A Transparency-Meter for Ocean Water

By N. G. JERLOV, Oceanographic Institute, Gothenburg

(Manuscript received September 9, 1956)

Abstract

The significance of the geometry of the optical system in extinction measurements for a liquid dispersion is emphasized. In particular, the mechanism by which light is lost by scattering in a transparency-meter in the sea is discussed. The strongly selective absorption of yellow substance is demonstrated. A new transparency-meter sufficiently accurate for measurements in clear ocean water is described. A long optical path in the meter is attained by multiple reflection between three concave mirrors of equal curvature. The depth is recorded by means of a new device.

It has been clearly demonstrated that the penetration of daylight into the sea is dependent chiefly on absorption caused by the water itself, by dissolved substances, and by particles, whereas scattering by the particulate matter has less influence on the reduction of daylight with increasing depth. The results of such measurements are affected by the distribution of daylight above the sea, particularly by the sun's altitude, and generally they do not give a fully satisfactory representation of transparency as a property of the water.

The term transparency is more adequately applied to data obtained with a transparency-meter in which a beam of artificial light is used. Experiments with the transparency-meter lowered *in situ* can be conducted in all weathers when ordinary oceanographic work at sea is practicable.

The attenuation of light in the transparency-meter is due to absorption and scattering by the water and by suspended and dissolved matter. The sum of both effects of absorption and scattering is conventionally designated as extinction.

As a rule, sufficient attention has not been paid to the difficulties involved in extinction measurements for a liquid dispersion. These concern chiefly the usual arrangement at which a parallel beam of light is projected through the liquid after which it impinges on a photoelement or a phototube mounted behind a glass window. The mechanism at which light is lost by scattering in such a system is not *a priori* clear, and it is worth while to consider the role which scattering plays in the extinction.

The phototube intercepts scattered light from any object illuminated in the beam and the quantity of scattered light reaching the phototube depends on the location of the object (fig. 1). It has been shown (BLUMER, 1926; JERLOV and LILJEQUIST, 1938; POOLE, 1945; JERLOV, 1951, 1955; ATKINS and POOLE, 1952) that the angular distribution of scattered light in the sea approaches a pattern the polar surface of which is an ellipsoid of revolution, the point of observation being in one focus and the forward scattering strongly predominating.

Seeking an approximate expression for the light flux received at the phototube, we deliberately introduce some simplifications. Thus a strictly parallel beam is assumed and the random effects are entirely neglected as well as the increase in the path length due to obliquity of the rays. The deflection of the

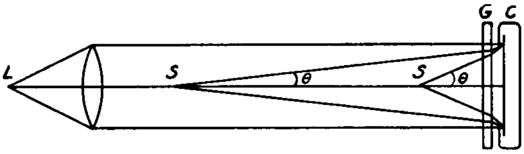

Fig. 1. Extinction measurement with a parallel beam of light from the source L. Two different distances from the scattering object S in the water to the photocell C behind the window G.

rays when crossing the glass window is, however, taken into account.

The light intensity in the direction Θ is called J_Θ. It is readily seen that the light flux received at the phototube is proportional to

$$\int_0^\Theta J_\Theta^3 \sin\Theta\cos\Theta d\Theta$$

or to

$$\int_0^\Theta \frac{\sin\Theta\cos\Theta d\Theta}{(1-\varepsilon\cos\Theta)^3}$$

where ε is the eccentricity of the ellipse.

The result of the integration is conveniently reduced to the formula

$$\left(\frac{\varepsilon}{1-\varepsilon}\right)^2 - \left(\frac{\cos\Theta}{1/\varepsilon-\cos\Theta}\right)^2$$

Evidence in the above-mentioned investigations argues in favour of the ellipsoid being much elongated as fairly large particles in the sea are mostly responsible for the scattering. It seems reasonable to choose a relation between the ellipse axis of 20 : 1 which gives $\varepsilon = 0.99875$.

