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DETERMINATION OF THE LIGHT QUANTUM SURVIVAL PARAMETER FROM THE --ETC(U)
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(Opredeleniye velichiny parametra vyzhivaniya knvanta sveta po kharakteristikam svetovykh poley v more)

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DETERMINATION OF THE LIGHT QUANTUM SURVIVAL PARAMETER FROM THE CHARACTERISTICS OF LIGHT FIELDS IN THE SEA

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An important optical characteristic of seawater is the ratio of the light scattering index σ to the attenuation index ε, called the quantum survival parameter, which in many cases is known with insufficient confidence. The widely used method of determination of this quantity involving separate measurement[1] of σ SIGMA and ε EPSILON is frequently associated with large instrumental errors. Of interest in this connection is the possibility of calculating the parameter Λ from light field characteristics measured directly in a scattering medium. /157*

Described below is a method of determining the parameter Λ (a) in a plane-stratified inhomogeneous medium from the parameters of the light field inside the medium when its surface is uniformly illuminated by a flux of solar radiation, and (b) in a homogeneous medium from the light field parameters of an isotropic source placed inside the medium at a sufficient distance from its boundaries.

In describing the process of propagation of solar radiation in the sea, it is convenient to use the radiation transfer equation in the following form:[2]

$$\cos\theta \frac{dB(\theta,\varphi)}{dz} = -\varepsilon B(\theta,\varphi) + \sigma \int_{4\pi} \chi(\theta,\theta',\varphi-\varphi') B(\theta',\varphi') \cdot \frac{d\omega'}{4\pi}. \qquad (1)$$

where $B(\theta,\phi)$ is the luminance of the radiation in the direction characterized by angle θ with the vertical and azimuth ϕ; $\chi(\theta,\theta',\phi-\phi')$ is the indicatrix of single scattering of a ray following the direction (θ',ϕ') and falling on the scattering volume in the direction (θ,ϕ); $d\omega' = \sin\theta' d\theta' d\phi'$; the z axis points vertically downward. /158

In a plane-stratified medium, the luminance remains unchanged in the direction $\theta = \pi/2$. Integrating Eq. (2) with respect to ϕ and choosing the corresponding order of integration in the triple integral, we obtain

$$-\varepsilon \int_0^{2\pi} B\left(\frac{\pi}{2},\varphi\right)\frac{d\varphi}{2\pi} + \sigma\int_0^{\pi}\left[\int_0^{2\pi}\chi\left(\frac{\pi}{2},\theta',\varphi-\varphi'\right)\frac{d\varphi}{2\pi}\right]\times \left[\int_0^{2\pi} B(\theta',\varphi')\frac{d\varphi'}{2\pi}\right]\frac{\sin\theta' d\theta'}{2} = 0. \qquad (2)$$

We introduce the notation

$$\overline{B}_\varphi(\theta') = \int_0^{2\pi} B(\theta',\varphi')\frac{d\varphi'}{2\pi}; \qquad (3)$$

$$\overline{\chi}_\varphi(\theta') = \int_0^{2\pi}\chi\left(\frac{\pi}{2},\theta',\varphi-\varphi'\right)\frac{d\varphi}{2\pi}. \qquad (4)$$

It follows from Eq. (3) that $\overline{B}_\phi(\theta)$ is the azimuth-averaged luminance value propagated at a given depth at angle θ with the vertical. The quantity $\overline{\chi_\phi}(\theta)$ is the value of the scattering indicatrix of a ray falling on the scattering volume at

*Numbers in the right margin indicate pagination in the original text.

angle θ with the vertical, averaged over all the directions lying in the horizontal plane. $\bar{\chi}_\phi(\theta)$ is independent of ϕ', since a periodic function of $(\phi - \phi')$ is integrated in Eq. (4) with respect to ϕ over the segment $[0,2\pi]$. The initial function for calculating $\bar{\chi}_\phi(\theta)$ is the experimentally determinable indicatrix of single scattering $\chi(\gamma)$.

