INVESTIGATION OF CERTAIN HEAT- AND MASS-TRANSFER PARAMETERS IN THE OCEAN BY AN OPTICAL METHOD

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An optical method for studying fluctuations of the index of refraction of liquids and gases is described. The apparatus is described and experimental values of the coefficient of anisotropy and the magnitude of the temperature fluctuations for seawater are presented.

It is known that the variation of the physical properties of a medium affecting its index of refraction leads to fluctuations of the parameters of radiation propagating in the medium.

By measuring the statistical characteristics of radiation, information can be obtained on the limits of applicability of underwater holographic viewing systems. Knowing the statistical characteristics of the radiation one can judge the changes of physical properties of the medium and its structure [1].

Optical research methods based on measurements of fluctuations of the amplitude and phase of vibrations have been rather widely employed, but few experimental papers have appeared on the determination of the properties of optically transparent media by recording the angle of arrival of the radiation. This results from the considerable technical difficulties encountered in determining the angle of arrival of a beam.

The apparatus for measuring the angle of arrival of radiation and its fluctuations consists of a gas laser ($\lambda = 0.63\ \mu$), a sensor, and measuring apparatus (Fig. 1). The laser, placed in a positioning device, was mounted on one arm of an L-shaped bracket. The radiation was propagated along the axis of a tube rigidly attached to the bracket and designed to shield against the undesirable effect of the rough water surface on the beam. The beam then fell on a mirror which diverted it along the other arm of the bracket and directed it into the window of the sensor located on this arm.

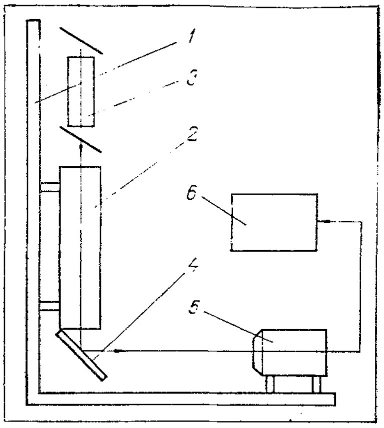

Fig. 1. Block diagram of experimental arrangement: 1) L-shaped bracket; 2) shielding tube; 3) LG-56 gas laser; 4) mirror; 5) measuring sensor; 6) recording apparatus.

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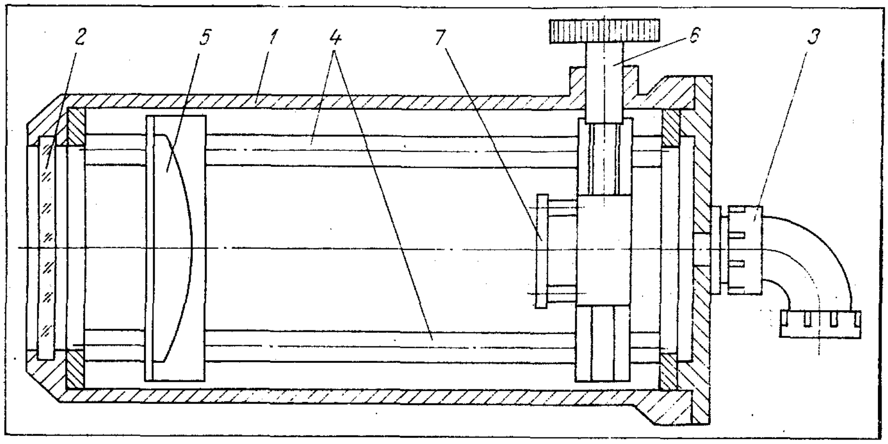

Fig. 2. Construction of sensor.

The bracket was immersed in water in such a way that the beam from the mirror to the sensor was propagated horizontally. By rotating the bracket about its vertical arm a definite orientation of the beam in the horizontal plane was achieved. The maximum depth of submersion of the sensor was limited to 5 m, mainly by the length of the laser power-supply cable. The construction of the sensor is shown schematically in Fig. 2. It consists of a housing 1 with an optical glass window 2. The laser power supply and its connections to the measuring apparatus are made through a hermetic joint 3. A position-sensitive photoresistor (PSPR) 7 on rails 4 inside the sensor housing in the focal plane of the cylindrical lens 5 can be displaced 0.125 mm in the plane perpendicular to the radiation by one turn of knob 6.

