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PARTICLE DISTRIBUTION AND LIGHT ENERGY UTILIZATION WITH SPECIAL REFERENCE TO THE INDIAN OCEAN*

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ABSTRACT

Particle distributions in the Indian Ocean have been studied by means of light scattering observations made through 45° on collected water samples. Since a rough relationship exists between primary production, stock of phytoplankton and total amount of particles such observations are indicative of oceanic productivity. Thus an abundance of particulate matter is found at the fertile divergence zone associated with the boundary at 8°-9°S between the South Equatorial Current and the Countercurrent. Several series of measurements in the Indian Ocean and the Red Sea show that the penetration of radiant energy (from sun and sky) in areas of high productivity is less effective than it is in areas which are poor in particles. —A newly developed quanta meter is briefly described. This meter records number of quanta in the spectral range of 350-700 nm which is photosynthetically active. A method is presented which allows of converting simple underwater observations of blue light into quanta within the range mentioned.

INTRODUCTION

THE particle content in the ocean is readily studied by means of light scattering methods. The general procedure involves projection of a light beam into the water and recording by a sensitive detector the scattering produced by particles through a defined angle or angular range. The scattering values represent the particle content in the sense that they yield a measure of the total particle surface.

PARTICLE DISTRIBUTION

The author utilized an *in vitro* method for recording scattering through 45° on water samples collected in the Indian Ocean during the Swedish Deep-Sea Expedition. For detailed information especially concerning the precautions necessary to secure uncontaminated samples reference may be made to the general report (Jerlov, 1953).

The mentioned data include a vertical section of particle distribution across the Equatorial Currents near long. 88°E (Fig. 1) as well as a series of vertical profiles of particle content for various stations (Fig. 2) the localities of which are shown in Fig. 3.

The chief object of this paper is to consider physical factors related to the productivity aspect and so our interest will be limited to the upper layers of the ocean. The particle distributions of Figs. 1 and 2 bring out several important features. In the meridional section across the Equatorial Currents an abundance of particles occurs at the divergence associated with the boundary at 8°-9°S between the South Equatorial Current and the Countercurrent. On the other hand the convergence zone at 4°S is relatively poor in particles. The pattern conforms with the distribution of primary production which is believed to be proportional to the total particle content (Jerlov, 1968).

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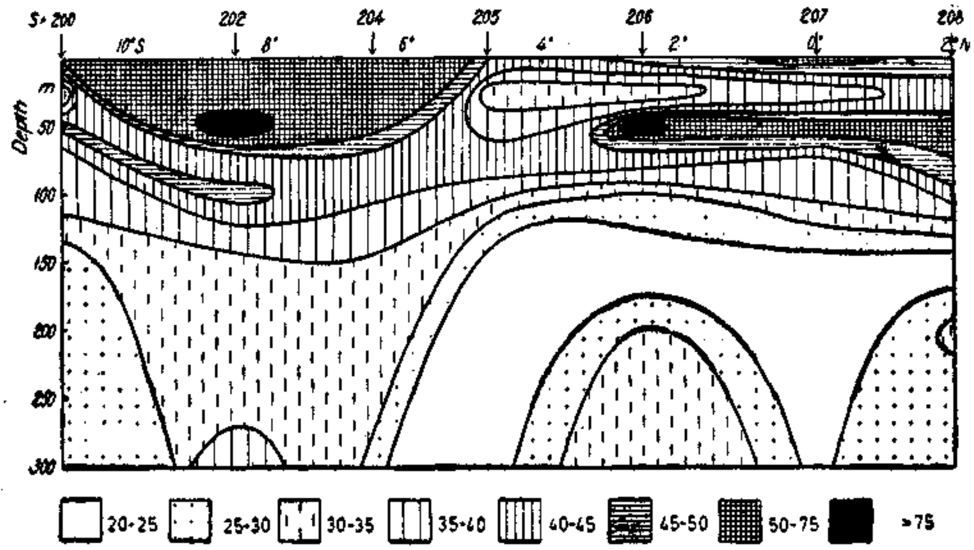

Fig. 1. Vertical section of particle distribution across the Equatorial Currents near long. 80°E in the Indian Ocean.