Taking Eqs. (3) and (4) into account, we represent (2) in the form

$$\Lambda = \frac{\sigma}{\epsilon} = \frac{1}{\int_0^\pi \bar{\chi}_\varphi(\theta')\, b(\theta')\, \frac{\sin\theta'\, d\theta'}{2}}, \tag{5}$$

where

$$b(\theta) = \frac{\bar{B}_\varphi(\theta)}{\bar{B}_\varphi\left(\frac{\pi}{2}\right)}. \tag{6}$$

Formula (5) makes it possible to calculate Λ in a plane-stratified medium at any depth, since there are no restrictions on the shape of the luminance solid.

In the case of symmetry of the light field with respect to the vertical axis (the luminance is independent of the azimuth), expression (6) simplifies to /159

$$b(\theta) = \frac{B(\theta)}{B\left(\frac{\pi}{2}\right)}. \tag{6a}$$

This condition is fulfilled in the sea in cloudy weather at any depth or in sunny weather when the sun is at the zenith, and also in the state of optical equilibrium under any conditions of surface illumination. The condition of light field symmetry does not necessarily imply the advent of the state of optical equilibrium; the latter may fail to take place in a vertically inhomogeneous medium.

In deriving the formula for calculating Λ from the parameters of the light field of an isotropic source, we will use the transfer equation in spherical coordinates

$$\frac{dB(\theta, r)}{dl} = -\epsilon B(\theta, r) + \sigma \int_{(4\pi)} \chi(\theta, \theta', \varphi - \varphi')\, B(\theta', r)\, \frac{d\omega'}{4\pi}, \tag{7}$$

where r is the distance from the source; θ is the angle between the specified direction and the direction of the source; ϕ is the azimuth. The luminance B in the field of the isotropic source is independent of the azimuth (the luminance solids possess axial symmetry with respect to the direction of the source). We will consider the change in luminance in the plane perpendicular to the direction of the source: $\theta = \frac{\pi}{2}$.

The left-hand side of Eq. (7) may be represented as

$$\frac{dB(\theta, r)}{dl} = \frac{\partial B}{\partial r} \cdot \frac{dr}{dl} + \frac{\partial B}{\partial \theta} \cdot \frac{d\theta}{dl}. \tag{8}$$

It follows from geometric relationships that $d\ell = -rd\theta$; $dr = -d\ell d\theta$. Omitting the second-order term, we obtain from Eq. (8)

$$\frac{dB(\theta, r)}{dl} = -\frac{1}{r} \cdot \frac{\partial B(\theta, r)}{\partial \theta}\bigg|_{\theta = \frac{\pi}{2}}, \tag{8a}$$

and Eq. (7) becomes

$$-\frac{1}{r} \cdot \frac{\partial B(\theta, r)}{\partial \theta}\bigg|_{\theta = \frac{\pi}{2}} = -\epsilon B\left(\frac{\pi}{2}, r\right) + \sigma \int_0^\pi \left[\int_0^{2\pi} \chi\left(\frac{\pi}{2}, \theta', \varphi - \varphi'\right) \frac{d\varphi'}{2\pi}\right] B(\theta', r)\, \frac{\sin\theta'\, d\theta'}{2}. \tag{9}$$

Dividing both sides of the equation by $B(\frac{\pi}{2})$ and using the notation of (4) and (6a), /16
and considering that $\varepsilon = \kappa + \sigma$, where κ is the absorption index, we arrive at the following expression for Λ:

$$\Lambda = \frac{\kappa - \frac{1}{r} \cdot \frac{\partial B(\theta)}{B(\theta)\,\partial\theta}\Big|_{\theta=\frac{\pi}{2}}}{\kappa \int_0^\pi \bar{\chi}_\varphi(\theta)\, b(\theta) \frac{\sin\theta\, d\theta}{2} - \frac{1}{r} \cdot \frac{\partial B(\theta)}{B(\theta)\,\partial\theta}}, \tag{10}$$