Calculations for such an ellipsoid distribution were based on the geometrical dimensions of a transparency-meter with a light-path of 2 m and provided with a selenium barrier-layer cell with an active surface of 37.5 mm behind a glass window of a thickness of 15 mm. It is apparent from the diagrammatic representation of the results in fig. 2 that the light flux received by the cell is highly dependent on the distance to the particle. The total flux equals that obtained with a constant value of Θ of $1^\circ 25'$ over the whole path length. In the region near the cell the flux is irrespective of the distance, which proves that practically all scattering is included within a cone with a half-angle of 10°.

The pronounced forward scattering has bearing on subsurface daylight measurements. An ordinary photometer in the sea, recording daylight illumination on a horizontal surface, receives light from the whole upper hemisphere *i.e.* almost the total amount of scattered light. This explains why the reduction of daylight intensity with increase of depth is only in a small degree due to scattering. As a consequence it is possible to arrive at a measure of the scattering term by comparing extinction coefficients obtained by the transparency-meter with those obtained by the daylight photometer (JERLOV, 1946, 1951, 1953).

The significance of the geometry of the optical system in extinction measurements has also been realized by ATKINS, JOSEPH, POOLE, and others, particularly GUMPRECHT and SLIEPCEVICH (1952). The two latter evade the difficulty by using a lens-pinhole system. This is most useful whenever a strict definition of the scattering in relation to minimum angle is needed.

Thus the response of the transparency-meter to scattering by particles is dependent on the average minimum angle through which light is received by the phototube. When passing particle media the light is to some degree subjected to absorption which is generally selective. In addition an absorption by dissolved substances, in the first line by yellow substance, occurs.

Yellow substance, which is a fairly stable decomposition product of organic matter, exhibits a strongly selective absorption. This is

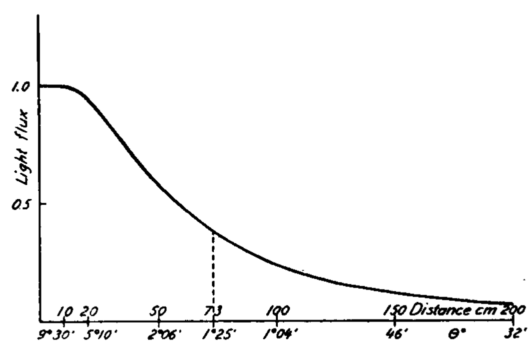

Fig. 2. Light flux (relative units) received by the photocell as a function of the distance to the scattering object in the water.

demonstrated by the absorption curve in fig. 3 which is derived from measurements with a Beckman quartz spectrophotometer. Two samples were studied. One was surface water collected in the Gullmar fjord. This sample was evaporated to a quarter of its volume and then filtered. The other sample was prepared by adding salt water to brown fresh water typical for some Swedish lakes. The flocks which gradually precipitated were filtered off after half a year. The results gained with the two samples are so conform that they are illustrated by one curve in fig. 3. This appears to be a case of almost logarithmic increase of absorption towards shorter wavelengths. It must be observed, however, that so far we do not know the molecular structure of yellow substance, or whether it includes several substances with different optical characteristics. An indication is given by KALLE (1937) who has found that yellow substance is always accompanied by a substance exhibiting fluorescence.

On account of its selective absorption yellow substance is readily studied by combining measurements to the red and to the ultra-violet (JERLOV, 1955).

In conclusion it may be remarked that the use of the transparency-meter has a twofold aim, one to trace accumulations of plankton or detritus in the upper strata in the ocean, and the other to determine the amount of yellow substance, which serves as an indicator of the organic production.

The method of recording the transparency *in situ* with a meter has met with considerable success in coastal waters. It has failed to yield any palpable results in the ocean, for the small variations in oceanic transparency require a meter with a longer light path than 2 m, which is the maximum for instruments hitherto built. It seems essential to increase the accuracy of the determinations in the ocean by increasing the light path and also by reducing the minimum angle. Considering the aim of these transparency measurements, we may as well desist from securing a strict definition of the scattering as to minimum angle according to the above deliberations, and thus avoid irrelevant complications. In view of this, an optical system of the following type has been devised, which does not render the instrument clumsy by increasing its length.

