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THE TRANSPARENCY OF SEAWATER.

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THE transparency of sea water has a twofold importance. Firstly it is the factor, which determines the strength of submarine illumination for any given intensity of the daylight incident on the water surface. Consequently transparency also limits the depth of the productive surface-layers, where the photosynthesis of marine algae and phyto-plankton still gives a positive yield. Secondly, transparency observations afford a measure of the amount of solid particles present in the water, which, leaving inorganic detritus aside, can be considered as potential food for marine organisms. For both reasons measurements of the transparency of sea water have considerable interest both to physical oceanography and to marine biology.

The traditional method of measuring the transparency of sea water which makes use of the Secchi disc or of some similar contrivance, lowered into the sea at daytime until it just disappears and raised again until it becomes barely visible, is very crude and admittedly only gives a rough indication of the transparency of the water relatively near the surface. Thanks to the advent of photo-electric cells and more recently of "photo-elements" (rectifying cells) it has become possible to measure submarine illumination down to moderate depths and to work out mean values of the "vertical extinction coefficient", as defined by Atkins and Poole, for the columns of sea water lying between the depths in which measurements are made. Apart from the errors inherent in subsurface light measurements, due to variations in the incident daylight, to wave-motion and to shadowing effects from the hull of the ship[1]) the method suffers from the limitations set by turbid surface layers to daylight measurements with the Secchi disc. Further, the rapid variations in spectral composition which daylight undergoes with increasing depth, makes the extinction coefficients worked out from such measurements not strictly comparable *inter se*, unless the measurements are made with filtered, nearly monochromatic light, which again further reduces the depth to which measurements may still be carried out. Finally, owing to the highly diffuse character of subsurface daylight, the vertical extinction coefficient does not refer to any well-defined length of path of the lightrays, since their majority is more or less oblique to the vertical.

A special instrument designed for measuring *in situ* the transparency to electric light of a column of sea water of sharply defined length was constructed in Bornö Station some years ago and has since then been used on board our research ship "Skagerak". Since the "transparency-meter" has already been shown to this Council in 1934 and has been described in the *Journal du Conseil*[1]), it may suffice to recall the principle of its construction (Fig. 1 a). A slightly divergent cone of electric light is sent out into the sea water through a plate-glass window from an autocar-lamp behind a hemispherical lens. The beam is reflected against a mirror 100 cm. distant from the window and returns to a second window, where it impinges on a photo-element, a rectifying selenium cell from Dr. B. Lange. Keeping the lamp-current constant, the photo-current from the cell gives a measure of the transparency of the 2 metres length of sea water through which the light passes. Reading the photo-current produced in air, before the instrument is immersed, one can compute values for the extinction coefficient of the water at each depth where readings are taken. Recent modifications in the construction are: (a) the introduction of a second cell exposed behind a milk-glass to the direct light from the lamp, enabling the observer to correct the readings with the "water-cell" to constant emission from the lamp; (b) a more robust construction of the envelope and taking the windows from "securit" glass makes it possible to use the transparency-meter also at

[1]) On board of the new Swedish research ship "Skagerak" an arm 7 metres in length is mounted from the stern by means of which light measurements can be carried out with a minimum of shadows from the hull.

[1]) Vol. X, p. 48.

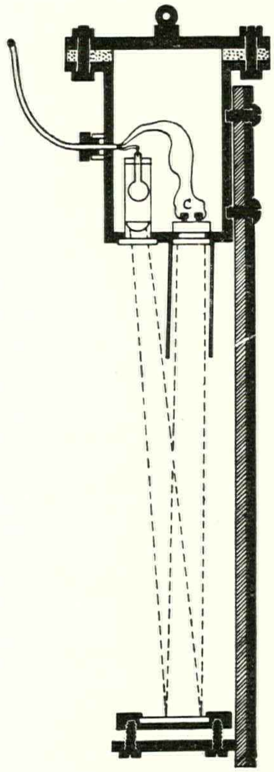


Fig. 1 a.