or, in view of the notation

$$\alpha_B = -\frac{1}{B(\theta)} \cdot \frac{\partial B(\theta)}{\partial\theta}\Big|_{\theta=\frac{\pi}{2}}; \tag{11}$$

$$I = \int_0^\pi \bar{\chi}_\varphi(\theta)\, b(\theta) \frac{\sin\theta\, d\theta}{2}; \tag{12}$$

$$\Lambda = \frac{\kappa + \frac{\alpha_B}{r}}{\kappa I + \frac{\alpha_B}{r}}. \tag{13}$$

When $r \to \infty$, Eq. (13) becomes Eq. (5).
Finally, when $\theta = 0$, it follows from Eq. (7) that

$$-\alpha_{B(0)} = -\varepsilon + \sigma I^*, \tag{14}$$

where

$$\alpha_{B(0)} = -\frac{\partial B(0, r)}{B(0, r)\,\partial r}, \quad I^* = \int_{(4\pi)} \chi(\xi) \frac{B(\theta)}{B(0)} \cdot \frac{d\omega}{4\pi}. \tag{15}$$

Also using the expression[3] for κ

$$\kappa = \bar{\eta}\alpha_F, \tag{16}$$

where

$$\bar{\eta} = \frac{\int_0^\pi B(\gamma) \sin\gamma \cos\gamma\, d\gamma}{\int_0^\pi B(\gamma) \sin\gamma\, d\gamma} = \frac{H}{h} = \frac{E - E'}{h} \tag{17}$$

is the mean cosine of the radiation;

$$\alpha_F = -\frac{dF(r)}{F(r)\,dr}; \tag{18}$$

$$F(r) = 4\pi r^2 H = 4\pi r^2 [E(r) - E'(r)]; \tag{19}$$

$$E'(r) = \int_0^{\frac{\pi}{2}} B(\theta, r) \frac{\sin\theta \cos\theta\, d\theta}{2}; \qquad /161$$

$$E'(r) = -\int_{\frac{\pi}{2}}^{\pi} B(\theta, r) \frac{\sin\theta \cos\theta\, d\theta}{2}, \tag{20}$$

we obtain from (14) the following formula for calculating Λ:

$$\Lambda = \frac{\alpha_{B(0)} - \alpha_F \bar{\eta}}{\alpha_{B(0)} - \alpha_F \bar{\eta} I^*} = \frac{\alpha_{B(0)} - \kappa}{\alpha_{B(0)} - \kappa I^*}. \tag{21}$$

In the state of optical equilibrium $\alpha_{B(0)} = \alpha_F = \alpha$, and Eq. (21) becomes

$$\Lambda = \frac{\alpha - \kappa}{\alpha - \kappa I^*} = \frac{1 - \bar{\eta}}{1 - \bar{\eta} I^*}. \tag{22}$$

Thus, four formulas have been proposed for calculating Λ: in a plane-stratified medium illuminated by a wide light beam, at any depth, (5); in the state of optical eqiulibrium, (22); from the light field of an isotropic source, (13) and (21).

2. Measurements of the luminance $B(\theta,r)$ of the light field of an isotropic source and luminance of the light field of solar radiation in the state of optical equilibrium were performed in the Black Sea (1970), Mediterranean Sea (1966), and certain regions of the Atlantic and Pacific Oceans during the fifth cruise of the research ship DMITRIY MENDELEYEV (1971). The instruments and methods used for measuring the light field characteristics of an isotropic radiator are described in Ref. 3. "Deep" luminance solids were measured in the Black Sea by using the same instruments, and in the other waters, by means of an underwater photoelectric luminance meter designed by A. S. Suslyayev, mounted on an underwater photometric bench with a scanner.