The fluctuations of the bright line formed by the cylindrical lens are transformed into an electric signal by the PSPR. The error of transformation is no more than 5% in the present case.

Since in general for a small load resistance ($R_l \leq 5$ mΩ) the sensor reacts also to a change in illumination [2], it was necessary to calibrate it by a fixed displacement of the PSPR.

Since the base length of the beam was short (L = 2 m), additional errors in determining the magnitude of the fluctuations of the angle of arrival of the beam could arise for a change in the oscillation mode of the laser or because of appreciable fluctuations in the transparency of the sea water. To eliminate the possibility of such errors the sensor was calibrated before each series of experiments.

The experiments were performed in "Hero" bay in the Sea of Japan in the evening at depths of 0.5, 1, and 1.5 m in a slight sea and in complete calm.

The results obtained are shown in Table 1 and Figs. 3 and 4. The table shows that in a slight sea the fluctuations of the angle of arrival are quite anisotropic. If the coefficient of anisotropy is expressed in the form [3]

$$\gamma = \sqrt{\frac{\langle \varepsilon_1^2 \rangle}{\langle \varepsilon_2^2 \rangle}},$$

it can be seen from Fig. 3 that in our case the coefficient of anisotropy increased monotonically with increasing depth. It can be assumed, however, that at a certain depth γ reaches a maximum and then decreases. Thus the depth of propagation of surface waves can be determined from the form of the experimental relation $\gamma = f(Z)$.

Figure 4 illustrates the dependence of the magnitude of the fluctuations of the angle of arrival on the depth of submersion. It is clear that an increase in depth leads to a decrease in the magnitude of the fluctuations.

Using Eq. (1), which relates the magnitude of the fluctuations of the angle of arrival and the index of refraction [4],

$$\langle \varepsilon^2 \rangle = \frac{4L \langle \mu^2 \rangle \sqrt{\pi}}{R} \quad (1)$$

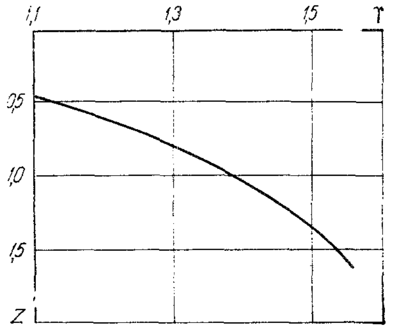

Fig. 3

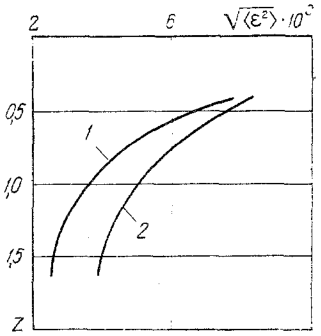

Fig. 4

Fig. 3. Dependence of coefficient of anisotropy γ on depth of submersion Z, m.

Fig. 4. Dependence of magnitude of fluctuations of angle of arrival of radiation $\sqrt{\langle\varepsilon^2\rangle}$ on depth of submersion: 1) parallel to wave; 2) perpendicular to wave; Z, m; $\sqrt{\langle\varepsilon^2\rangle}$, rad.

TABLE 1. Experimental Values of Fluctuations of Angle of Arrival of Laser Beam

Depth of submersion Z, m	$\sqrt{\langle \varepsilon_1^2 \rangle}\cdot 10^3$, rad	$\sqrt{\langle \varepsilon_2^2 \rangle}\cdot 10^3$, rad	Note
0,5	7,6	6,7	slight sea
1	5	3,6	slight sea
	0,87	0,87	calm
1,5	4	2,6	slight sea