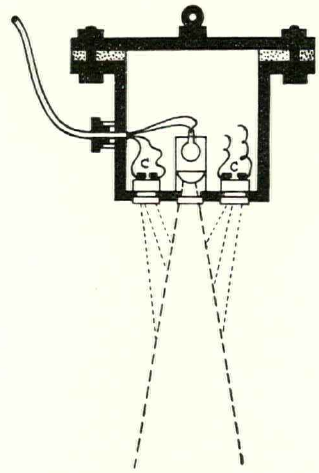


Fig. 1 b.

greater depths. The cable used with the new instrument has 5 leads instead of 4, as with the older, I-cell instrument. The transparency-meter is preferably to be used in a horizontal position, when the transparency of a water layer only 15 cm. thick may be measured.

Observing the photo-current on a high-sensitive "light-spot" microammeter from Siemens & Halske or a "multiflex-galvanometer" from B. Lange, while the instrument is being lowered with the lamp-current on, an examination of the optical properties of the sea water at different depths can be made very quickly. In Swedish fjords very abrupt variations in the transparency with depth are as a rule found, the photo-current changing by 50 % or even more within a sheet of water less than 1 metre thick. A sudden drop generally occurs at the density boundary, revealing a "cloud" suspended particles, plankton or organic detritus, which accumulated there. A rise in transparency is very often found at the level of the threshold of the fjord, below which the water is more or less stagnant, leaving time for the suspended particles to settle.

Measurements with the transparency-meter appear to be the quickest way of locating layers of special interest to the plankton biologist. They can be carried out at any time of day or night, independant of surface-illumination, and also beneath a turbid surface layer almost impermeable to daylight, such as one often encounters in our fjords. Since the spectral composition of the light beam leaving the first window always remains the same, the values of the extinction coefficients found at different depths are always comparable *inter se*, which is not the case with those computed from daylight measurements. Finally the beam of electric light is much more sensitive to the scattering effect due to suspended particles than subsurface daylight, with which scattering is largely compensated through back-scattering.

The "scattering-meter" (Fig. 1 b), also constructed at Bornö, affords evidence supplementary to that given by the transparency-meter. Thus where reduced transparency to light is due to suspended particles, the scattering-meter, which reacts only to light scattered backwards from a strong beam of light against particles suspended in the surrounding sea water, will give an increased photo-current. Where on the other hand reduced transparency is due to dissolved coloured matter, no corresponding increase in the scattered light will occur. In the open sea such substances are no doubt a rare occurrence, but in fjords and still more in lakes, where the run-off water will carry a certain amount of humus, this may form a contributory cause to the extinction of light.

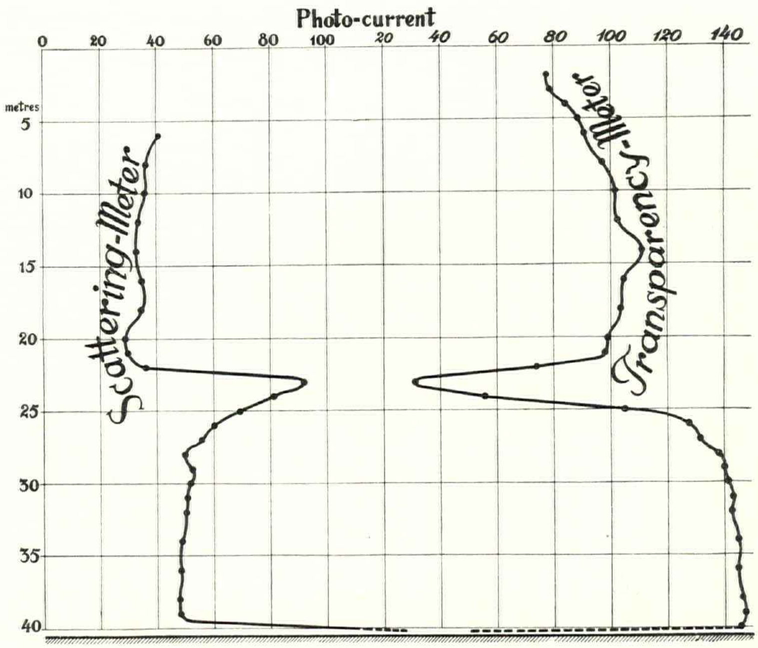


Fig. 2.

