce big changes in the sensitiveness of the spore toward light, which means failure of experiments with monochromatic light until the right combination of other external £ factors in produced.

that although the produce a conspicuous negative heliotropism of the rhizoids gad developed. ONly seven hour exposures were used to that although the second in the course of the intensity of the electric are used was too low to orient the cleavage plane of the egg and too low to cause the cell away from the light to become the rhizoidal cell, it was strong enough to produce a conspicuous negative heliotropism of the rhizoids of these same spores if the illumination was resumed after the rhizoids gad developed. Only seven hour exposures were used to

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It washoon discovered in the course of this inventigation that although the stand intensity of the electric and used was too low to orient the cleavage plane of the eng and tee low to onuse the cell away from the light to become the raisoidal cell, it was strong enough to produce a conspicuous mescative helicitopism of the raisoids of those above apores if the illustration was resumed after the raisoids had develop a saly seven hour exposures very used to

obtain this effect. On the day after such illumination examination showed that the rhizoids of the cultures behind the sharply blue and violet filters were all turned away from the light. Those behind att the filters continued in the direction in which they had started, appearing no different than the control in darkness. Therefore the wave lengths responsible for the negative phototropism and the light are those of the blue end of the spectrum. It should be remembered that the there is no question of a difference in intensity entering here because each screen was placed at such a distance from the arc that the quantity of light in each box was the same. These results are summarized in the following table

HELIOTROPISM DISTANCE FROM Filter No. CO'OR WAVE LENGTHS CULTURES NO. I +] LIGHT 80 6600-7000 A.U. red 70 6200-6800 " orange 68 71 5000-6200 orange yellow 5600-5900 5200-5600 green 4800-5200 blue violet 4000-4700 80 4000 - 7000 + white are the distances of Table I The same

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4000-5200 (engstrom whits) is responsible for the phenomenon, but that some rhizoids, more sensitive, will respond to those of 5200-5600. It seems very possible in view of the results on

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A similar experiment was triedwith sunlight as the source of illumination. The young plants were exposed behind the filters all day in a south window. The same results were obtained as when the arc was used. Then the experiment was repeatedwith diffused light. The boxes were placed in an east window for eight hours ---10 A.M. to 6 P.M.---on March 28. Again the rhizoide in the blue and violet light showed the tropies. But in addition a considerable but much smaller portion were affected in the came

4000-5200 (emgstrom whits) he responsible for the phenomenon, but that some rhizoids, more sensitive, will respond to those of 5200-5600. It seems very possible in view of the results on

These experiments indicate that the light of wave length

way behind the green filter. Eidently the wend

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Volvox reported in the third part of this paper that with a greater & intensity, the rays of the red end of the spectrum might callse the same negative phototropism.

Only the growing tips of the Mhizoeds are sensitive to light.

This results in a sharp angular turn if the derection of illumination is changed through 90 or i80 degrees, or if the plants be brought from darkness into unilateral light. As pointed out by Loeb and others the tropisms is undoubtedly due to the difference in the speed of the chemical reactions going in the two dides of the growing tip.

The first protuberance of the germinating spore is not affected by light striking it from the side; and if it is so illuminated during the early stage of elongation of this cell, the first bend occurs at the cross wall separating it from the next rhizoidal cell. In other words, the first rhizoidal #elongation continues in the original direction established by the first cleavage plane, and the wall separating it from the next cell of the growing chizoid appears as the axis of the tropism.

IV. Group Directation in Jucus inflatus.

In every culture of Fucus evanescens whether germinated in darkness or in strong unilateral light a most striking orientation of the first cross-wall with reference to adjacent spores appears. Wherever a group of spores are lying within about 0.2 mm. of each other, the first cleavage plane is perpendicular to the direction of the center of the group. The cell toward the interior invariably becomes the rhizoidal cell. This phenomenon was reported by Rosenvinge in other species of Fucus and in Ascophyllum. For want of a better than I have collected in a study of this phenomenon was made to determine the strength of the stimulus producing this effect, and that of light, in produce at their power to

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evident that for most spores the former prevails when the spores are within a short distance of each other -- .2 mm. or often more -- and beyond this distance, the chemical stimulus becomes too weak and only the light is able to determine the polarity of the plant.

Only the comparatively isolated spores therefore ever show the orientation to light in this equation with the source of illumination used here.

eggs as well as in masses of fifty or a hungred. In these large groups it is made evident by the invariable rule that no //////rhizoid ever extends outwards from a group. When two spores are within the distance which through the stimulus is effective, the first cleavage planes of the two are often parallel and the rhizoids grow towards each other and often meet tip to tip. The groups of five or six often make symmetrical star-like designs when the rhizoids have grown and project beyond the group.

The spores are more rarely affected in the way when the distance between them is over 0.3 mm, but the phenomenon is sometimes observed in spores as much as 0.5 mm. apart. Within a distance of 0.2 mm. there are practically no exceptions.

The relative sensitiveness of a spore towards light and towards this chemical(?) stimulus varies greatly for different spores. When cultutes were placed in the window to get as strong a light stimulus as possible in order to determine at what distance from each other the eggs had to be not to show a greater sensitiveness towards the chemical stimulus than towards the light, it was found that this distance followed no rule, the spores showing the greatest individual differences. Of two spores lying within 0.3 mm. of each other one might be centirely oriented by the adjacent spore while the other, apparently like it, would show only the action of the light stimulus.

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The phenomenon is very conspicuous in groups of 2, 3, or 4 eggs as well as in masses of fifty or a hungred. In these 1 rgs roups it is made evident by the invariable rule that no rhat/rhizoid ever extends outwards from a group. Then two spores are within the distance which the stimulus is effective, the first cleavage planes of the two are often parallel and the rhizoids grow towards each other and often meet tip to tip. The groups of five or six often make symmetrical star-like designs when the rhizoids have grown and project beyond the group.

