Measurement of Submarine Daylight

By Dr. H. H. Poole

SUBMARINE measurements of solar radiation are of interest to oceanographers, who are concerned with such problems as the rate of rise of temperature of the water, the rate of photosynthesis, the movements of zooplankton, or the depth limits of daylight vision for fish. They also enable us to measure the opacity of the water, which, being an index of the amount of matter in suspension, may give valuable evidence as to its previous history, and is likely to be of importance in connexion with the nutrition and migration of fish.

A thermopile with suitable colour filters has been used by Birge and Juday to measure the total radiation, and that in different spectral bands, at various depths in American lakes, but for work at sea the measurement of the very small potential differences presents difficulties. As the spectral sensitivity range of the selenium rectifier photoelectric cell covers the band showing appreciable penetration through sea-water, it appears to be the most convenient instrument at present available for submarine work.

This cell has a range of sensitivity extending somewhat beyond both ends of the visible spectrum, with a maximum about 595 mμ (that of the eye being about 555 mμ). It appears to be permanent, apart from temporary fatigue or temperature effects, which may amount to a few per cent in strong illumination. For small illuminations the current generated is proportional to the light, but in strong light the ratio current/illumination falls appreciably, and the necessary corrections must be found if the cell is to be used to measure intense illumination. The fall in this ratio with increasing illumination becomes much more important with a high-resistance external circuit, so that a low-resistance measuring instrument is always desirable, and sometimes essential.

The Weston selenium cell which has been used by Utterback, and also by Atkins and Poole, gives, when exposed under a sheet of opal-flashed diffusing glass, a current of one microampere for about 20 lux. With a 10 ohm galvanometer the sensitivity would fall to about 1 μamp. per 25 lux in full sunlight. The Lange selenium cell used by Pettersson is more sensitive, giving 1 μamp. for about 5 lux in weak light. The fall in sensitivity in strong light is, however, so great that the cell must be protected by a suitable reducing screen when used to measure bright daylight. This screen must be removed for weak light readings.

The choice of a suitable instrument to measure the current presents certain difficulties, as the claims of current sensitivity, lowness of resistance, quickness of reading, and insensitivity to the motion of the ship, are not easily reconciled. Utterback has used a special marine galvanometer, Atkins and Poole a modified form of their potentiometer method previously used with emission cells, adapted so as to include the principle and advantages of the zero-resistance circuit devised by Campbell and Freeth, while Pettersson, aided by the greater sensitiveness of his Lange cells and the comparative steadiness of his ship, has found simpler pointer and light-spot galvanometers satisfactory in his work.

The cell mounted behind a strong glass window in a watertight case is lowered to any required depth by means of a wire and a spar projecting over the ship's stern, thus minimizing the shading effect of the ship and the vertical movements due to rolling. Utterback uses a case large enough to contain a set of colour filters, which can be interchanged by an electromagnetic device. This is a great advantage, but the size and complication of the apparatus are drawbacks, and most workers have contented themselves with the use of external filters laid on the window, which is generally horizontal, and changed by hauling the photometer on board. Above the colour filter is placed the opal diffusing glass, the use of which is rendered necessary by the varying obliquity of the illumination to be measured. The transmission of the colour filter is not affected by such variations in obliquity, as the filter is below the opal, and submarine light the obliquity of which is greater than 48°, and which would be prevented by internal reflection from reaching the cell if the diffusing glass were absent, can reach the internal diffusing layer in the opal glass and be duly measured.

The use of colour filters to limit the range of sensitivity is rendered necessary by the differential absorption of the water, which entirely alters the average composition of the radiation with depth, and thus alters also the sensitivity of the cell, so that it is very difficult to interpret the submarine readings of a selenium cell without filter. The following Jena glass filters, each 2 mm. thick, seem to be suitable for general work : red, 720–600 mμ, *RG* 1 ; green, 600–480 mμ, *VG* 9 ; blue, 480–360 mμ, *BG* 12. The limits are only approximate and are affected by the falling sensitivity of the cell towards both ends of the spectrum.

