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OBJECTIVE HYDROSPECTRONEPHELOMETER FOR IN SITU MEASUREMENT OF O--ETC(U)
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10 AUTHOR(8): B.B./ Kel'balikhanov, E.I., Krasovskiy, E.I.

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OBJECTIVE HYDROSPECTRONEPHELOMETER FOR *IN SITU* MEASUREMENT OF OPTICAL
CHARACTERISTICS OF SEAWATER

[Kel'balikhanov, B. F. and E. I. Krasovskiy, Ob'yektivnyy gidrospektrofelometr dlya izmereniya "in situ" opticheskikh kharakteristik morskoy vody, in: Optics of the Ocean and Atmosphere (Optika okeana i atmosfery), Institute of Oceanology of the USSR Academy of Sciences, "Nauka" Publishing House, Leningrad, 1972, pp. 113-119; Russian]

The light scattering indicatrix is an important optical characteristic that must be known in solving many theoretical and applied problems of hydrooptics. Measurements of the scattering indicatrix in water samples may give distorted results because of the physical and chemical changes occurring in water during the ascent to the surface.¹ /11

An experimental determination of this characteristic under natural conditions has been found to be necessary for a qualitative estimation of the results of studies. A number of instruments²⁻⁵ for measuring the light scattering indicatrix of seawater *in situ* are known. The nephelometer described in Ref. 2 is designed for measurements of light scattering in the angular range from 3 to 163° at 5° intervals. In the nephelometer shown in Ref. 3, the measurements of scattered light are made at 12 fixed angles: 10, 20, 30, 45, 60, ..., 165°. Reference 4 discusses a nephelometer /1 with a laser light source, permitting measurements at fixed angles (1, 2.5 or 3.5° by changing the optical system), and further, from 25 to 135°. The most advanced nephelometer is the one described in Ref. 5. It can be used to measure scattering at angles from 1 to 170°. However, this nephelometer is designed for mounting on a submarine and is not suitable for operation from expedition ships.

Of all the above nephelometers, none covers the range of angles below 1°. And yet, it is necessary to know the scattering indicatrices in the range of small angles (below 1°) for a number of applications: for example, calculation of the light fields of a narrow-beam source and determination of the size distribution of a hydrosol by the method of solving inverse problems.

In the last few years, nephelometers permitting the measurement of scattering indicatrices in the angular range from 20' to 5-7° have been designed and tested. In particular, Ref. 6 describes a nephelometer that was subsequently modified by the staff of the Institute of Oceanology of the USSR Academy of Sciences. It is a laboratory instrument, and the measurements are performed on water samples. An *in situ* nephelometer is described in Ref. 7. The instrument utilizes a linearly polarized light source (ruby laser).

The operating principle of the *in situ* nephelometer we are proposing is analogous to the laboratory meter of K. S. Shifrin and V. I. Golikov.⁶ In contrast to the above instruments, the nephelometer we are describing permits the measurement of the scattering indicatrix over a wide spectral range (340-760 nm) *in situ* with a spectral resolution no worse than 4 nm in the angular ranges 0.1-2 and 3°. The instrument is designed to operate from a cable down to depths of 200 m.