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In many cases two such spores would seem to show a resultant effect of the two stimuli so that both would be half turned towards each other with the rhizoidal ceals showing a to take a direction away from the the name.

light at a resultant angle.

to the concentration of oxygen or of nutritive substances on the two forms on the side sides of the spore. He thinks the rhizoid toward the center of a group or towards another egg because the water on that side is less rich than on the outer side of the spore as a result of their metabolism. Winkler(1900) working with Cystoseira barbata that a difference in oxygen concentration has no such effect. Apparently the phenomenon does not occur naturally inthis species since the figure given shows nothing but the effect of light. I have never seen a culture of Fucus evanescent ith spores germinating so near each other, which showed only light orientation and not the group orientation. aAlmost invariably when the spores of this species germinate in such close proximity, light appears to have no power to establish the polarity of the plant.

The possibility that the group orientation is due to a polarity established by the position of the egg in the cogonium is suggested by finding many groups of lying just as they escaped from the cogonial sac and conspicuously oriented with respect to each other. The fact that groups of ten or of two are as regularly oriented would refute the suggestion; but in order to prove that the phenomenon is the result of a stimulus acting after the eggs leave the cogonium, a group of them were transferred to a watch crystal and mixed with the point of a needle until their relative positions were entirely changed. But when they germinated the characteristic orientation with respect to each other was found to be without an exception.

In many cases to such stores would seem to show a resultant effect of the two stimuli so that both would be half turned towards each other with the rhizoidal ceals showing a to take a direction away from the Hight at a resultant engle.

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The only apparent explanation of the group orientation is that of a diffusion gradiant of some substance emanation from a growing spore, or of some substance being used up by it. A continuation of the inversigation of this problem will be an attempt to discover a substance or substances which can so effect the dividing nucleus of the egg cell that its unequal distribution on the sides of the cell will orient the axis of the spindle. The effect of bubbling carbon dioxide or oxygen through one end of a culture will be tried as being the most probable factors involved.

A striking phenomenon which seems to be further evidence of the power of a chemical stimulus to orient the spores was found in three different cultures. Small pieces of a foreign substance, apparently sand, caused the orientation of the spores adjacent to them. the property sand, caused the orientation of the spores adjacent to them. the substance. This material was present in too small amounts for chemical analysis. A search for some difficultly soluble substance, or an insoluble substance which might be slightly soluble in the weak carbonic acid produced by the growing spores, which, when added to the cultures, might orient the eggs adjacent to it, has failed to bring any positive results. They do show however, that the phenomenon is not due to a contact stimulus. The third substances tried were scheelite (Ca, Wo, 04), Magnetite (Fe, 04), Barite (Ba/Sa), Cassereite (Sn 04), Hornblend, Kubellite, beach sand, granite, and silve r filings.

The substance or condition originating in the activety of adjacent spores which has so powerful an effect in orientating the first clearly plane and in determining which cell shall become the rhize zoidal cell has no power to cause any chemotropism of the rhizoids after they are started. No rhizoid has been found to have its direct ion modified by the presence of other spores adjacent to it. In the absence of any light stimulus the rhizoids continue in the direction that they take priginally from the spore.

of a diffusion gradiant of some substance emanation of from a growing spore, or of some substance being used up by it. A continuation of the inversity of this problem will be an attempt to discover a substance or substances which can so effect the dividing aucleus of the egg cell that its unequal distribution on and sides of the cell will orient the qxis of the spindle. The effect of bubbling sarbon dioxide or oxygen through one end of a culture will be tried as being the most probable factors involved.

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(d) Summary

To summarize briefly thes work on light and chemical stimuli as they affect the polarity of Fucus eggs and the direction of growth of the rhizoids:

- (1) Green, blue, and violet light (4000-5600 A.U.) of an intensity great enough to produce negative phototropisms of the growing rhizoids is without effect on the direction of the first cleavage plane of the egg.
- first cleavage plane and determines which cell shall become the group originations rhizoidal cell when the eggs are within a certain distance of the another again has no power to cause a protropism of the rhizoids.
- (4) The negative phototropism of the rhizoids in monochromatic light is primarily a function of the quality of the light since, with equal intensity of illumination, the light behind the color screens of the red and of the spectrum are without effect.

in accophyllum nodown and Tucus vesciculosus I spiralis and I servatus is also a conspicuous phenomenon in every culture of Is inflation must be stronger in this species than in any of the other species sported, since within a distance of 2 mm and often more, light stimuli as a rule fail to overcome it.

(d) Summy .

To anmount to priority of Foods and the direction of the the rhizoids:

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riret cleavage plane and determines which cell shall bedome the chizoidal cell when the chemical artificial cell when the chemical cells are the clean distributed of the clean cells and the clean cells are contained to cause a clean clean of the cause of the cause

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V. -- Phototropisms of Volvox in Monochromatic
Light of Equal Intensity.

Oltmanns (189%), Holmes (1903) and Mast have reported in detail the reactions of Volvox to light stimuli. No one, however, has studied its response to monochromatic illumination. The purpose of the present study is a comparison of its phototropisms in different spectral regions for which the intensity is made equal.

The recent article by Mast (1917) sums up in a table the literature on the reactions of plants and animals to colored light so completely and so concisely that there is no necessity for a repetition here. He summarizes briefly results given in the table as follows:

"For seedlings of green plants, plunules and radicles, the region in the spectrum of maximum stimulating effect is in the blue or violet. For the fungi it is somewhat nearer the red. For Bacterium photometricum it is in the infra-red and the orange. For Oscillaria and Paramecium bursaria is it questionable, activity and aggregation being probably determined by chemical changes in the solution associated with the colors. For Chlamydomonas it is in the green; for all other unicellular forms tested it is in the blue, as it is also for the coelenterates and vermes and for a few of the molluses and arthropods. But for most of the molluses and arthropods it appears to be in the green or yellow."