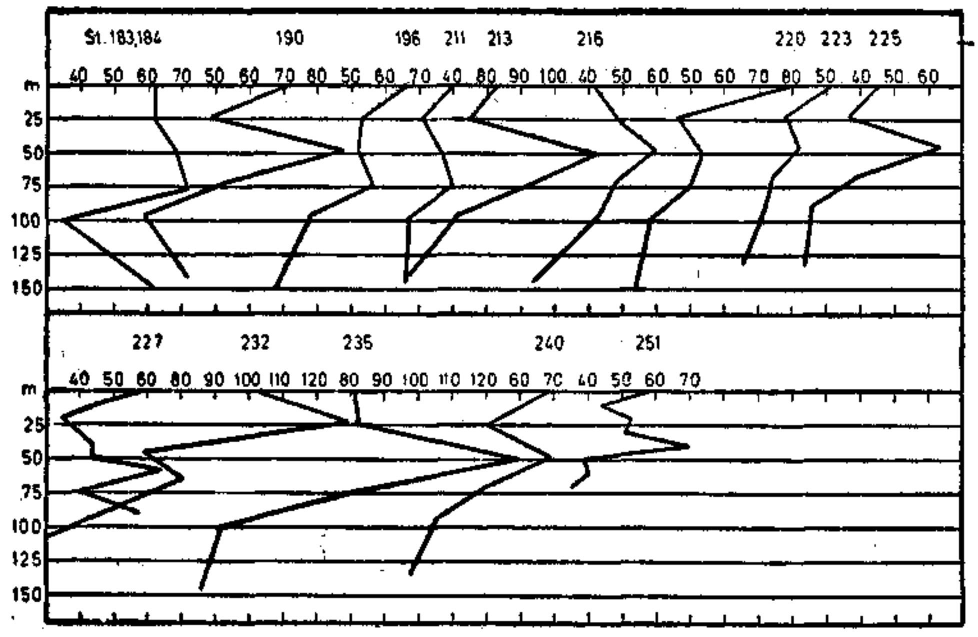

Fig. 2. Vertical profiles of particle content for various stations.

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Among the vertical scattering profiles in Fig. 2, high production is strongly indicated at St. 232 and 235 in the northeastern part of the ocean. This is consistent with the horizontal representation of primary production given by Ryther *et al.* (1966).

As a general characteristic, a particle maximum appears at 50 m (or 75 m) in the vertical structure. A similar maximum in particulate carbon is also encountered in the upper zone (Newell and Kerr, 1968). The fairly complicated mechanism by which a particle maximum is formed in the ocean involves the growth and decay of plankton in combination with dynamic factors. The vertical movement of the particles is strongly influenced by the actual turbulence and also by changes in the density of the water (Jerlov, 1959). At most stations the subsurface salinity maximum typical for the Indian Ocean is present at 75 m. It acts as a stabilizing factor favouring the creation of a particle maximum.

Furthermore the vertical distributions in Figs. 1 and 2 confirm the established fact (Bruneau *et al.* 1953) that the particle content in the Indian Ocean generally decreases below the photic zone and forms a minimum at 150-200 m.

UNDERWATER RADIANT ENERGY

The following survey of the underwater light pattern in the Indian Ocean will deal exclusively with the most significant component viz., the downward irradiance, E_d. Complete spectral measurements using 10 colour filters were made only at St. 191 for 30° solar elevation and at the adjacent St. 192 for 80° elevation. These localities in the most eastern equatorial part of the ocean represent fairly clear ocean