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

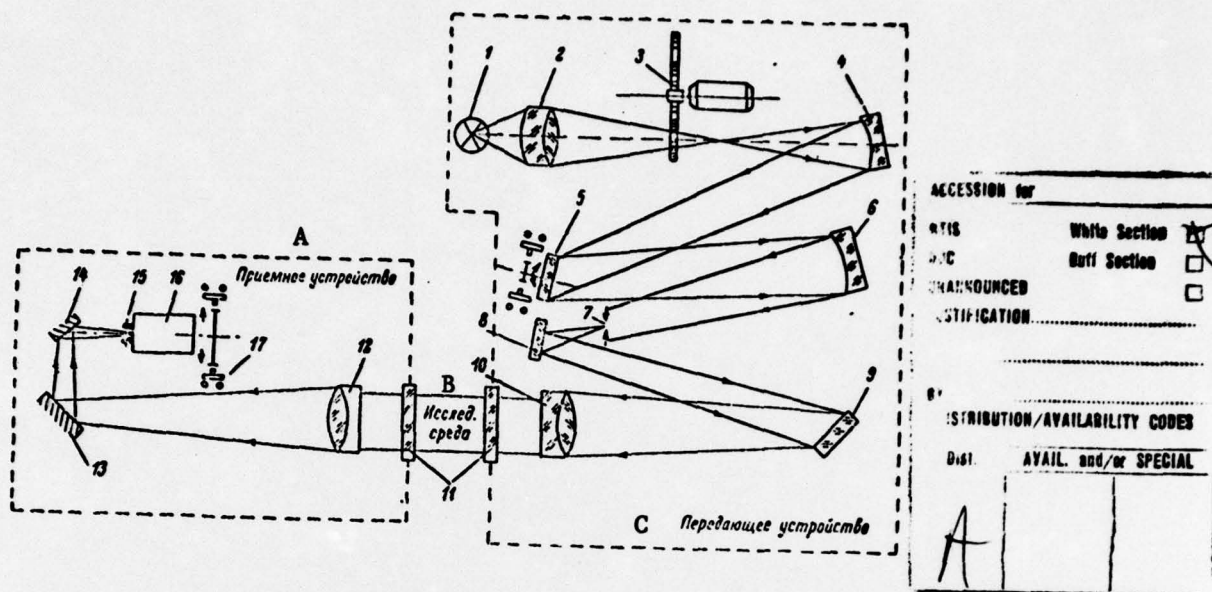


Fig. 1. Optical diagram of hydrospectronephelometer.

Explanations in text.

A - Receiving device; B - Medium studied; C - Transmitting equipment.

In addition to the scattering indicatrix, the instrument can measure the attenuation index in various regions of the spectrum, and can thus provide the necessary data for estimating the transfer of luminous energy in water.

Figure 1 shows an optical diagram of the submersible portion of the instrument. The light flux of radiator 1 is focused by condenser 2 onto the diaphragm of modulator 3, which functions as the entrance slit. The divergent modulated light flux is converted by lens 4 into a parallel one and projected on diffraction grating 5. The dispersed light flux reflected from the grating strikes spherical mirror 6, in the focal plane of which is located exit slit 7.

By scanning the grating on exit slit 7, one can obtain a light flux of different spectral composition. The degree of monochromatization is determined in this case by the number of lines of the grating, parameters of the optical system, and size of the entrance slit. The spectral region of the light flux defined by slit 7 is directed by mirrors 8 and 9 to objective 10, and, passing through protective illuminator 11, emerges into the medium under analysis. The light flux transmitted through the medium and illuminator 11 of the receiving unit is focused by mirror-lens system 12, 13 and 14 onto slit diaphragm 15. The diaphragm is rigidly joined to photomultiplier 16 of type FU-51 and constitutes the analyzer system of the receiving device. The analyzer scans linearly in the focal plane of objective 12 and thus measures the light flux in this plane photometrically. The linear scanning of the analyzer is converted into angular scanning and applied on the scale of a synchro receiver in the control desk.

The electric signal from the PM load is sent by cable to the control desk, where it is suitably amplified and fed to an EPP-09 recorder. Thus, the tracing made by the EPP-09 represents the distribution of the light flux in the focal plane of objective 12 of the receiving unit as a function of the analyzer scanning angle.

The equipment consists of a unit submerged in water, an optical diagram of which is shown in Fig. 1, linked by cable to the desk recording the signal and performing the remote control of the instrument as a whole.

All the manipulations carried out in the submerged portion of the instrument are controlled from the control panel by means of indicating lights.

The radiator and receiver units are placed in sealed pressure chambers and linked to each other and to the control panel by an NRShM type cable. In addition, the receiver and radiator units are linked mechanically by means of sectional cylindrical tubes with holes for sampling water, and are attached coaxially to each other. The number of sections determines the base between the receiver and radiator, and is established tentatively on the basis of the water transparency expected in the medium studied.

The scattering indicatrix is measured as follows: before the instrument is immersed in water, the light flux of the "dry" instrument is measured photometrically. At the same time, a spot of finite dimensions is measured photometrically in the focal plane of the objective (Fig. 1, 12). Under these conditions, the medium, which is actually "optically" pure, does not superpose any distortions. The instrument is then immersed to a given depth in the medium studied. Because of scattering properties, the medium disturbs the original image of the light spot and deforms it. The deformation will be greater, the more pronounced the scattering properties of the medium. Both the scattered and the direct light flux are subsequently measured photometrically by scanning the analyzer in the receiving /11 device. Superposing the tracings of the distribution of the light flux of the "dry" instrument and instrument immersed in the medium studied makes it possible to get rid of the direct light flux. The remaining difference carries information only on the scattering properties of the medium and characterizes the scattering indicatrix.

In addition to the scattering indicatrix, the instrument makes it possible to measure the attenuation index. For this purpose, readings corresponding to the zero position of the scanning angle of the analyzer are taken from the tracing of the distribution of the light flux of the "dry" instrument and instrument immersed in the medium. The value of the attenuation index is then calculated from the formula

$$\epsilon = \frac{1}{L} \log \frac{F_0}{F_x}$$

using Bouguers' law, formulated for an ideal case, namely, for monochromatic parallel radiation.

Here L is the distance between the receiving device and the source; F_0 and F_x are the light fluxes of the "dry" instrument and instrument immersed in water, respectively.