That the most effective wave lengths are not the same for even related forms in the lower organisms is further borne out by Masts' (1917) results. He found that the maximum efficiency is near 483 pp for Euglena, Tracnelomonas, Phacus, Gonium, Arenicola and Lumbricus;

V. -- Phototroplems of Volves in Monochronatic

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near 524 pp for Pandorina, Eudorina and Spondylomorum; and near 503 pp for Chlamydomonas and blowfly larvae. The work of Schaeffer() on amaebae is interesting as his results indicate that the power of a beam of red light to cause the organisms to move towards it is as great as a beam of white light, and has more attraction than the blue. Most investigators of phototropisms find either that the red is less effective than the blue or that it has no effect. A few find that in equal brightness, the effect is nearly the same for all colors.

The Volvox colonies upon which the following experiments were made were collected by Dr. N. L. Gardner in a small lake in Golden Gate Park on April 2, 1918. They were so abundant that the water was quite green with them.

On April 5 they were exposed to direct sunlight behind the seven Wratten light filters used in the work on Fucus. The same rectangular, flat-sided dishes made of microscope slides cut and cemented together were used. The dishes, filled with a Volvox suspension were placed in the dark boxes in one end of each of which a color screen was fitted. The series of eight boxes were then exposed to direct sunlight. At intervals the covers were raised to determine roughly the percentage of organisms responding, as shown by the completeness of their aggregation. The results of this series are summarized below, the plus sighs indicating an obvious positive heliotropism with the organisms collected against the glass on the side toward the sun, a zero indicating no evidence of any effect of the light.

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Table No. 1.

Volvox Reactions to Sunlight behind Wratten Colored Filters.

Filter	Wave Length in	Color	Exposure
all over to the ball	Angstrom units.	AT THE	THIH IH
70	6600 - 7000	Red	0.0 + 0 + 0
12100 20 71 WYOR, C	6200 - 6800	Orange	00 00 +0
detin 72 2 7egs 5	5900 -6200	Orange	00 00 00
- 11 73 - 4 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1	5600 - 5900	Yellow	+++++
74 miliang	5200 - 5600	Green	++++++
75	4700 - 5200	Blue	++++++
76 110 12	4000 - 4700	Violet	+++++
Control.	4000 - 7000	White	+++++
Table No. 2.		ess in the	3 10 15 20 30
11 11 0 1 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0	6600 - 7000	Red	0 0 0 0 +
71 m the s	6200 - 6800	Red	0.00++
72 Manas	5900 - 6200	Orange	000++
73	5600 - 5900	Yellow	+ + + + + +
74	5200 - 5600	Green	+ + + + + +
the water 75	4700 - 5200	Blue	+ + + + +
there we 76 wet her	4000 - 4700	Violet	+ + + + +
Control.	4000 - 7000	White	++++
		Laures ali	looked alive. This

Table 1 shows that wave lengths from 4000 to 4700 A. are decidedly more powerful in directing the movements of Volvox than are those of the remainder of the visible spectrum, 4700 to 7000 A. U. There is an indication, however, that some individuals respond to the long waves.

Table 2 shows that the stimulating effeciency of the different

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	erus			Color	Wave Length in	Filter
Ext.	1,01		TC _		. edinu mordenna	was the state of t
0 +	0	7 7	0.0	Ped	6600 - 7000	70
0 +	0	0		Orange	6200-6800	The second
00	10	0	00	SPITETO	5900 - 6200	
++			++	Hellow	5600-5900	73
+ +	1+	+	++	Green	5200-5600	74
+ +	+	+		BIVE	4900 - 5200	
+ +	+	+	++	Kalet	-0074 - 0004	. 87
++	1+		+ +	White	4000 - 7000	Control,
29 80	61	01	3			Table Mo. 2.
+10	0		0.	Les	6600 7000	70
+ +	0	0		Red	0089 - 0029	TA
+ +	0	0		Orange.	. 5 400 - 6200 ·	27
+ +	-	+	+	Yellow	2000 - 2000	73
+ +	1 +	+	+	Green	0200 - 5600	74
+ +	+	- +	+	Blue	008.0 - 006.41	75
+ +	+	+	+	I Isla N	4000 - 4700	96
1 1 3	4 +	+	14	While	0001 - 0004	.Fortrol.

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colors is dependent on the duration of the exposure. At the end of only three minutes, the organisms of the green, blue and violet were all over to the brighter side of the dish. At the end of 15 minutes the red, orange and yellow had still produced no visible effect. But, after 20 minutes, all but the longest waves, 6600 to 7000 had caused a definite ag regation; and after thirty minutes, the effect was seen benind this red screen.

As striking as this relation of the time factor to the power of light stiumli to produce the phototropism was the difference in the response behind the four fitters of the green, blue, and violet. After only 3 minutes of exposure the aggregation effect was most marked in the violet, less in the blue and still less in the green. difference in the appearance of the four dishes was due to the difference in the number of individuals that had responded positively and the completeness of their response, i.e. in 4000 - 470 practically every colony was against the glass on the outer side of the dish; in $\lambda = 4700-5720 \mu\mu$ there were more scattered about in 5200 - 560 py still more and in there were just barely enough affected to make it evident that some were positively affected: After 10 minutes this gradiant was still visible. After about 15 minutes, the dishes all looked alike. again shows the importance of the time factor, since the less sensitive organisms which respond less rapidly are after a longer time aftected to the same degree.

In all the succeeding exposures with sunlight this rule held good, that the organisms behind 76 and 75 respond most rapidly and mest

colors is dependent on the duration of the exposure. At the end of only three minutes, the organisms of the green, blue and violet were all over to the brighter side of the dish. At the end of 15 minutes the red, grange and gellew had still eroduced no visible effect. But, after 20 minutes, all out the longest waves, 6600 to 7000 had caused a definite an regation; and after thirty minutes, the effect was seen beaund this red screen.