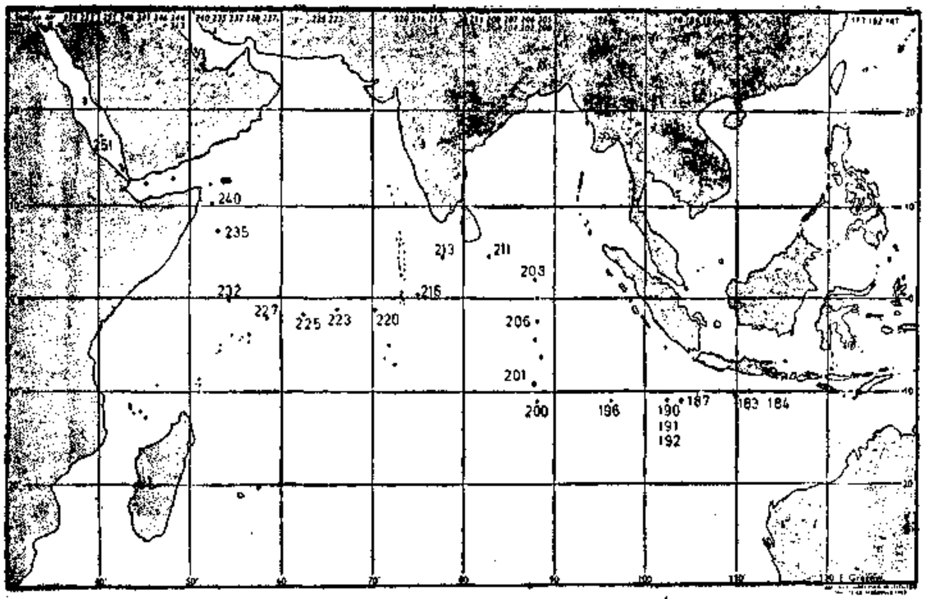

Fig. 3. Localities of stations.

water, intermediate between Type I and Type IA in the optical classification (Jerlov, 1968). The well known attenuation process for E_d with increasing depth is exhibited in Fig. 4. The spectral curves are—irrespective of depth—peaked at 465 nm which thus represents the wavelength of maximum transmittance for daylight.

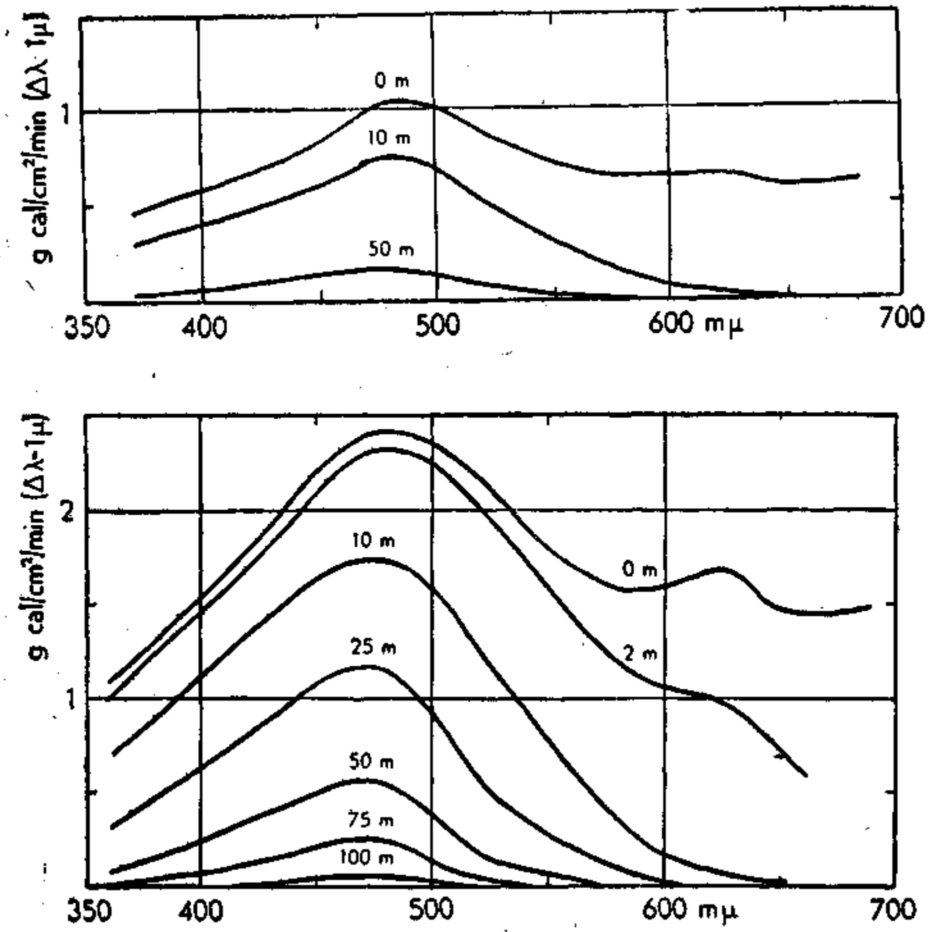

Fig. 4. Spectral energy for downward irradiance at St. 191 for 30° solar elevation (upper diagram) and at St. 192 for 80° elevation (lower diagram).