The variations in the surface light must be observed by a second cell exposed under a similar filter and opal glass in a position on deck as free as possible from shading by spars and rigging. The photometer is directly compared side by side with the submarine photometer, and the simplest means of expressing the submarine illumination is as a percentage of the surface light in the same spectral band at the same instant.

It is more difficult to express the submarine illumination in definite units. The selenium cell, being more sensitive than the eye to both ends of the visible spectrum, does not differ very greatly from the latter in its estimate of common illuminations of different predominant colours. Thus, if it is standardized with a filament lamp at a colour temperature 2,360° K., it appears to under-rate average sunlight by some 10–20 per cent. The use of a higher temperature source for standardization reduces this discrepancy, and some workers have used for this purpose the Davis-Gibson colour filter, reproducing with fair accuracy average noon sunlight. We can then express in 'lux' the reading of a cell exposed without colour filter in air, without introducing any serious error, by the use of a term which is strictly only applicable to visual measurements. With colour filters, however, or under water, which acts as a colour filter, this quasi-visual scale becomes meaningless and misleading.

The ideal procedure is evidently to express the results in terms of the radiant power in the different spectral bands, say, in microwatts per square centimetre. Clarke has used this method of presentation for his work with emission cells in the western Atlantic, and Atkins and Poole have also standardized some of their cells in power units. The lowness of the colour temperature of all ordinary sources, however, limits the accuracy of the standardization, and has led Ångström to suggest a method of standardization by means of sunlight which may prove to be the best available.

There is general agreement between the results obtained by workers on both sides of the Atlantic and in the north-eastern Pacific, the large variations in the opacity of the water found by all being obviously due to local conditions. The clearest water so far recorded was found by Clarke in the Sargasso Sea. Working down to 180 metres, he found a value as low as 0·03 for the extinction coefficient of blue light. This means that the fall in the illumination on a horizontal surface was only 3 per cent per metre, the light falling to one tenth of its value at about 80 m. depth. In this water both green and violet light gave coefficients close to 0·05, while for the light passing through an *RG* 1 filter Clarke found a coefficient 0·08 for depth range 20–80 m. This is an extraordinarily low coefficient for 'red' light, and may possibly be due to the action of the overlying water layers (in which the absorption was much more rapid) in removing all wave-lengths much longer than 600 mμ, leaving only a very narrow spectral band of orange-red.

In coastal waters higher coefficients are always found, the absorption of the shorter waves increasing more rapidly than that of the longer. Thus, in both the English Channel and in the north Pacific the coefficient for blue and green is generally about the same, and not far from 0·1 at a distance of 20 miles off shore, the illumination falling to one tenth of its value every 23 m., the corresponding average figures for red being 0·4 and 5·75 m. Closer inshore, green becomes the most penetrating colour, the coefficients for all colours rising with the increased turbidity of the water.

In considering the variation of opacity with depth, one must remember the 'hardening' effect of absorption on polychromatic radiation, although this effect is greatly reduced by the use of colour filters. It is still probably of importance with the *RG* 1 red filter, as the longer wave-lengths of the range covered are absorbed even more rapidly than those near the 600 mμ limit. The effect is probably of much less importance with the green and blue filters.

Real variations of opacity with depth are often met with. As a general rule, ocean water becomes clearer below the surface layers, but inshore waters often show irregular variations, which may be very useful for studying their stratification. For exploring these rapid changes of opacity the use of Pettersson's transparency meter, which measures the intensity of a beam of artificial light reflected through 2 metres of water, is almost certainly preferable to the deduction of the opacity from the ratio of the daylight illuminations at two different depths, but it is not easy to correlate the results obtained by the two methods.

It is evidently highly desirable that oceanographers should be provided with a standardized method suitable for routine measurements of submarine daylight, and with this end in view the International Council for the Exploration of the Sea arranged for a special meeting of workers in the subject at the 1936 meeting at Copenhagen. It would seem that some further experience of the available cells and modes of measurement is desirable before any definite specification of apparatus and methods can be drawn up. In the meantime, a fairly full review by different authors of the work done up to date, with extensive bibliographies, will be found in the report of the 1936 meeting of the Council, and a report of the special sub-committee then appointed to consider the question is being presented at the meeting this month in Copenhagen.