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to the same degree.

completely, followed by those behind 74 and then 73. It was often quite impossible to detect any difference in the response behind 75 and 76.

It was noticiable in every series exposed that in the white light of the control, complete aggregation of the colonies as the result of their phototropism was not so rapid as in $\lambda = 4000 - 44700 \mu \mu$. Repeatedly the observation was made that the control locked more like the culture in $4700 - 4020 \mu \mu \mu$. The explanation is probably either that the intensity was so much greater that some individuals were caused to respond negatively, or were neutral; or that the greater reflection from the back of the dish made all parts of the water more nearly alike in intensity of illumination and so tended to equalize the stimulus acting on the different sides of the organism.

When a series of cultures was exposed in the same way with the sun hidden by clouds no response could be obtained behind the red, orange and yellow filters.

These experiments snow the greater stimulating enticiency of the blue end of the spectrum since comparison of the order of efficiency of the screens in producing the positive response is not in agreement with the order of the intensity of the light behind them. (see table 1) In fact the stimuli of least energy produce the most rapid response. They also show that with a longer exposure or more intense stimulus the less effective wave lengths may produce the same degree of response. In none of the exposures to sunlight were there any negative reactions or reversals of the response.

On April 6, the experiments were repeated with the electric arc as the source of light, and with the dark boxes at such distances from it that the intensity behind all was the same. The results are

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equalize the stimulus acting on the different sides of the organism.

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as follows:

conditions.

Filter	Wave Length	Color	Distance	Exposure
70	6600 - 7000	red	80 cm.	3'5'-
71 200 300	6300 - 6800	red	48 11 19	+
72	5900 - 6200	orange	38	+
73	5600 - 5900	yellow	62	* * * * * * * * * * * * * * * * * * * *
74	5200 - 5600	green	200 800	+
75	H 700 -5.300	blue	62	+ 100 000+
76	4000 - 4700	violet	62 2000	-temperat
Control.	4000-7000	white	85	+ +

The rapid response in the red was surprising since the energy must have been less than in sunlight. It took 20 minutes to get a noticeable reaction in the orange and yellow in sunlight the day befor Here with the arc as a source of light it took but three minutes. It took 30 minutes to get the response in the red that was produced by the arc in 5 minutes. The explanation might be that the colonies were more sensitive to light on April 6. It was unfortunate that this day was cloudy so that the experiment with sunlight could not be repeated. That the ability of the colonies to respond is dependent to a large extent on their own condition as affected by external factors of their invironment was shown strikingly by the fact that organisims kept over night in a small mouth bottle would not respond to any light stimulus, while others of the same collection kept in shallow pans reacted rapidly. Mast (found considerable difficulty in getting consistent responses on account of the great change in the reactions of his organisms with change in their condition due supposedly to the light and temperature

He follows:

97020			Colog		
	- 18	. 80 cm		6600-7000	
+		. 37		6200 - 6800	
+	+		marge		
7999	+	62		0600 - 0400	
+					
+	+	62		602.9 - 00 H	
+	+	7.7	nidel	0466-0004-10	
+	+	. 68		pool-coot	.fortno0

The rapid response in the red was surprising since the energy must have been less that is enalight. It took ED minutes to get a deticestic resolies in the erange and yellow is suclimit the day befo by the are in a minutes. The explanation might be that the -ujtalou sew dl . . d litth on that! of evillance eron erry selection Trivilines dilly insultance out decit on thuolo any tab sint land sine ould not be repeated. The ability of the entent of appendent to a large extent on their own condition as - anidrie myone eaw inemorital wieds to erosal lenspike yd bojeella yibiger beteasy anny wellans at ton Castas flor smas

ism. Also it is probable in view of Loob's work (1916) that the phototropic reactions of all organisms change with their age.

Another explanation which was suggested by the fact that white light was often slower in producing a response than the b lue and violet, is that the greater energy of the red in sunlight might have tended to reverse the positive reaction or neutralize it; or it might have been so reflected within the dish as to act more nearly with the optimum intensity on all sides of the organism. Be that as it may, the fact remains that repeated trials prove conclusively that at the end of a five minute exposure, all wave lengths of the visible spectrum have produced equal effects when the source of light is the electric arc. This is further proof of Mast's (1917) contention that: "There is no evidence indicating that stimulation in any of the species studied is independent of luminous intensity, for if the light in the spectrum on either side of the maximum be made sufficiently intense it becomes more effective than at the maximum."

On April 20, another collection of Volvox was made. It was hoped that a rough approximation of applicability of the Roscoe-Bunsen Law in the reactions of this form to light. This law states -ing that other conditions be/equal, the product of the intensity and the duration of the exposure is a constant. Owing, however, to the short time required for response and the variations in the sinsitiveness of individuals making it impossible to determine the end points exactly nothing can be concluded as to the truth of this law for Volvox until more accurate means of measuring the beginning and end of the reactions is obtained. To show the difficulty produced by

And the constant of will organisms change with their age.

Another contential which was engineered by the foot that white light was often alower in producing a response than the b lue and violet, is that the present energy of the red in sunitable might have been to reverse the positive resention or neutralize it; or it might have been so mellected within the dien as to set more beenly with the options intensity on all sides of the arganism. The that the options intensity on all sides of the arganism. The that the options in a first what repeated vitals prove conductively that at the cost of a first minutes exposure, all move lengths of the visit at the abstract and the source of the light a particle are. There is in avident and the source of antice is independent of the stimula. The first also a vital to the species active is independent of the species active to because more street; and of the species is because more street; then and of the maximum."

one of the training and the contraction of volver was made. It was noted that a rough approximation of applicability of the paragraph of the stant. This law states durate Law in the resettions of this form as itself. This law states that other own distant based on the intensity and the duration of the ampoints in the made the account to the variations of the meanities and the variations in the meanities are not individuals solving it impossible to severation the the end points are the most of motiving our be constuded as to the truth of this law for analysis and in the means of cascutting the truth of this law for the way and in the means of cascutting the truth of this law for

the quick responses of the colonies, --- the time taken for most individuals to cross the dish, i.e. 25 mm., in white light 50 cm. from the source in a straight line towards the arc was about 1 minute. When this distance was doubled, the time was still about 1 minute. When the culture was removed 200 cm. many colonies still required only 1 minute to get across the dish.