A comparison between St. 191 and St. 192 affords opportunity to investigate the effect of solar elevation. A considerable difference in percentage of surface radiation occurs at 50 m depth for the two stations (Table 1) due to increased average obliquity of the light when the sun goes from 80° to 30° elevation.

Underwater irradiance from other stations are collected in the survey picture of Fig. 5. The trend of these logarithmic curves for blue light (465 nm) indicates that the irradiance attenuation increases with depth which is consistent with the theory of radiative transfer in the sea. The entire group of curves gives evidence of relatively small variations of the daylight penetration in the Equatorial part of the Indian Ocean. The clearest water is encountered at St. 192 (Type I-IA) whereas St. 187 on account of higher particle content (Fig. 2) displays somewhat stronger attenuation below 40 m and comes close to Type IA. The experiments at St. 227

TABLE 1. *Percentage of surface irradiance at 50 m in the Indian Ocean for the solar elevations* 30° *and* 80° (*St.* 191 *and* 192)

Wavelength nm	Percentage Elevation 30°	Elevation 80°
500	12.4	15.8
475	15.8	22.7
450	16.2	22.7
425	13.8	20.2
400	12.3	17.0
375	8.5	11.2

TABLE 2. *Computed quanta values (per* cm^2 *and sec.) for a clear day with a solar elevation of about* 80°

Depth m	Station 187	192	201	206	251
0	$1100 \cdot 10^{14}$	1100.10^{14}	1100.10^{14}	1100.10^{14}	1100.10^{14}
5	630	620	580	580	590
10	460	430	370	380	400
20	290	280	250	260	240
30	187	187	165	180	139
40	114	123	100	136	53
50	73	85	50	88	21
60	46	57	24	53	7
70	27	42	12	32	
80	12	27		18	
90		15			
100		9			

were conducted at lower solar elevation (65°) than those at other stations (80°) which tends to reduce percentage of surface irradiance. St. 227 displays an attenuation at depth which is similar to that found by Clarke and Kelly (1964) in the same area. A definitely lower rate of transmission is discernible at St. 201 (Type IB) chiefly due to the mentioned abundance of particles in the divergence zone at 8°-9°S. Finally St. 251 in the Red Sea (Type IB-II) shows a considerable deviation which, since the particle content is not high—may be attributed to dissolved red or brown matter originating from plankton.

QUANTA METER

Since photosynthesis is a quantum process it is appropriate to measure the irradiance at various depths in the sea in terms of number of quanta per surface unit and second. The need for a device recording quanta within the photosynthetically active range of 350-700 nm was recognised by Working Group 15, (IAPSO, SCOR). A solution to the problem of measuring quanta inside this range was presented by Jerlov and Nygård (1969). The meter devised by them has a simple and robust design suitable for routine work. Its principal design consists of a photovoltaic cell in combination with colour filters, collimator and collector, usually an opal glass. The essential components are depicted in Fig. 6 ; no details

