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Abstract

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Dependence of the Shape of the Stationary Diagram of Brightness Distribution on the Ratio of the Absorption and Scattering Coefficients

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The aim of the present work is an experimental study of the dependence of the shape of the diagram of brightness distribution by directions on the ratio of the absorption and scattering coefficients for limiting diffuse light (the question of the influence of the scattering indicatrix on the shape of the diagram is not considered here).

Since in the present work media were used that not only scatter but also absorb light, the investigation, in contrast to previous ones (1), was carried out in different regions of the spectrum, i.e., with the use of light filters. The angle of view of the photometer was varied from 5 to 15° (in special problems it was taken equal to 0°,39).

The turbid media used were mainly milk media, uncolored and colored; occasionally rosin media were used. The milk concentrations ranged from 10 to 30 cm^3/l. To prepare colored milk media, a stock solution of blue ink was used as the dye. The dye concentrations ranged from 1 to 10 cm^3 of stock solution per 1 l of turbid medium.

The scattering coefficient k of the milk medium was determined on a König–Martens spectrophotometer (1). The determination of the absorption coefficient m_{cr} of the colored milk medium (due only to the dye) was reduced to finding the absorption coefficient of tinted water (with the same dye concentration), since specially arranged experiments showed that the addition of milk to tinted water does not change its absorption coefficient.

Let us note that we are interested in the absorption coefficient for that region of the spectrum which, on the one hand, corresponds to the limiting diffuse light in the medium filtered to a considerable degree and, on the other hand, is registered by the photometer with a light filter. Therefore, in order to determine the value m_{cr}, we proceeded as follows.

In tinted pure water, relative brightnesses were determined for various depths, using the same photometer, with the same light filter; the water was tinted with the same dye (only without milk) and illuminated by the same luminous flux as

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when obtaining the diagram of brightness distribution by directions for limiting diffuse light. From the data obtained, a graph was constructed of the logarithm of relative brightness versus the depth of immersion of the photometer. From the practically rectilinear portion of the resulting curve the absorption coefficient m_{cr} was determined. It corresponds to the region of the spectrum with the maximum transmittance of the medium in the range of wavelengths perceived by the photometer with the light filter.

The diagrams of brightness distribution in different directions for limiting diffuse light in colored milk media with various ratios of the absorption and scattering coefficients were determined by means of—

by the method described by us earlier ([1]), but with the use of light filters. As a sample of such diagrams we give in Fig. 1 diagrams obtained with a blue Bg-12 light filter and a photometer field of view of 15° in colored milky media for ratios m_{kr}/k from 0 to 0.03. The segments of the diagrams represent, on a definite scale, the values of the relative brightnesses $B_{\varphi=0}/B_{\varphi\neq0} = R$, where $B_{\varphi=0}$ is the brightness in the direction toward the light source; $B_{\varphi\neq0}$ is the brightness in some other direction φ.

From Fig. 1 it is seen that, as the ratio m_{kr}/k increases, the value of R increases, the diagrams become elongated, the pole shifts to the side opposite the direction of the incident light, and the relative amount of light emerging from the medium (the albedo) decreases.

The dependence between the value R and the ratio m_{kr}/k for various angles φ is given in Fig. 2. In processing the experimental material this dependence was constructed separately for the green and blue filters. It turned out that the straight lines obtained practically coincide. Consequently, the dependence $(R, m_{\text{kr}}/k)$ is universal, i.e., valid for all wavelengths. Therefore in Fig. 2 experimental points obtained both with the blue (a) and with the green (b) filters are used. Let us note that the experimental points obtained in the rosin medium (v) are also plotted in Fig. 2 and lie near the straight lines with the same degree of accuracy as the other points. In order not to clutter the drawing, the experimental points are given only for two directions φ.

Fig. 1. Dependence of the form of the stationary diagram on the relative magnitude of the absorption and scattering coefficients

All the straight lines in Fig. 2 pass in such a way that their extensions intersect (with an error not exceeding the limits of experimental error) at one point located to the left of the ordinate axis. This is explained by the fact that in Fig.

Fig. 2. Dependence between relative brightness and the relative value of the absorption and scattering coefficients

Figure 2: Fig. 2. Dependence between relative brightness and the relative value of the absorption and scattering coefficients

2 the quantities plotted on the abscissa axis took account of absorption in the colored milky medium only due to the dye (i.e., absorption by water was not taken into account).