This effect of changing the distance was repeated with the No. 70 filter, since as it transmits the longest wave lengths the time of the reaction should be longer. However, they were still too short to obviate the large errors due to the indefinite end points. At a distance of 25 cm. there was a noticeable collection on the lighter side of the dish. After 5 minutes nearly all had moved over. At a distance of 50 cm., 100 cm., and 200 cm., the same positive results were obtained with the five minute exposure. Although failing to show the applicability of the Roscoe-Bunsen Law this experiment shows the potency of the long red rays to cause the same prototropisms produced by the blue waves when they act with the right intensity.

Every exposure throughout these experiments was made with a fresh culture so that in no instance was there a chance of the sensitiveness being different for the successive exposures because of the effect of a preceeding illumination.

Holmes, (1903) reports that the positive phototropism in medium light is reversed by strong light. Attempts were made therefore to find the turning point for each screen by lessening its distance from the arc. But the control behind clear glass was the only one in which any negative phototropism could be obtained and the response here varied at different times. In one experiment, the

the quid responses of the colonies. -- the time the for most led and the form of the source of the course in a virelent line towards the era was about I minute. I want the time was about I minute. I want the time was raill shout with the course was raill shout.

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notion (1908) reported the positive protection that the protection is reversed by strong light. Attempts were made there add notion that to the to the the point for each section by lessening the city of the from the area of the course was the early one in that any negative phototrousement the obtained and the response here were of at all the obtained and the response here were of at atterest times. In the expense and the

organisms reacted positively at 40 cm. from the arc, negatively at 20 cm. In another, the neutral point seemed to be 50 cm. away. Quite often at this distance there were nearly as many colonies swimming away from as towards light. The response was always more definitely positive at 100 cm. than at 50 cm. Sometimes, however, the response was mostly positive as close as 10 cm., so that the reversal is dependent to a large extent on the condition of the organisms as for the other screens, the greatest intensity obtainable behind any was too low to produce any negative response.

An entire carbon arc spectrum was projected on one dish of organisms. By looking down it could be seen immediately that while those organisms finding themselves in the yellow, green, blue and violet light swam towards the light, those of the red moved not towards the front of the dish but in a direction parallel to it, i.e. towards the yellow. The yellow appeared to the eye the brightest part of the dish. The organisms in it were doubtless decidedly phototropic because of the relatively greater intensity, while those of the blue were so in almost equal degree because of the greater effectiveness of these wave lengths even at low intensity. In the red the intensity was not great enough to overcome the ineffectiveness of the long rays, so the organisms responded either to an intensity gradiant which led them thwards the yellow, or to a wave length gradiant which would also lead them toward the yellow. Or the result might have been due to a diffusion of the more enticient rays into the red. The same red rays in the naked are exposure there was no deflection of the path leading directly towards the source of light.

organisms respond positively at 40 cm. from the arc, negatively at 20 cm. in smother, the neutral point seemed to be 50 cm. away. Quite often at this distance there were nearly as many opionies evinating away from as towards light. The response was always more definitely positive at 100 cm. than at 50 cm. Sometimes, however, the response was mostly positive as 100 cm., so that the reversal is dependent to a large extent on the condition of the organisms as for the other sensens, the greatest intensity obtainable beating any was too low to produce any megative response.

