The Effect of Circularly Polarized Light on the Photosynthesis and Chlorophyll *a* Synthesis of Certain Marine Algae[1]

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ABSTRACT

The net photosynthesis and chlorophyll *a* synthesis of certain marine algae show a gradation in response to various types of polarized light. Right circularly polarized light increases the net photosynthesis and chlorophyll *a* synthesis as compared with light through neutral density filters, whereas the effect is reversed with left circularly polarized light. This suggests that the receptor pigments are anisotropic and exhibit circular dichroism.

There are contradictory views in the literature on the part played by polarized light in certain photochemical reactions and in photosynthesis. Zurzycki (1955) in a recent paper, reviewed the literature, and disclaimed any significant effects of linearly or circularly polarized light on the photosynthesis of *Lemna trisulca* L. leaves. Rabinowitch (1951), however, has pointed out that chloroplasts may exhibit circular dichroism (*i.e.*, differential absorption of right- and left-handed circularly polarized light), particularly in weak light and when the chloroplast is in the profile position. Measurements of circular dichroism are important aids in the study of the optical properties of compounds.

In the following report some experiments will be described concerning the effects of various types of polarized light on carbon-14 uptake and chlorophyll *a* synthesis in the unicellular marine flagellate, *Dunaliella euchlora*.

One and one-half liters of enriched sea water medium were inoculated with a bacteria-free culture of *Dunaliella euchlora* giving an initial cell concentration of 10^5 cells/ml.

The culture was kept in the dark for two days, and then exposed to approximately 1000 foot-candles of non-polarized fluorescent light at 20°C. After 12 hours the culture contained 2×10^5 cells/ml. Exponential growth continued for four days, and the growth stopped after the fifth day.

During the exponential growth aliquots of the culture were suspended in enriched sea water, and the cell density was adjusted to 1×10^5 to 1.5×10^5 cells/ml. The cell suspension was tagged with carbon-14, after the method of Steemann Nielsen (1952), and siphoned into 35-ml glass-stoppered bottles which were placed in finger bowls blackened so that light could enter only through a three-inch square at the top. Neutral-density or polaroid filters were taped to the top of the finger bowls.

The samples were placed at 20°C under 1000 foot-candles of fluorescent light. With filters this intensity was reduced to 300 to 500 foot-candles, which was above the light saturation of the organisms used (Ryther 1956). After varying lengths of exposure, the samples were filtered on millipore filters, the filters dried, and the radioactivity and chlorophyll *a* content (Yentsch 1957) were determined on samples from each experiment. In a series of similar experiments the rate of oxygen production was measured under polaroid and neutral-density filters. Oxygen production was measured by the Winkler method and corrected for respiration by means of a third sample in a darkened bottle.

A bank of daylight fluorescent lamps, used as a light source, showed no polarization when tested with a polaroid analyzer. Light polarization was obtained by Polaroid HN plastic filters, which circularly polarize light throughout the visible spectrum.

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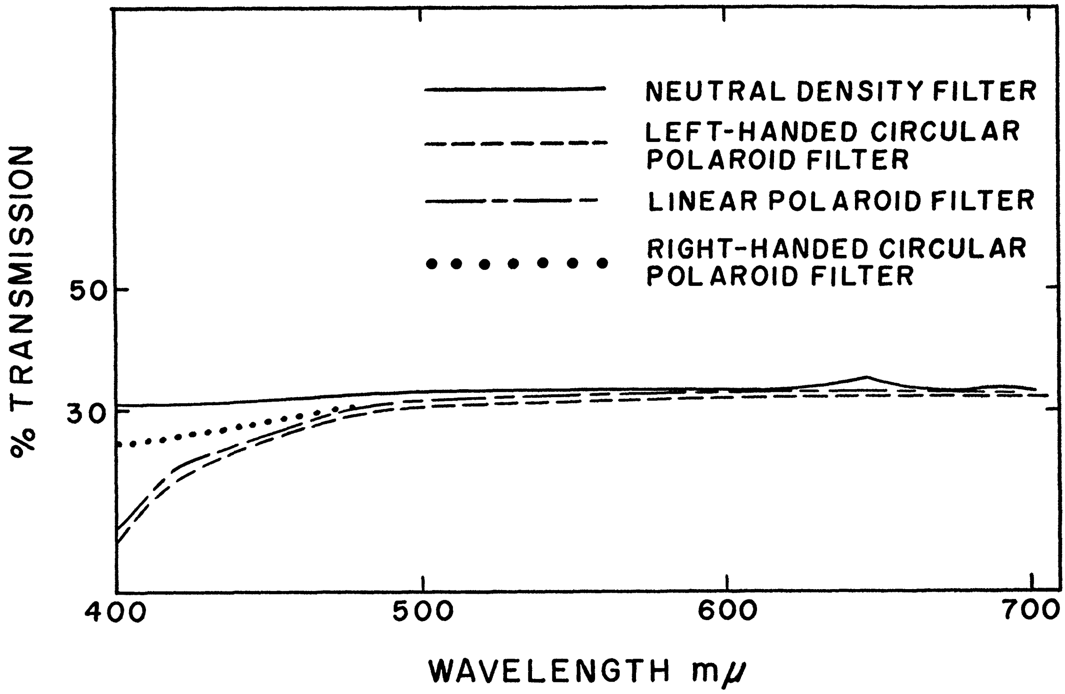

FIG. 1. Transmission curves for polaroid and neutral density filters.