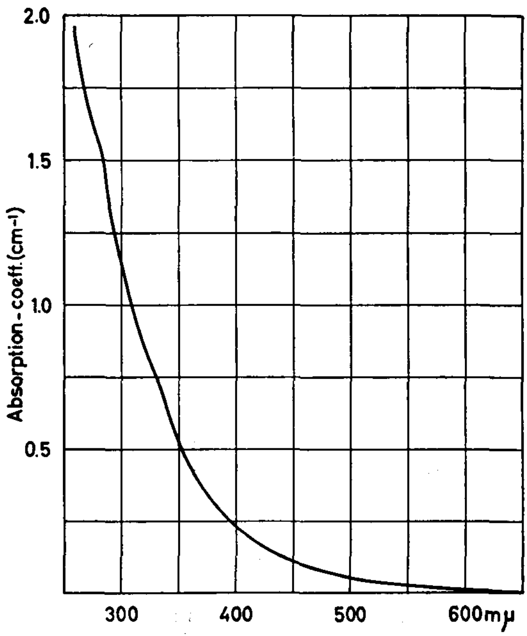

Fig. 3. Absorption curve for yellow substance.

A long optical path is obtained by multiple reflection between three concave mirrors of equal radius of curvature. This is according to a method suggested by WHITE (1942). Such an optical system was used by HERZBERG (1948) for the interpretation of planetary absorption spectra.

The optical arrangement in the transparency-meter is shown in fig. 4. One square mirror *C* is placed in the main case, two others *A* and *B* cut from one circular mirror are mounted in a small case attached to the main case. The radius of curvature of all three mirrors is one m. The distance between the windows of the cases must be somewhat above one m in order to compensate for refraction in the system air-glass-water. Light from the lamp filament *L* is focused on the entrance slit *S* by means of a mirror *D*. The emerging light is received by a multiplier phototube *P*. In spite of great reinforcement of the bars connecting the two cases, small displacements of the final beam cannot be avoided. Therefore, the inlet aperture is somewhat oversized and furthermore an opal glass *O* is mounted in front of the tube, which is placed as far back as possible in order to receive a cone of

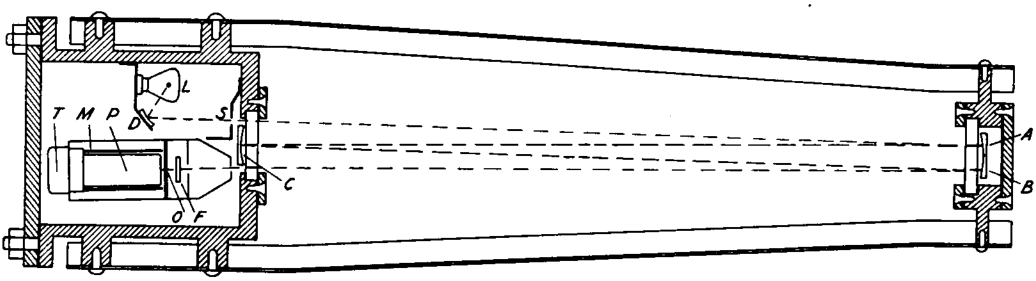

Fig. 4. Plan of the new transparency-meter.

minimum angle of scattered daylight. The disturbing light is further suppressed by placing a short screening tube outside the inlet and the window (not shown in fig. 4).

The system has the advantage that light losses only occur by reflexion at the mirrors and the windows. With proper adjustment of the mirrors, the number of light transversals between the mirrors can be chosen at ten or even more. An optical path of 10 m seems to be quite satisfactory for ocean water. Two interference filters F (575 and 375 mμ) can be introduced in front of the phototube by an electromagnetic device with remote control. The tube is provided with a mu-metal magnetic shield as suggested by WERTHEIM (1954).

The adjustments of the mirrors must be made with water between the windows of the two cases. There is certainly some advantage with another type of meter in which the mirrors are placed externally in the water exactly one m from each other. This would facilitate the adjustments but on the other hand expose the mirrors to the risk of damage.

The high voltage is supplied from the mains (220 V, a.c.) by stabilization (R.F.), transformation and rectification. The unit employs 9 steps of voltage accurately reproducible from 320 to 900 V.