A real beam has a divergence different from zero. Comparison of the experiment with the calculations shows that increasing the beam divergence from $1'$ to 1° does not appreciably affect the change in the attenuation index and is in the range of experimental error (10%). This conclusion will be applied to the case in which the measurements are made by use of the base method of comparison. However, in the method based on a comparison of the results of measurement in air with those in water, it is necessary to use the formula

$$\epsilon = \frac{1}{L} \log \left(pq \frac{F_0}{F_x} \right),$$

where $p = 1.081$ is a coefficient allowing for the difference in light losses due to reflection at the air-water and water-glass interfaces. This coefficient is calculated from the Fresnel formulas; q , a coefficient allowing for the change in the illumination of the exit illuminator on passing from measurement in air to measurements in water, is given by the empirical formula

$$q = \frac{(D_0 + L)^2}{\left(D_0 + \frac{L}{n}\right)^2},$$

where D_0 is the diameter of the light beam of the exit illuminator; α is the divergence angle of the light beam in air, and n is the refractive index.

Thus, the distinctive characteristic of the instrument described consists in the use of a luminous energy analyzer made up of a diaphragm and PM, which scan jointly in the focal plane of the optical receiving system, combined with a diffraction grating permitting the measurement of the scattering indicatrix and attenuation index in a narrow band of any portion of the visible spectrum. /118

Principal (Optical) Parameters of the Instrument

1. Plane diffraction grating $b \times h = 25 \times 25 \text{ mm}^2$. $N = 500$ lines/mm.
2. Focal distance of mirror and lens objectives, $f = 500 \text{ mm}$.
3. Entrance and exit slits $d = 0.5 \text{ mm}$.
4. Diameter of diaphragms of the analyzer of the receiving device (set) $d_a = 0.05, 0.1, \text{ and } 0.5 \text{ mm}$.
5. Diameter of light spot in the focal plane of the objective (Fig. 1, 12) of the receiving device $d_n = 0.8 \text{ mm}$.
6. Linear course of analyzer $\ell = \pm 20 \text{ mm}$.

Figure 2 shows the result of measurement of the scattering indicatrix by the instrument described in the range $0.1-2^\circ$. At the same time, the scattering indicatrix was studied in the range $1-160^\circ$ by means of the SCN-57 standard instrument.

The measurements were performed in collaboration with the staff of the Hydro-optics Laboratory of the Institute of Oceanology, USSR Academy of Sciences.

The results of measurement of the scattering properties of the medium at small angles were calculated from the formula

$$G(\gamma) = c \frac{dF(\gamma)}{dF(0)},$$

where c , the instrument constant, is determined by such optical parameters of the receiving device as f , L and d_a , and is equal to $1.07 \cdot 10^4$; $F(0)$ and $F(\gamma)$ are the magnitudes of the signals measured at angles $\gamma = 0$ and $0.1-2^\circ$, respectively.

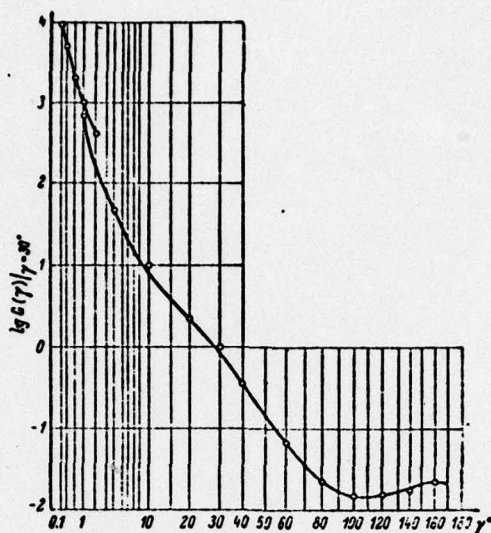


Fig. 2. Scattering indicatrix measured with hydrospectronephelometer in the angular range 0.1-2° and with a standard SGN-57 meter in the angular range 1-160°.

The measurements were made with the position of the diffraction grating corresponding to a wavelength of 0.53 micron and bandwidth of spectral radiation of 4 nm. In the SGN-57 instrument, the interference filter was used at the same wavelength, but with a transmission bandwidth of 10 nm.

Thus, at angles from 1 to 2°, the scattering indicatrix was studied with two different instruments. The divergence in the character of the slope of the curves in this angular range is insignificant. The extent to which such an extrapolation is a valid comparison of the results of measurements with two different instruments can be determined only by a suitable selection of statistical material. The result of a single measurement is given here.

Obviously, the region of the scattering indicatrix from 0.5' may be studied after introducing several structural modifications into the instrument: for example, decreasing the analyzer diaphragm to the threshold value, determined by the appearance of a diffraction pattern, with a suitable amplification of the source brightness; reducing the aperture of the source beam; increasing its directivity, and many others. /11

The instruments we have described were tested in the Southern Section of IOAN (Institute of Oceanology of the Academy of Sciences) and showed their fundamental applicability to the study of the optical characteristics of water *in situ*.

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