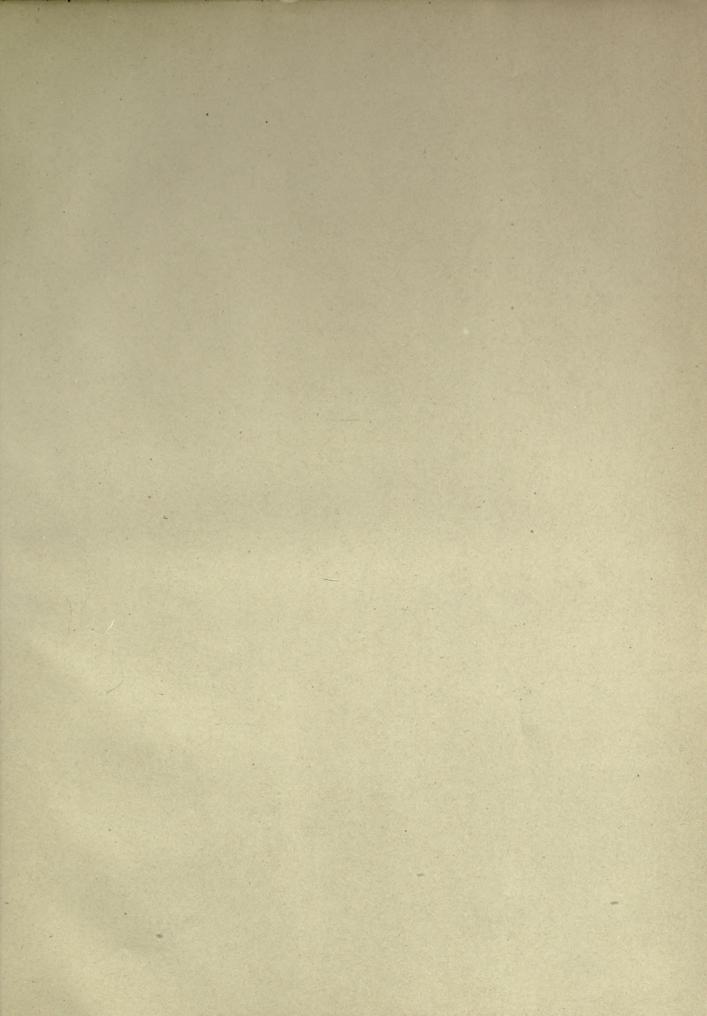
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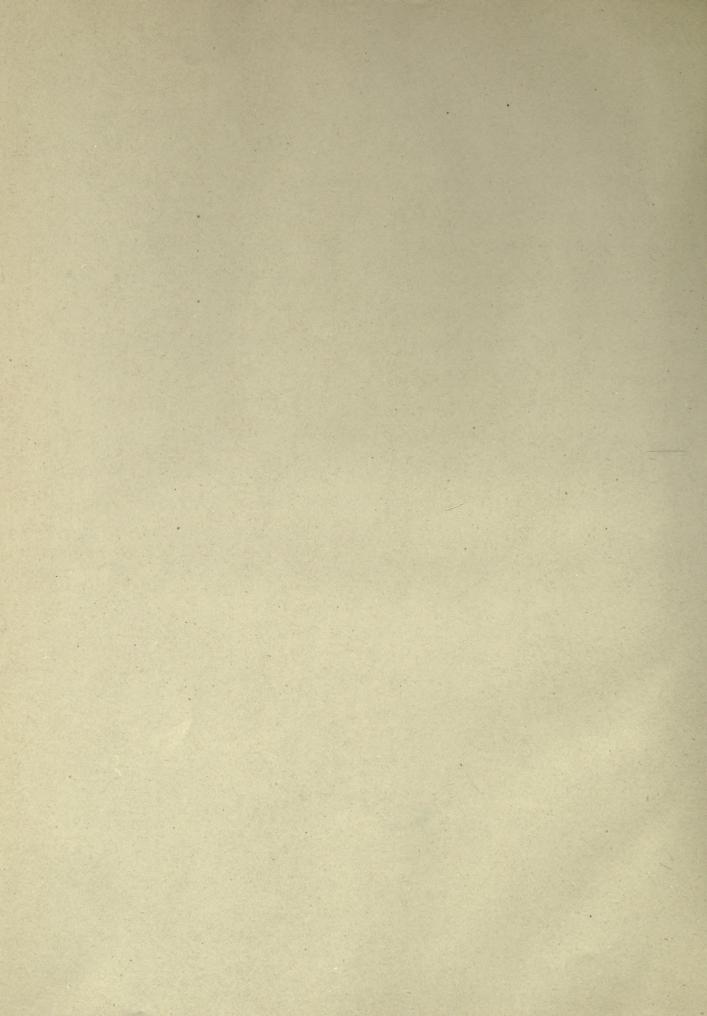
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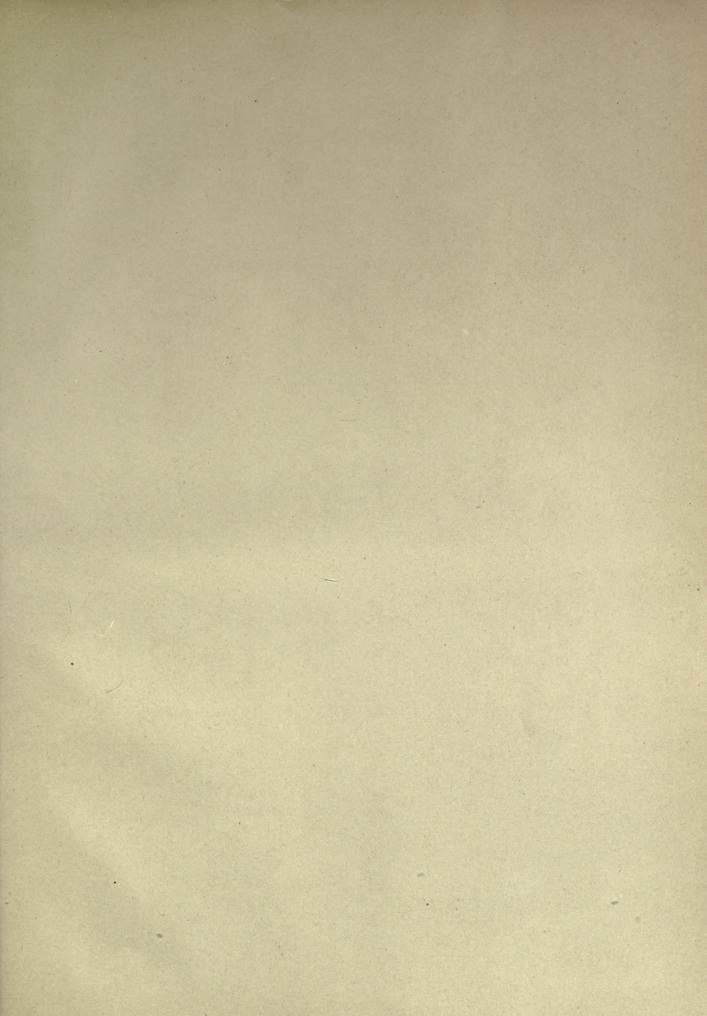
It is interesting in this connection to note Holt and Lee's (1900) conclusions as to the role of the intensity factor in phototropisms. They state that, "There is no evidence that organisms respond to any other property of light than its intensity. All phototatic response is explained by the intensity of the light, and the direction from which it comes." But my experiments with Volvox show conclusively that for any given intensity the blue and violet wave lengths have the greatest stimulating efficiency, but that by increasing the duration of the exposure the same effect is produced behind the other screens; and by modifying the intensity of the other colors they can be made to produce an equally rapid response. This is in accordance with Mast's (1917) conclusions that phototropic responses are not entirely independent of intensity.