The spectral range of the luminance measurements was 495±35 nm. The volume scattering function $\beta(\gamma)$ was measured in relative units by a standard method. Data on the measurements of $B(\theta,r)$ and $\beta(\gamma)$ in the Black Sea are given in Tables 1 and 2. Table 1 gives the angular luminance distributions in the light field of an isotropic source at different distances from the latter, and also in the state of optical equilibrium. The values of $\log \frac{B(\theta,r)}{\Phi_0}$ are given, where Φ_0 is the light flux of the source. Table 2 gives values of the volume scattering function $\beta(\gamma)$ - not normalized, in relative units - from measurements at st. 100 (Black Sea). Calculations of the quantum survival parameter Λ from formulas (5), (13), (21), and (22) were made on /162

Table 1

θ°	r, м								Глубинный режим (солнечное излучение)*
	10	15	20	40	60	78	102	115	
0	1.8	2.82	3.35	4.9	5.83	6.60	7.74	8.35	0
1	1.82	2.84	3.37	4.92	5.84	6.62	7.76	8.36	0.001
2	1.90	2.90	3.40	4.94	5.96	6.73	7.58	8.46	0.004
3	2.02	3.00	3.50	4.98	6.02	6.84	7.98	8.55	0.008
4	2.20	3.20	3.58	5.01	6.08	6.94	8.06	8.60	0.012
5	2.60	3.35	3.64	5.18	6.15	7.00	8.11	8.68	0.018
7	3.00	3.55	3.90	5.36	6.33	7.12	8.26	8.80	0.030
10	3.30	3.88	4.3	5.65	6.51	7.3	8.45	9.00	0.064
12.5	3.50	4.16	4.55	5.85	6.67	7.51	8.58	9.14	0.100
15	3.70	4.33	4.76	6.00	6.80	7.63	8.73	9.27	0.125
12.5	3.89	4.50	4.90	6.12	6.93	7.80	8.87	9.42	0.170
20	4.10	4.70	5.08	6.25	7.08	7.90	8.97	9.36	0.201
22.5	4.23	4.79	5.17	6.36	7.19	8.02	9.09	9.67	0.250
25	4.38	4.88	5.28	6.47	7.29	8.12	9.22	9.78	0.310
27.5	4.50	5.00	5.38	6.59	7.39	8.22	9.33	9.88	0.365
30	4.58	5.10	5.48	6.7	7.50	8.35	9.45	9.96	0.438
35	4.74	5.30	5.68	6.87	7.7	8.52	9.61	10.16	0.577
40	4.90	5.49	5.85	7.05	7.88	8.70	9.80	10.35	0.735
45	5.10	5.68	6.00	7.27	8.07	8.90	9.97	10.50	0.896
50	5.29	5.88	6.20	7.45	8.25	9.12	10.11	10.65	1.064
55	5.48	6.05	6.38	7.62	8.43	9.30	10.27	10.83	1.204
60	5.65	6.20	6.52	7.77	8.57	9.48	10.43	10.98	1.352
65	5.79	6.35	6.66	7.89	8.75	9.62	10.55	11.12	1.486
70	5.90	6.50	6.80	8.01	8.87	9.75	10.67	11.25	1.626
75	6 02	6.62	6.92	8.14	9.02	9.88	10.78	11.39	1.760
80	6.10	6.72	7.02	8.25	9.16	10.	10.9	11.49	1.870
85	6.20	6.81	7.10	8.35	9.26	10.12	11.00	11.59	1.967
90	6.30	6.90	7.16	8.43	9.36	10.2	11.08	11.68	2.050
95	6.37	6.91	7.21	8.5	9.44	10.28	11.15	11.71	2.155
100	6.41	6.99	7.25	8.55	9.52	10.36	11.22	11.83	2.208
105	6.45	7.01	7.27	8.61	9.58	10.40	11.28	11.89	2.266
110	6.48	7.03	7.3	8.65	9.63	10.41	11.34	11.93	2.300
115	6.49	7.04	7.31	8.67	9.68	10.46	11.38	11.96	2.352
120	6.50	7.04	7.32	8.69	9.70	10.50	11.40	12.00	2.372
130	6.50	7.01	7.33	8.72	9.74	10.53	11.41	12.06	2.415
140	6.50	7.01	7.33	8.73	9.77	10.55	11.46	12.08	2.458
150	6.50	0.01	7.33	8.71	9.79	10.56	11.47	12.08	2.458
160	6.50	7.04	7.33	8.74	9.8	10.56	11.47	12.08	2.458