In order to obtain the ratio of the total absorption coefficient of the medium to its scattering coefficient, one must add to the abscissa m_{kr}/k the quantity m_{v}/k, where m_{v} is the absorption coefficient of pure water (without dye). This is equivalent to shifting the ordinate axis to the left by the quantity m/k. It is natural to assume that the straight lines of Fig. 2 intersect at the point with abscissa $m/k = 0$, where $m = m_{\mathrm{kr}} + m_{\mathrm{v}}$. Then the graph gives the mean value $m_{\mathrm{v}}/k = 0.012$. Taking the mean value of the scattering coefficient of the uncolored milky media used in the experiments as 1.2 cm^{-1}, we calculate also the water absorption coefficient averaged over all the experiments. It is equal to 0.014 cm^{-1} and corresponds to the region of the spectrum with maximum transmission of water in the range of wavelengths perceived by the photometer with the filter. In the experiments two light filters were used, but only one intersection point was obtained. Consequently, the value found for the absorption coefficient of water pertains to both regions of the spectrum (let us note that the magnitude of the scattering coefficient of the milky media used practically does not depend on wavelength); in other words, the absorption coefficients of water for the two considered wavelength ranges turned out, by chance, to be close to one another, which is not difficult to verify by taking for comparison, for example, the absorption curve of optically pure water.

The absorption coefficient of water, generally speaking, depends on wavelength and, consequently, for different regions of the spectrum the abscissas of the intersection point must be different (in this case the straight lines of Fig. 2 for the corresponding angles will be shifted relative to one another, but will be mutually parallel).

It follows from this that, if one takes a receiver possessing sufficiently selective sensitivity, then the method indicated above can be used to determine the spectral absorption curve of transparent liquid media with a very small absorption coefficient (for example, seawater). In this case the medium under investigation should be poured into the tank, then a certain quantity of milk should be added to it, and subsequently, by adding various known quantities of dye, the value of R should be determined each time (in the given problem it is sufficient to determine R for one arbitrary angle φ) for

Fig. 2. Dependence between relative brightness and the relative value of the absorption and scattering coefficients

different regions of the spectrum. The points of intersection of the straight lines (R, m $/k$) with a straight line parallel to the abscissa axis and passing through the ordinate axis at the point $R = 1$ will give the values of m $/k$ for the medium under investigation in various parts of the spectrum. Knowing the value of k for the medium (without dye), it is evidently not difficult to determine the values of the absorption coefficient of the medium (seawater) for various regions of the spectrum. The more selective the receiver, the more accurately the desired spectral absorption curve can be obtained. A very valuable feature of this method is that the scattering of light in the medium under investigation may be neglected in comparison with the scattering of light in the turbid medium prepared on its basis.

Since at $m = 0$ the ordinate of the point of intersection of the straight lines in Fig. 2 is equal to unity, it is evident that at $m = 0$ the brightness is the same in all directions. This means that the diagram of the distribution of brightness by directions for limitingly scattered light in a turbid medium with absorption coefficient $m = 0$ is spherical.

If in Fig. 2 the ordinate axis is shifted to the left by 0.012, i.e., drawn through the point of intersection of the straight lines, and the values of the total absorption coefficients are plotted along the abscissa axis, then from the resulting graph one can find the following empirical relation between the quantities of interest to us, R and m/k:

$$R = 1 + \mu \frac{m}{k}. \tag{1}$$

The parameter μ, which characterizes the slope of the straight lines in Fig. 2, depends on the angle φ and may also depend on the scattering indicatrix of the particles, which, however, requires special study.

Using relation (1), for a given value of the ratio m/k one can find R for any angle φ, i.e., determine the form of the stationary distribution diagram, by directions, of the brightness of limiting scattered light.

With the aid of relation (1) one can also solve the inverse problem, namely: from a given ratio of brightnesses R for any angle φ, determine the ratio m/k for the turbid medium and, consequently, find separately the coefficients of absorption and scattering of it, if the extinction coefficient of this medium has been measured beforehand. This method indicates the promising possibility of separately determining the absorption and scattering coefficients in the sea, provided, however, that the dependence of μ on the scattering indicatrix of the particles of the turbid medium has been studied in advance.

Fig. 3. Comparison of calculated and experimental values of relative brightnesses

In conclusion we give examples of calculating the relative brightnesses R by relation (1), using the method indicated above. Figure 3 shows stationary diagrams

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of the distribution of the brightness of limiting scattered light for different ratios m/k, calculated by relation (1). The diagrams also show experimental points obtained with an LF-2 photometer with a 15° field of view in dyed milky media with different dye concentrations. The diagram for $m/k = 0.023$ was obtained with a green filter, and the diagrams with $m/k = 0.044$ and $m/k = 0.067$ with a blue one. In all cases the experimental points lie quite close to the calculated ones. The systematic lowering of the upper experimental points (for $\varphi > 90°$) in comparison with the calculated ones is explained by the presence of a shadow from the photometer when measuring brightness in the indicated directions.

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Note: Figure translations are in progress. See original paper for figures.