The first stage of d.c. amplification is effected by a cathode-follower connected with the phototube in the case. A microammeter circuit of the balanced type is used. The microammeter has a full scale of 100 μA, and two other ranges of lower sensitivity, 1/10 and 1/100, are obtained by means of load resistors across the current. A smoothing circuit can be employed which introduces the time constants of 1, 5, and 10 sec., respectively. This is applied when the unit is connected to a daylight photometer in order to reduce fluctuations in the signal due to waves and swell in the upper layers of the ocean.

Utilizing a power amplifier the circuit can be connected with a Dewak recorder (JOSEPH, 1950). In this way records of the transparency are taken when the meter is lowered in the sea. It is advantageous to use a pressure or depth recorder the measuring head of which is incorporated in the transparency-meter. Such a depth recorder has been built according to the following principles.

When the measuring head is lowered into the water the pressure effects a stretching of the wire in a Wheatstone's bridge, and the accompanying changes in resistance unbalance the bridge. This is supplied with a constant direct voltage, and connected with a d.c. amplifier in series with a potential divider across which a battery is applied. The divider is run in steps by a reversible motor which is actuated by a polarity-sensitive Weston-relay supplied with the output voltage of the amplifier.

In the rest position the voltage from the bridge is thus balanced by that from the potentiometer and the input voltage to the amplifier is zero. A pressure change is linearly transformed into a voltage change applied to the amplifier. For a certain change corresponding to 5 m depth the relay responds, the motor starts and turns the divider one step which brings down the voltage to the amplifier to zero.

The device is connected with the Dewak recorder which marks every fifth meter on the wax paper, in separate columns for increasing and decreasing depth. The depth range of the device so far built is 0—300 m. The accuracy in the absolute depth determination is one per cent but obviously the relative accuracy is higher. The depth can also be directly read on a voltmeter.

REFERENCES

ATKINS, W. R. G., and POOLE, H. H., 1952: An experimental study of the scattering of light by natural waters. *Proc. Roy. Soc.* B, p. 321.

BLUMER, H., 1926: Die Farbenzerstreuung an kleinen Kugeln. *Zeits. f. Physik*, **39**, p. 195.

GUMPRECHT, R. O., and SLIEPCEVICH, C. H., 1953: Measurement of particle sizes in polydispersed systems by means of light transmission measurements combined with differential settling. *Journ. Phys. Chem.*, **57**, p. 95.

HERZBERG, G., 1948: Laboratory absorption spectra obtained with long paths, p. 346—54 in Kuiper (ed.), The atmospheres of the earth and planets.

JERLOV, N. G., 1946: On antirachitic ultra-violet radiation in the sea. *Medd. Oceanografiska Institutet*, Göteborg, No. 8.

— 1951: Optical studies of ocean water. *Rep. Swedish Deep-Sea Exp.*, **3**, No. 1.

— 1953: Particle distribution in the ocean. *Rep. Swedish Deep-Sea Exp.*, **3**, No. 3.

— 1955: The particulate matter in the sea as determined by means of the Tyndall meter. *Tellus*, **7**, p. 218.

JERLOV (JOHNSON) N. G., and LILJEQUIST, G., 1938: On the angular distribution of submarine daylight and on the total submarine illumination. *Svenska hydr.-biol. komm. skrifter*. Ny serie, Hydrography 14.

JOSEPH, J., 1950: Durchsichtigkeitsregistrierungen als ozeanographische Untersuchungsmethode. *Deutsche Hydr. Zeits.*, **3**, p. 69.

KALLE, K., 1937: Meereskundliche chemische Untersuchungen mit Hilfe des Zeisschen Pulfrich Photometers. *Chem. d. Hydr. mar. Meteor.* H. VI.

POOLE, H. H., 1945: The angular distribution of submarine daylight in deep water. *Scient. Proc. Roy. Dublin Soc.*, **24**, No. 4.

WERTHEIM, G. K., 1954: Design and operation of a bathyphotometer. Woods Hole Oceanographic Inst., Ref. No. 54—65 (Unpublished manuscript).