*State of optical equilibrium (solar radiation)

Table 2

$\gamma°$	0.5	1.5	2.5	3.5	4.5	7.5	12.5	17.5
$\beta(\gamma)$	282 000	35 500	12 600	6300	3390	1120	282	115
$\gamma°$	22.5	27.5	35	45	55	65	75	85
$\beta(\gamma)$	55	27.5	13.5	5.5	2.82	1.62	1.02	0.69
$\gamma°$	95	105	115	125	135	145	155	165
$\beta(\gamma)$	0.53	0.46	0.46	0.51	0.66	0.96	1.29	1.62

a Minsk-22 computer. The results of the calculations of Λ for different areas of the World Ocean are summarized in Table 3, which shows that the four formulas for calculating Λ at st. 100 (Black Sea, 1970), where the most complete measurements of the light fields were performed, gave very consistent results. The discrepancies in the value of Λ do not exceed the limits of error estimated below. The much greater /16
discrepancies observed at st. 367 and 397 may be explained by the following factors: (a) measurements of "deep" luminance solids were made during the day, whereas the distribution of luminance in the light field of an isotropic source was measured at night (the ship could have been drifting into waters with somewhat different optical characteristics); (b) the values of the parameter Λ, calculated from formula (13), were averaged over a certain depth range, whereas formulas (5) and (22) determine Λ at a depth of 100 m. The highest value, Λ = 0.82, corresponds to the Black Sea, and the lowest, to clear waters of the Sargasso Sea in its southern fringe.

It is interesting to compare the value Λ = 0.32 obtained for the Sargasso Sea (at a depth of 300 m) with the value of this parameter for "ocean waters of maximum purity," proposed in Ref. 4. According to the data of this study, in ocean water of maximum purity Λ = 0.32 at λ = 550 nm.

The last two columns of Table 3 give values of the attenuation index ε and mean scattering angle

$$\bar{\gamma} = \frac{\int_{(4\pi)} \gamma\beta(\gamma)\,d\omega}{\int_{(4\pi)} \beta(\gamma)\,d\omega},$$

characterizing the elongation of the single scattering indicatrix.

The three quantities - quantum survival parameter Λ, attenuation index ε and scattering indicatrix - which completely determine the intrinsic optical characteristics of a medium, are mutually independent. However, for natural waters, not all combinations of (Λ, ε, $\bar{\gamma}$) are equally probable, and a relationship is observed /165
between them, as illustrated in the figure.

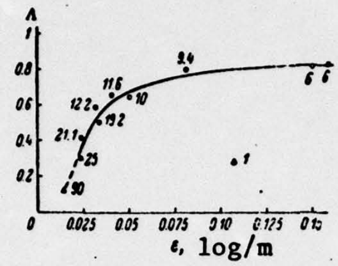
The figure gives values of Λ, ε and $\bar{\gamma}$ from the data of our measurements. A smooth decrease in Λ and increase in $\bar{\gamma}$ with decreasing index ε is observed. The following explanation of this dependence is possible. On passing from polluted waters to purer ones, primarily the concentration of the coarsely dispersed suspension decreases, so that the scattering indicatrix becomes less elongated ($\bar{\gamma}$ increases),