and knowing the correlation distance R, the magnitude of the fluctuations of the index of refraction can be determined from the known value of $\langle\varepsilon^2\rangle$. Taking R = 0.5 m for the correlation distance [5], we obtain $\sqrt{\langle\mu^2\rangle} = 1.4\cdot10^{-3}$. From data in [6] the index of refraction of water for radiation of wavelength $\lambda = 0.63\ \mu$ is $n = 1.3314$. Assuming that the fluctuations of the angle of arrival result solely from temperature fluctuations, and using Eq. (2) in accord with [6],

$$\frac{dn}{dT}\,10^{-4}\ \text{deg}^{-1} = 0.985, \tag{2}$$

we find for $\sqrt{\langle\varepsilon_1^2\rangle} = 7.6\cdot10^{-3}$ rad, which is the maximum value in our experiments, the corresponding magnitude of the temperature fluctuations $\sqrt{\langle t^2\rangle} = 1.5\cdot10^{-3}$ deg.

Thus, knowing the statistical characteristics of the parameters of the radiation propagating in an inhomogeneous medium, the structure of the medium and the variation of its physical parameters can be determined. Using the optical method described, based on measurements of the statistical characteristics of the fluctuations of the angle of arrival of a beam, such physical parameters of the medium as temperature fluctuations, index of refraction, coefficient of anisotropy, correlation distance, etc. can be determined with sufficiently high accuracy.

It should be noted that the component variations of the index of refraction of biological material moving as a result of convective displacement in the surface layer of the medium can also contribute to the value of the angle of arrival and its fluctuations in our experiments.

NOTATION

λ, wavelength; R_l, load resistance of measuring sensor; L, base length of beam; γ, coefficient of anisotropy; $\sqrt{\langle\varepsilon_1^2\rangle}$ and $\sqrt{\langle\varepsilon_2^2\rangle}$, mangnitudes of fluctuations of the angle of arrival of beam propagating perpendicular to and parallel to a wave, respectively; Z depth of submersion of measuring sensor; $\sqrt{\langle\mu^2\rangle}$, magnitude of fluctuations of index of refraction; R, correlation distance; n, index of refraction; T, temperature; $\sqrt{\langle t^2\rangle}$, magnitude of temperature fluctuations.

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A METHOD FOR CALCULATING HEAT CAPACITY AND THERMAL CONDUCTIVITY OF LIQUIDS

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Methods employing easily obtainable empirical data are described for calculation of heat capacity, speed of sound, and thermal conductivity of liquids.

The methods proposed in this study for calculation of thermophysical properties are based on the theory of thermodynamic similarity. Use of thermodynamic similarity principles for description of the thermal properties of liquids and gases reveals a number of important principles and makes it possible to develop effective methods for computation of a large number of properties [1, 2]. One of the most important principles is the one-parameter law of corresponding states for the class of normal, nonassociated substances, i.e., the existence of one and only one dimensionless parameter (the defining criterion) that characterizes the individuality of the substance in the dimensionless equation of state [1].

The basis for description of thermal properties using thermodynamic similarity theory is the so-called expanded law of corresponding states [3], according to which the differences between values of the thermodynamic properties under given conditions and the same values for the ideal gas state at the same temperature must obey the rules of thermodynamic similarity. In the case of heat capacity, on the saturation line the expanded law of corresponding states for normal substances should have the form

$$C_p = C_p^0 + \Delta C_p(\tau,\ A),$$
$$C_v = C_v^0 + \Delta C_v(\tau,\ A), \tag{1}$$

where C_p and C_v are the molar heat capacities on the saturation line (for the liquid or vapor branch); C_p^o and C_v^o are the corresponding values in the ideal gas state) and ΔC_p and ΔC_v are the configuration heat capacities, which must be identical functions of the dimensionless temperature $\tau = T/T_{cr}$ and the defining criterion A for the entire class of materials considered.

The functions $\Delta C_p(\tau, A)$ and $\Delta C_v(\tau, A)$ for the liquid state were studied using available data on 60 materials and are presented in Table 1. [numerator, ΔC_p; denominator, ΔC_v, J/(mole•°K)].

For practical calculation of configuration heat capacity it is not obligatory to know explicitly the critical temperature and parameter A. Methods may be used to determine these

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