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Abstract

Full Text

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ON THE STUDY OF THE POLARIZATION CHARACTERISTICS OF THE LIGHT FIELD IN TURBID MEDIA

(Presented by Academician V. V. Shuleikin on 20 March 1961)

The question of studying the polarization of light scattered in turbid media under laboratory conditions was raised at the Black Sea Division of the Marine Hydrophysical Institute of the Academy of Sciences of the USSR in connection with the problem of investigating the polarization of light in the sea. The study of the polarization of underwater daylight has in fact been undertaken only since 1954 ^(1,2). By the present time Ivanov and Waterman have already accumulated a fairly large amount of material from natural measurements ⁽³⁾. However, on the basis of this material the authors did not succeed in obtaining more or less general regularities (suitable for any bodies of water). It is evident that natural measurements must be supplemented by corresponding laboratory investigations based on the general theory of light propagation in a scattering medium.

The aim of the present work is to study the angular distribution of the degree of polarization of light scattered in turbid media at great depths (where the light is ultimately scattered ⁽⁴⁾), as a function of the dimensionless quantity represented by the ratio of the scattering coefficient to the extinction coefficient. As far as we know, analogous laboratory investigations are not being carried out anywhere.

The laboratory measurements were made on an apparatus that had previously been used to study light scattering in turbid media and was described in ⁽⁴⁾.

The medium under investigation was placed in a tank of sufficiently large dimensions (diameter 70 cm, height 90 cm) and was illuminated from above by a vertical flux of solar rays directed by a heliostat ⁽⁵⁾. The tank was located indoors, and the medium was protected from the entry of extraneous light.

The photometer (with a field-of-view angle of 6°.3) was rotated about a horizontal axis and fixed in any required position. We shall denote by φ the angle between the optical axis of the photometer and the vertical (the direction toward the light source). The analyzer (a Polaroid filter) was rotated in front of the photometer objective about its optical axis and could likewise be set in any required position. We shall denote by β the angle between the direction

Fig. 1. Dependence of brightness and degree of polarization on depth

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of the oscillations transmitted by the analyzer and the direction parallel to the horizontal axis of rotation of the photometer.

Polarized light from the medium, on entering the photometer, first passes through the slowly rotating analyzer. In this process the illumination of the photocell changes periodically in accordance with the change in the position of the analyzer relative to the directions of the principal oscillations of the light beam under study. Changes in the illumination of the photocell produce corresponding changes in the magnitude of the photocurrent, measured by a galvanometer. The degree of polarization P was calculated from the formula

$$P = \frac{\alpha_{\max} - \alpha_{\min}}{\alpha_{\max} + \alpha_{\min}},$$

where α_{\max} , α_{\min} are, respectively, the maximum and minimum galvanometer readings. Analysis of the curves (α, β) showed that, in the turbid media studied, the scattered light is partially linearly polarized in the plane of incidence.

In order to reduce the influence of the albedo of the walls and bottom of the tank on the value of P , the media were placed in a tank with blackened walls and bottom, with a black gelatin coating that eliminated glare. As turbid media, water with an admixture of milk was used, tinted with the optically neutral dye nitrosine.

Before turning to the depth regime, it is necessary to dwell briefly on the results obtained in studying the dependence of the degree of polarization on the depth at which it is measured (the depth is measured vertically).

In Fig. 1, l denotes depths in centimeters, and a the galvanometer readings proportional to the brightness inside the medium. The numbers on the curves denote the angles φ . The extinction coefficient of the medium is $C = 0.65 \text{ cm}^{-1}$. As we see, with increasing depth P at first decreases rather rapidly (especially for angles close to 90°); then, beginning at some depth, the fall of the degree of polarization slows down, and finally P reaches a certain constant value. Comparison of the families of curves P and $\lg a$ shown in Fig. 1 shows that the depth at which P reaches its limiting minimum value for all directions coincides (as was to be expected⁽⁶⁾) with the depth at which the diagram of the brightness distribution in different directions in the given medium becomes stationary, and the luminous flux becomes ultimately diffuse. Hence there follows a very important conclusion, fully consistent with theory⁽⁶⁻⁸⁾:

Fig. 1. Dependence of brightness and degree of polarization on depth

A diffuse luminous flux is characterized not only by a stationary diagram of

Fig. 2. Diagram of the distribution of the degree of polarization in different directions as a function of the ratio of the absorption and scattering coefficients

Figure 2: Fig. 2. Diagram of the distribution of the degree of polarization in different directions as a function of the ratio of the absorption and scattering coefficients

brightness distribution in different directions, but also by a stationary angular distribution of the degree of polarization.

Let us now consider the dependence of the stationary angular distribution of the degree of polarization on the optical parameters of the medium, i.e., turn to consideration of the results obtained in the study of polarization at great depths.

After the corresponding processing of the material, Fig. 2 was constructed, in which the dimensionless quantities χ —the ratio of the scattering coefficient σ to the extinction coefficient k —are plotted along the abscissa axis. The numbers on the curves denote the angles φ . Unfortunately, we were unable to measure polarization in media with small values of χ (strong absorption) and thus to extend the curves of Fig. 2 toward $\chi < 0.67$, since this would have required exceptionally high-sensitivity apparatus, which we did not have.

The scatter of the experimental points shown in Fig. 2 only for the curves $\varphi = 30^\circ$ and $\varphi = 150^\circ$ is due mainly to the unequal purity of the tap water, and also to differences in the mean sizes of the milk particles in individual experiments. The maximum relative error in measuring the degree of polarization does not exceed 7%. This also includes the error due to the influence on the photocurrent of the direction of the plane of polarization of the light incident on the photoelement (2.5%).

From Fig. 2 it is seen that:

1. With increasing χ , the degree of polarization, as was to be expected⁽⁸⁾, decreases. For angles φ close to 90° , the decrease in P occurs rather...

rapidly; for small angles, for example for 30° , P is practically independent of χ up to the value $\chi = 0.98$, after which it rapidly falls to zero.

The rapid fall of P in the region $0.8 < \chi < 1$ may find an important practical application for the separate determination of the absorption and scattering coefficients in turbid media. Indeed, by measuring P in one, or for reliability in several, directions for which P changes rapidly with variation of χ , one can, using Fig. 2, determine the value of χ . Knowing χ and having determined the extinction coefficient (by ordinary photometry), it is not difficult to calculate the absorption and scattering coefficients separately. It should not be forgotten that the indicated method for determining the absorption and scattering coefficients is applicable only to media in which the indicatrices of particle scattering are analogous to those for milk particles at $\chi > 0.8$.

Fig. 2. Diagram of the distribution of the degree of polarization in different directions as a function of the ratio of the absorption and scattering coefficients

2. As should have been expected ⁽⁸⁾, as $\chi \rightarrow 1$ the degree of polarization tends to zero, i.e., in hypothetical purely scattering media the polarization of light is absent. The cause of complete depolarization of light in this case is the absence of absorption in the presence of multiple scattering.
3. As $\chi \rightarrow 0$ (very large absorption compared with scattering), the degree of polarization for all directions tends to limiting values that could be found by extrapolating the curves of Fig. 2 toward small χ . It follows from the theory that these limiting values of P correspond to single scattering.

In conclusion, we note the following. It is evident from the experiments that the angle φ_{\max} , at which the degree of polarization is maximal, increases somewhat as χ increases. However, this increase is small (2-3°), while the error in the measurements of P is comparatively small. Therefore it is difficult to say how the value of χ affects the angle φ_{\max} and, still more, the form of the stationary diagram of the distribution of the degree of polarization. This question requires further study.

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