Table 3

Region of measurement, No. of station, range of depths	Value of Λ averaged over the indicated depth range				$\varepsilon\left[\frac{\log}{m}\right]$	$\bar{\gamma}$[°]
	Calculation from light field of isotropic source		Calculation from light field of solar radiator			
	Formula (13)	Formula (21)	Formula (5)	Formula (22)		
Black Sea st. 100, 30-150 m	0.81±0.06	0.77±0.1	0.85±0.06	0.86±0.06	0.20	6.0
Black Sea, st. 33, 100-150 m			0.82±0.06		0.15	6.0
Pacific Ocean, Equator, Cromwell Current, st. 367, 30-60 m	0.75±0.06				0.06	9.4
Mediterranean Sea, st. 34, 100-150 m			0.65±0.04		0.04	10.0
Pacific Ocean, region southeast of Japan, st. 410, 30-150 m	0.65±0.04				0.041	11.6
Pacific Ocean, region of high transparency near Kuka Islands, st. 397, 30-150 m	0.62±0.04		0.70±0.1	0.73±0.1	0.037	12.2
Pacific Ocean, Equator, Cromwell Current, st. 367, 120-200 m	0.50±0.04		0.55±0.08	0.58±0.08	0.031	19.2
Atlantic Ocean, southern Sargasso Sea, st. 347, 30-100 m	0.46±0.03				0.028	21.1
Atlantic Ocean, southern Sargasso Sea, st. 347, 200-300 m	0.32±0.03				0.023	24.9

the scattering decreases, and hence, so does Λ, and the total attenuation index ε also decreases.

The following hypothesis may be proposed as a result of the examination of the above experimental data.



Relationship between Λ, ε and $\overline{\gamma}$ based on results of measurements in different water areas of the World Ocean (see also Table 3).

Arabic numerals next to points – $\overline{\gamma}$, deg; 1 - optical properties of pure water (Rayleigh scattering, absorption only by water molecules).

In the three-dimensional space formed by the quantities Λ, ε and $\overline{\gamma}$, the optical properties of the investigated waters fall near some curve (see figure) apparently corresponding to the zone of combinations of these quantities most frequently encountered in natural waters. Hence, from one of the three indicated characteristics one can estimate the other two. This hypothesis opens up the possibility of classifying the waters of the World Ocean according to the location of the point with coordinates (Λ, ε, $\overline{\gamma}$) on the indicated curve. The transition from the classification of waters into groups differing sharply in optical properties, as was done in Ref. 5, to a continuous distribution of waters according to (Λ, ε, $\overline{\gamma}$) along the indicated curve is more convenient in many respects. This hypothesis should be checked by using more extensive experimental material than what is available to us at the present time, and the scatter of experimental values about the specified regression line should also be quantitatively estimated.

3. The error in the determination of Λ from formulas (5), (13), (21) and (22) /166
is due to experimental errors in the measurements of luminance and volume scattering function, which were used as the basis of the calculation, and also to errors of the numerical integration. In the calculation with the Minsk-22 computer, the integration step chosen was small enough so that the computational error did not exceed a fraction of a percent; it may therefore be neglected in comparison with the measuring error. The error in the luminance measurement was in the range of ±18% for $0° \leqslant \theta < 10°$; 12% for $10° < \theta \leqslant 20°$; 9% for $20° < \theta \leqslant 30°$; 7% for $30° < \theta < 60°$; 6% for $60° < \theta \leqslant 180°$. In the measurement of $\beta(\gamma)$, the error did not exceed ±10% in the angular range $0° < \gamma \leqslant$ $\leqslant 10°$ and ±7% at $\gamma > 10°$.