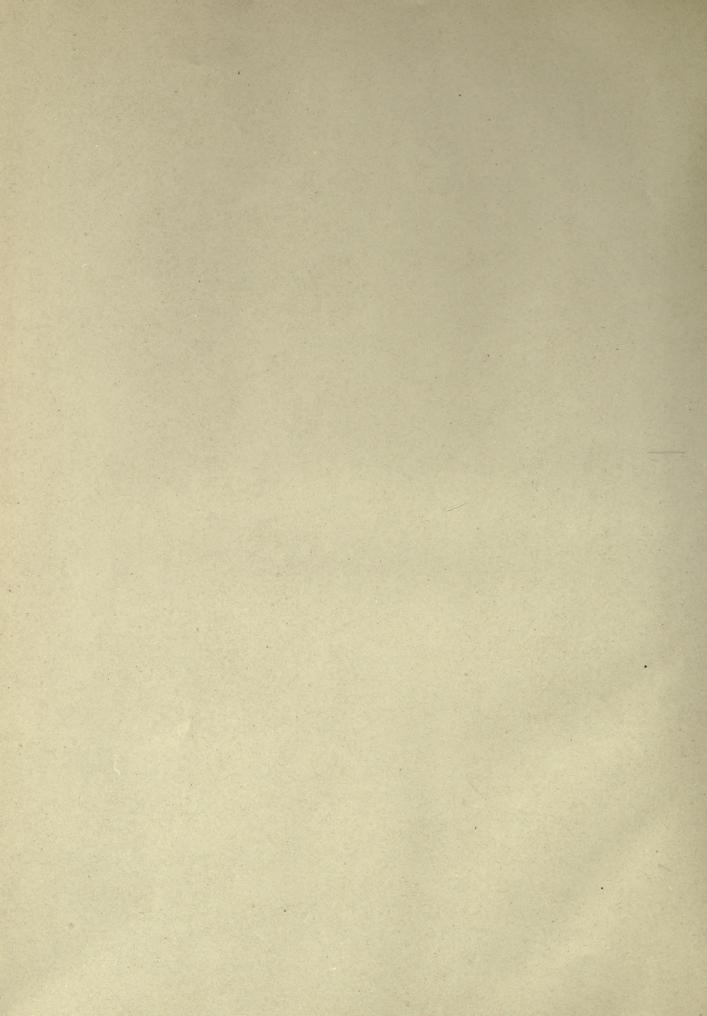
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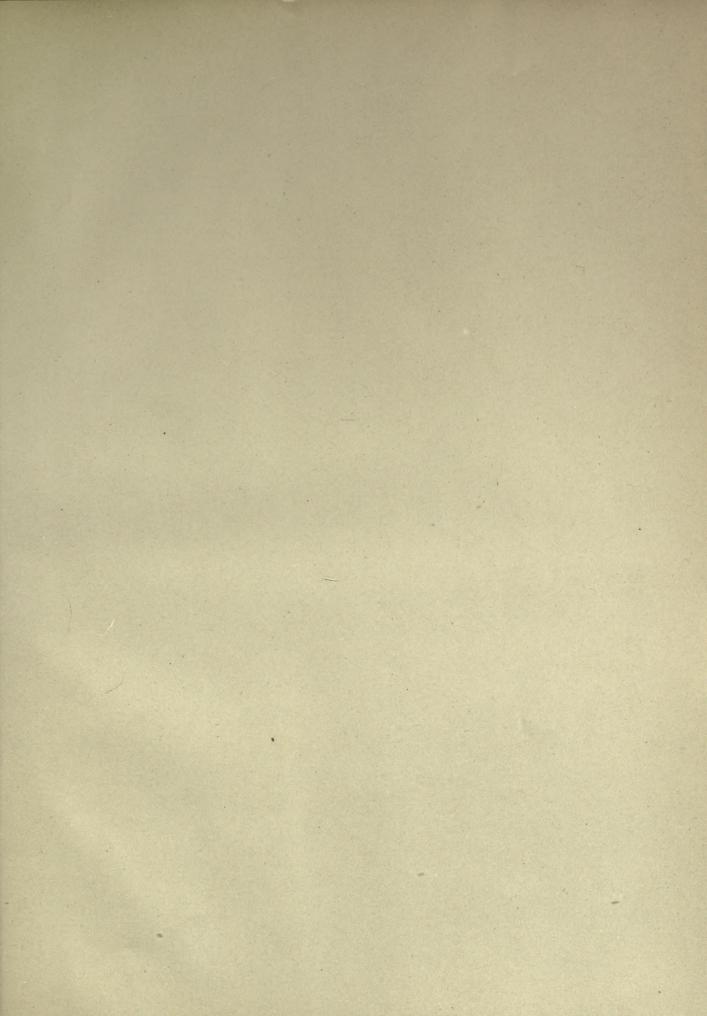