TABLE 1. *Per cent transmission of polaroid and neutral-density filter*

Filter	% transmission
Left-circular polaroid	33.0
Linear polaroid	34.2
Right-circular polaroid	35.8
Neutral-density	37.0

TABLE 2. *Mean percentage increase in carbon-14 uptake, chlorophyll* a *content and oxygen production in* Dunaliella euchlora *under right-circular polaroid filter as compared with neutral-density filter*
Light intensity 300–500 foot candles.

Exposure (hours)	Number of experiments	Carbon-14 uptake (cpm)	Chlorophyll *a* content (mg chl *a*/L)	Oxygen production (ml/L)
2	3	29	24	
3	2	24	28	
4	3	29	20	5
5	3	23	33	
9	3	35		
10	3	32	17	
15	3	22		
16	3	27	17	14
24	3	26	15	5

TABLE 3. *Effect of neutral-density, linear polaroid, and right-circular polaroid filters on the photosynthesis of four unicellular marine organisms*
Light intensity 300–500 foot-candles. Exposure 10 hours.

Organisms	Carbon-14 uptake Per cent increase over neutral-density	
	Linear	Right-circular
Dunaliella euchlora	4	25
Porphyridium cruentum	2	29
Skeletonema costatum	0	29
Olisthodiscus sp.	−2	25

TABLE 4. *Mean of four experiments showing chlorophyll* a *content of* Dunaliella euchlora *after ten hours exposure to polarized light*

	Filters			
	Neutral-density	Linear polaroid	Right-circular polaroid	Left-circular polaroid
mg chlorophyll *a*/liter	.22	.24	.30	.17
Percent increase over neutral-density	—	9	36	−23

Three types of polarization were tested: linear, left-handed circular, and right-handed circular polarization. For control measurements, neutral-density filters made from photographic film were mounted on glass plates.

Transmission curves for the polaroid and neutral density filters were plotted from measurements made in a Beckman DU spectrophotometer (Fig. 1). These curves show that the transmission within the visible radiation range is very similar for all filters.

To compare total intensities of the light transmitted by each of the filters, measurements were made with a General Electric Exposure Meter, Type DW – 68. The readings indicated that the polaroid filters transmitted less light than the neutral density filters as shown in Table 1.

Table 2 shows the effects of right-handed circularly polarized light on the photosynthesis of *Dunaliella euchlora*. In every case, this type of polarized light significantly increased the carbon-14 uptake and chlorophyll *a* content over that shown by the neutral-density filter.

The differences between values obtained by measuring oxygen production are less than those obtained by measuring carbon-14 uptake. The oxygen values were corrected for respiration and represent total photosynthesis, whereas the carbon-14 uptake is a measure only of photosynthesis above respiration (Ryther 1954). Since respiration was probably rather high compared to photosynthesis at the relatively low light intensities used in these experiments, the percentage differences between net photosynthesis (*i.e.*, total photosynthesis minus respiration) would appear larger than the differences between total photosynthesis.

A series of 10-hour experiments with four different unicellular marine organisms show that in all cases right-handed circularly polarized light increased the photosynthesis (Table 3), whereas there was no significant difference in photosynthesis between the organisms under the neutral-density and the linear polaroid filters.

According to physical theory (Glasstone 1940) there should be a gradation in response to various types of polarization. The absorption characteristics of linearly polarized light should not differ from those of unpolarized light, but right- and left-handed circularly polarized light should be absorbed to a different extent by the dextro and laevo molecules of an optically active substance.

Table 4 shows the effects of three different polaroid filters on the chlorophyll *a* synthesis of *Dunaliella euchlora*, over a period of ten hours. Again, right-handed circularly polarized light is most effective in chlorophyll *a* synthesis, whereas linearly polarized light is not significantly different from the control. The chlorophyll *a* synthesis with left-handed circularly polarized light, however, is below that of the control. This is in accord with an explanation based on simple circular dichroism of the receptor pigments.

These experiments indicate that chlorophyll *a* production and photosynthesis in certain unicellular marine algae are affected by polarized light, and suggest that the photosynthetic pigments may be anisotropic and exhibit circular dichroism. Waterman (1955) has shown that linearly polarized light penetrates to considerable depths in natural waters. If the same is true of circularly polarized light, it might have ecological significance in photosynthesis under natural conditions.

REFERENCES

GLASSTONE, S. 1940. Textbook of physical chemistry. Van Nostrand & Co., New York, pp. 594–597.

RABINOWITCH, E. 1951. Photosynthesis. Interscience Publishers, Inc., New York. Vol. I, pp. 362 and 366.

RYTHER, J. H. 1954. The ratio of photosynthesis to respiration in marine plankton algae and its effect upon the measurement of productivity. Deep-Sea Res., **2**: 134–139.

———. 1956. The measurement of primary production. Limnol. & Oceanog., **1**: 72–85.

STEEMANN NIELSEN, E. 1952. The use of radioactive carbon (C^{14}) for measuring organic production in the sea. J. Cons. Int. Explor. Mer, **43**: 117–140.

WATERMAN, T. H. 1955. Polarization of sunlight in deep water. Deep-Sea Res., **3**: 426–434.

YENTSCH, C. S. 1957. A non-extractive method for the estimation of chlorophyll. Nature, (in press).

ZURZYCKI, J. 1955. Photosynthesis in polarized light. Acta Soc. Bot. Polon., **24**(3): 539–547.