The limiting error in Λ was estimated from a formula derived from Eq. (13):

$$\frac{\Delta\Lambda}{\Lambda} = \frac{\alpha_b \varkappa (I-1)}{r(\varkappa + \alpha_b/r)(I\varkappa + \alpha_b/r)}\left(\frac{\Delta\varkappa}{\varkappa} + \frac{\Delta r}{r} + \frac{\Delta\alpha_b}{\alpha_b}\right) + \frac{\varkappa I}{\varkappa I + \alpha_b/r} \cdot \frac{\Delta I}{I}, \quad (23)$$

with $\frac{\Delta\kappa}{\kappa} = 0.1$, as was shown in Ref. 3; $\Delta r = 0.5$ m was the scale division of the winch indicator; $\frac{\Delta\alpha_b}{\alpha_b} = 0.1$ is the maximum deviation from the mean, obtained by processing a large number of measured functions $B(\theta)$; $\frac{\Delta I}{I} = 0.06$ is the maximum deviation in I, calculated as follows. In the calculation of I from Eq. (12), the absolute values of the functions $B(\theta)$ and $\beta(\gamma)$ do not affect the result - only their relative variation, i.e., the "degree of elongation," is important. Having specified the above limiting errors in $B(\theta)$ and $\beta(\gamma)$, we drew the curves $B'(\theta)$, $B''(\theta)$ and $\beta'(\gamma)$, $\beta''(\gamma)$ within the confines of the error zone in such a way that $B'(\theta)$ and $\beta'(\gamma)$ would have the maximum elongation, and $B''(\theta)$ and $\beta''(\gamma)$, the minimum elongation along the axis of ordinates. Calculation of I values for any two pairs of the indicated functions gives four values of the integral I. This procedure was carried out for three distances r from the source by using the data of measurements at st. 100 (in the Black Sea). The maximum deviation of the integral calculated in this manner for the entire set of calculated cases was 6% of the value of the integral itself; therefore, $\frac{\Delta I}{I} = 0.06$ was substituted into Eq. (23) as the limiting value.

Also substituted into formula (23) were values of the characteristics corresponding to measurements in the Black Sea: $\alpha = 0.9$, $\kappa = 0.03\ m^{-1}$, $r = 100$ m, $I = 1.28$; /16 as a result, $\frac{\Delta\Lambda}{\Lambda} = 0.065$ was obtained. According to measurements in the Sargasso Sea, $\alpha = 0.77$, $\kappa = 0.014\ m^{-1}$, $r = 100$ m, $I = 4.47$; correspondingly, $\frac{\Delta\Lambda}{\Lambda} = 0.062$. Considering that these cases are extreme, the errors in Λ values calculated from the data of the remaining measurements may be estimated as being approximately the same. It is interesting to note that the errors in κ, r and α make a very small contribution to the error of Λ, owing to the fact that these quantities are present in both the numerator and the denominator of formula (13). The determining error is the one in I, which we estimated in the manner described above. On the whole, the limiting error of the above Λ values in the calculation using Eq. (13) may be considered equal to ±7% of Λ. The corresponding estimates were made for the calculation using formulas (5), (21) and (22); the limiting errors given in Table 3 incorporate these estimates.

It is our view that the proposed method gives a more accurate value of the parameter Λ than the other methods in use at the present time, since the calculation involves the use of data of photometric measurements, which do not require calibration of the instruments (brightness and indicatrix meters) in absolute units. The dimensionless coefficient Λ is determined on the basis of measurements of the two dimensionless functions $b(\theta)$ and $\beta(\gamma)$; this is preferable to determining Λ by dividing by each other the two dimensional quantities σ and ε, measured independently in absolute units with various instruments and by different measuring techniques.

Conclusions

1. A method is proposed for determing the light quantum survival parameter Λ in seawater from the characteristics of the light field of an isotropic source and light field of radiation in the sea. This parameter was calculated for several areas of the World Ocean. The highest value $\Lambda = 0.82 \pm 0.06$ for the waters studied was observed in the Black Sea, and the lowest, 0.32 ± 0.03, in the Sargasso Sea.

A relationship was observed between the three intrinsic characteristics of seawaters - the parameter Λ, attenuation index ε, and shape of the scattering indicatrix, characterized by the scattering angle $\bar{\gamma}$. The remaining characteristics of the waters studied fell on a single curve in the space of $(\Lambda, \varepsilon, \bar{\gamma})$, which opens up new possibilities for classifying seawaters.

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