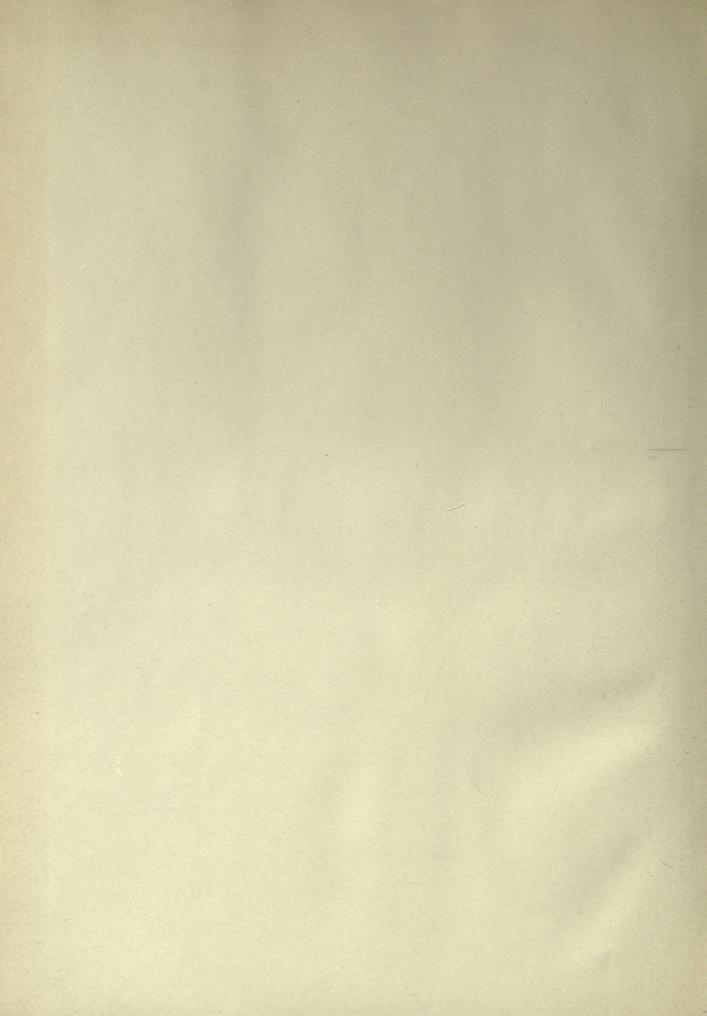


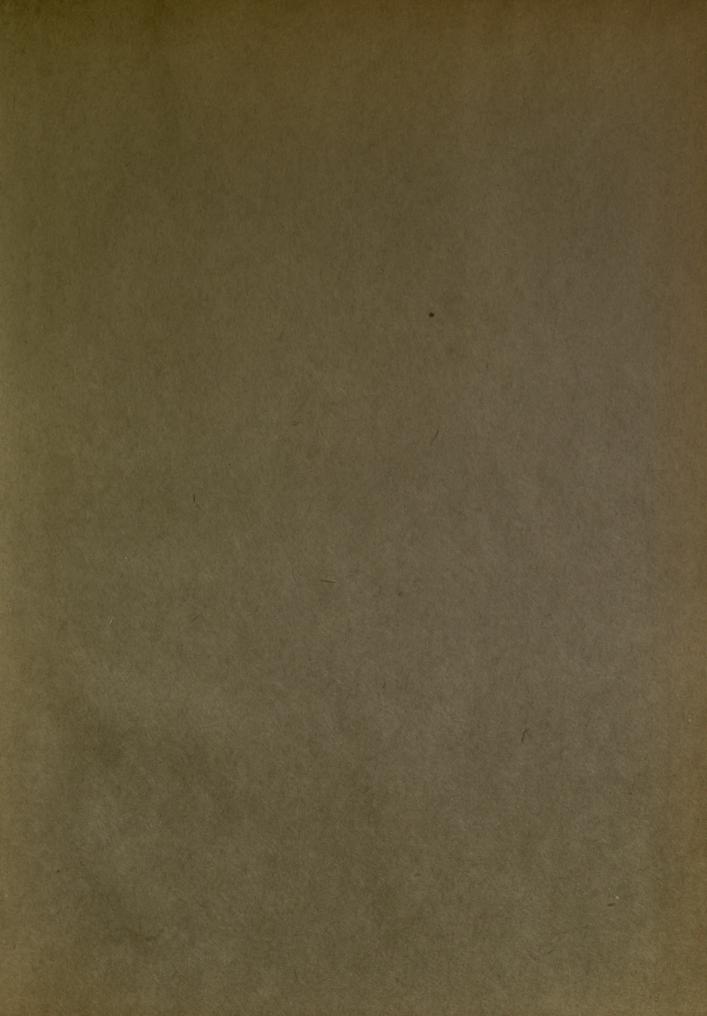


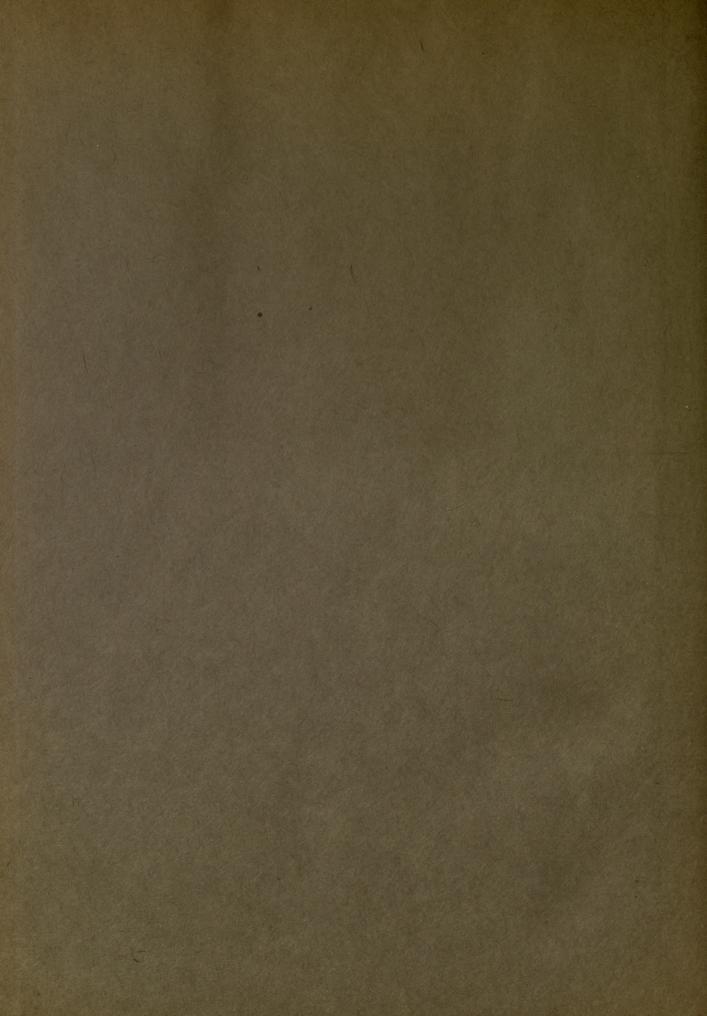












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