Both instruments may be used with colour-filters introduced, either in the way of the emergent lamp-light or else before the cells, so that the transparency of sea water to light of different spectral composition may be studied. It was hoped in this way to arrive at a better definition of the nature of the scattering particles, i. e. to find out whether they are organic detritus or plankton or inorganic detritus from the bottom or from rivers, but the experience so far gained is much too limited to allow of any definitive conclusions in this respect.

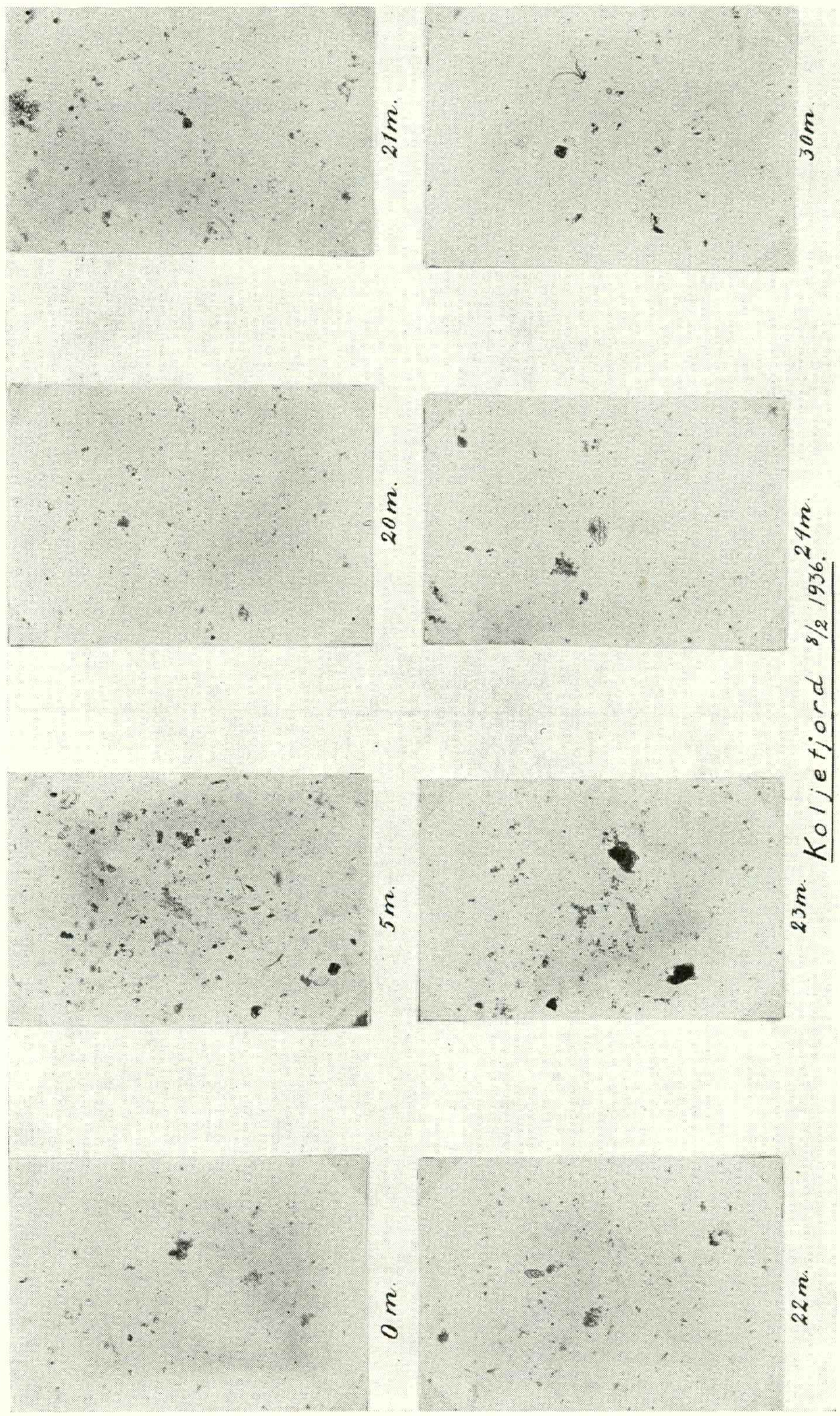
As an example of results obtainable with these two instruments[1]), graphs showing the variations in transparency and in scattering with depth in one of our most secluded fjords, the Koljefjord, to the N. of the large island Orust, west coast of Sweden, are reproduced in Fig. 2. Since the measurements were made in day-time, the scattering-meter, owing to diffuse daylight, was not used nearer the surface than in 6 metres. Both curves show an upper and a lower layer of nearly homogeneous optical properties separated by a very sharp drop in the transparency curve and a corresponding rise in the scattering curve at 23 metres. At this depth there was also a considerable rise in salinity, a "density boundary".