Greenland Culture: (1) The Norsemen*

ACCOUNTS of the ill-fated Norse settlements in Greenland in medieval times, such as that recently published by Dr. Nörlund (see NATURE, **133**, 949) have been based hitherto on the evidence afforded by the eastern settlement (now the district of Julianehaab), in which, thanks to the researches of the last fifty years, most problems of topography have been solved and the cultural history elucidated in no little detail by archæological discovery. Of the western settlement, however, in the Godthaab District little was known either from literary sources or from archæological investigation before the expeditions of the Commission for Scientific Research in Greenland, of which the results have been described recently by Dr. Aage Roussell. It was inferred, however, with reasonable certainty that the place now known as Kilaussarfik, visited by Daniel Brunn in 1904 and the site of Dr. Roussell's excavations in 1930, 1932 and 1934, was to be identified with Sandnes, and Ameralik Fjord with the ancient Lysufjördr, not least, perhaps, on account of the rarity of such a sandy formation on the rock-bound coast of Greenland. As, however, the area is being submerged rapidly, and the coast-line has changed considerably since the Middle Ages, this is by no means indisputable evidence.

Historical records relating to the west settlement are few. Apparently it was established simultaneously with, or just after, the east settlement, shortly before A.D. 1000. The Saga of Eirik the Red mentions a serious epidemic there in the first decade of the eleventh century. By the middle of the fourteenth century, Skraellings (Eskimo) had occupied all the west settlement, "so there are many horses, goats, cattle and sheep run wild, and no people, neither Christian nor heathen". All archæological finds, in default of evidence to the contrary, are to be regarded as prior to 1365.

In addition to the church at Sandnes and the neighbouring farm, of which the name is unknown, Dr. Roussell excavated in 1934 two other farm sites on the opposite side of the fjord. Of these, Umiviarssuk alone has been described, the important results obtained at Ujaragssuit still awaiting publication.

The site investigated at Sandnes included church and churchyard, house, smithy, and two large stable complexes. The store-house—invariably part of a Norse farm—presumably stood on the fjord bank, but, if so, it had been washed away. The central part of the farm had been built on sloping ground and a constant movement of soil has covered the whole site with midden, making it impossible to arrive at any accurate idea of stratification. At times, objects were found above others which obviously were of later date.

Since the date of Daniel Brunn's visit, the church ruins at Sandnes have suffered much damage owing to submergence and climatic conditions. Consequently it was found impossible to determine the extent of the churchyard; but accumulations of stones on the fjord beach indicate the probable limit of interment. Only in the westerly part of the churchyard were interments uncovered.

No less than forty-two burials were found huddled in a confined space. They lay under the midden in coarse yellow gravel and only just below the original surface. Owing to crowding, older graves frequently had been disturbed in digging new, and half skeletons, or skeletons with lower limbs hewn off, were found. As is usual in Christian burials, the body lay on the back with the head towards the west and arms crossed on the breast. One interment in the south end of the area contained two adults, presumably man and wife, with the skeleton of a child lying on each. Alongside and evidently buried at the same time lay a fifth skeleton, not fully grown, and beside the skeletons was a small crudely fashioned wooden cross, the only piece of grave furniture found *in situ*. It may be presumed that these five burials were the result of an epidemic, such as is mentioned in the sagas of Eirik and Thorfinn.

* Researches into Norse Culture in Greenland—Sandnes and the Neighbouring Farms. By Aage Roussell. Appendix: Greenland Runic Inscriptions, 4. (Meddelelser om Grønland, Bind 88, Nr. 2.) Pp. 232+6 plates. 11.00 kr.

Researches into Norse Culture in Greenland—Animal Remains from the West Settlement in Greenland, with Special Reference to Livestock. By Magnus Degerbøl. (Meddelelser om Grønland, Bind 88, Nr. 3.) Pp. 55+1 plate. 2.50 kr.

Researches into Norse Culture in Greenland—Evidence of Iron Extraction at Sandnes, in Greenland's West Settlement. By Niels Nielsen. (Meddelelser om Grønland, Bind 88, Nr. 4). Pp. 14+1 plate. 0.75 kr.

(København: C. A. Reitzels Forlag, 1936.)