In order to find additional evidence for the presence of scattering particles[1]) at this optical boundary, Lic. H ö g l u n d, plankton specialist to our Commission very kindly undertook to take micro-photographs of the particles accumulated in sedimentation cylinders from water samples, taken at certain depths. A series of such photographs is reproduced in Fig. 3 where the sample from 23 metres is seen to contain large and very opaque particles, obviously *débris* from algae, whereas both the samples from 22 and from 24 metres are seen to contain much less. Curiously enough there appeared on the sedimentation micro-photograph from the sample taken in 5 metres a second maximum of particles which were however relatively less opaque in character and to which no corresponding change is discernible in the transparency curve.

It is worthy of attention, that whereas the transparency of the upper layer in the fjord is distinctly *lower* than that of the deeper layer below the particle cloud at 23 m., there is no corresponding difference in scattering, in fact the scattering curve indicates that the upper layer is poorer in

[1]) A recent construction will enable us to send down the transparency-meter and the scattering-meter as one unit making use of a 6-lead cable and measuring the transparency to one direction and scattering to the opposite direction in the same water layer.

[1]) Mainly organic detritus plankton of all kinds being comparatively scarce at this occasion.



(Microphoto, Höglund).

suspended particles than the lower layer. To some extent this deviation from the general rule of an antisymmetrical trend of the two curves may possibly be due to a difference in size between the particles suspended within the two water layers. It seems however more plausible to assume the upper layer to be richer in humus from the shore than the water in the lower layer, which must be largely derived from the sea outside the fjord.

The same cloud of suspended particles was found also in the fjords inside Koljefjord, viz. in Kalvefjord and Havstensfjord, where it was found to be quite as pronounced but to occur at slightly lower levels, viz. at 24 and 25 metres respectively. Measurements with orange filter and a blue-green daylight filter inserted before the cells, which were also carried out, gave results very similar to those found with the electric light unfiltered.

It is of further interest to notice, how remarkably clear the bottom water of the Koljefjord is to within less than 1/2 metre from the surface of the very fine sediment covering its bottom. This proves that the water must for a very long time have been absolutely stagnant, allowing even the finest particles time to settle, a fact which is further borne out by the low oxygen content normal to the bottom water in these fjords.

As a remarkable contrast to these results observations made a few days before in the open Skagerak near the place where it attains its greatest depth, may also be quoted here. The transparency-meter was lowered to within 25 metres of the bottom at 525 metres. The transparency did not vary very much from surface to bottom, attaining its maximum at about 250 metres. But the influence of the bottom sediment in the shape of a decreased transparency here made itself felt already 50 metres above the bottom. The transparency-meter thus furnishes evidence regarding the state of motion near the bottom.

Further studies along the lines here set out will afford information on the amount and location of potential food stuff suspended in coastal waters which is of interest to the biologist and also, perhaps, where daylight measurements are difficult or impracticable, to allow the oceanographer to compute the intensity of subsurface daylight at various depths from measurements of its intensity above the surface. Attempts to this purpose will be made shortly from cruises with the "Skagerak".