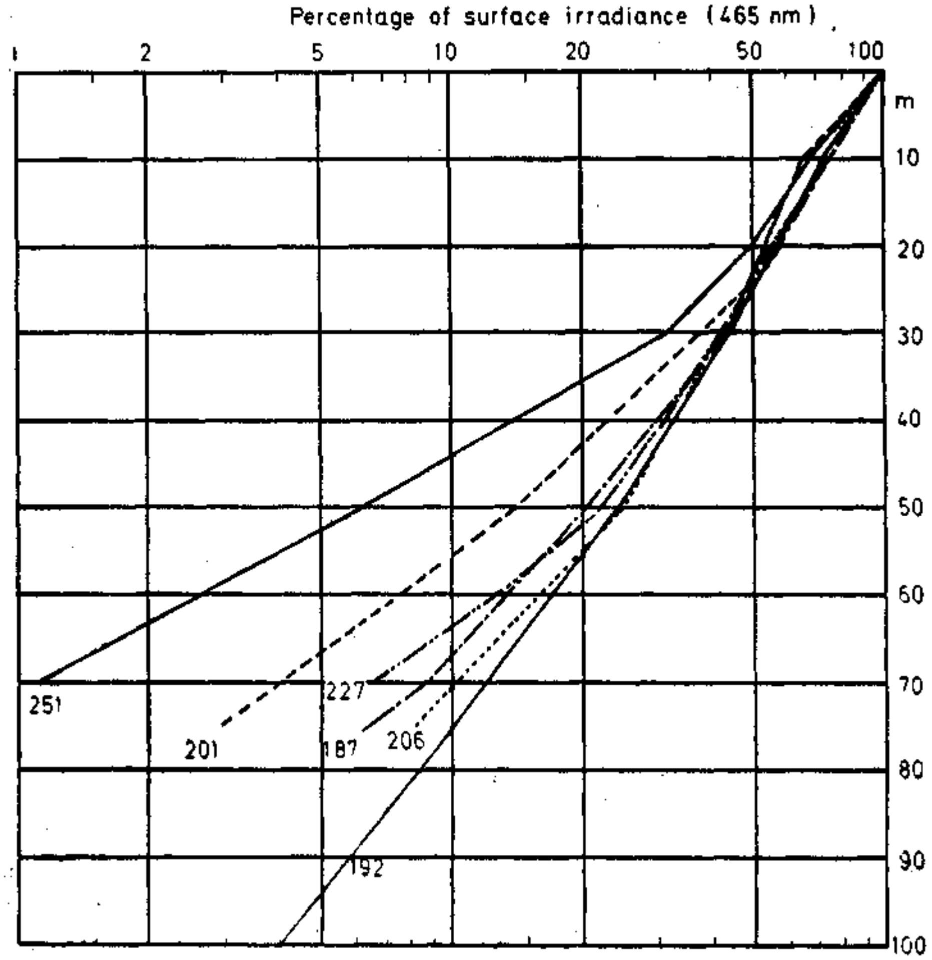

Fig. 5. Logarithmic curves for downward irradiance (465 nm) at various stations.

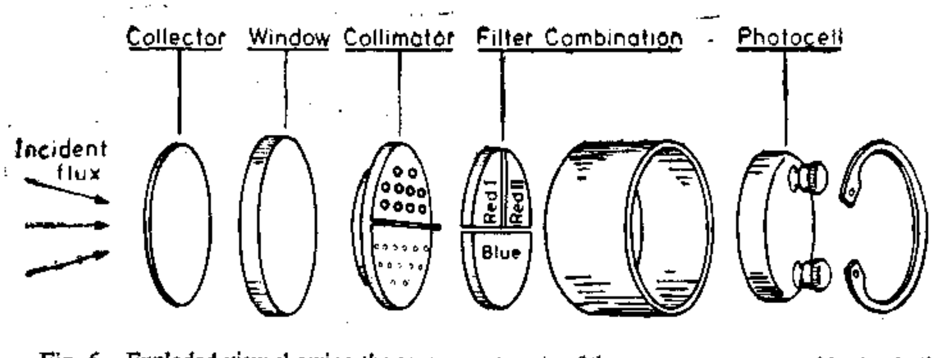

Fig. 6. Exploded view showing the component parts of the quanta meter assembly (excluding pressure housing).

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can be given in this context. Fig. 7 demonstrates how the quantum sensitivity of the meter fits to the requested constant sensitivity inside the range 350-700 nm. Careful tests also using different international standards prove that the absolute calibration of the meter is satisfactory.

Conversion of Data

In order to evaluate existing energy data in terms of quanta, a mode of conversion is actually wanted, especially if the energy values are obtained for one relatively narrow spectral band only. The investigation of Jerlov and Kullenberg

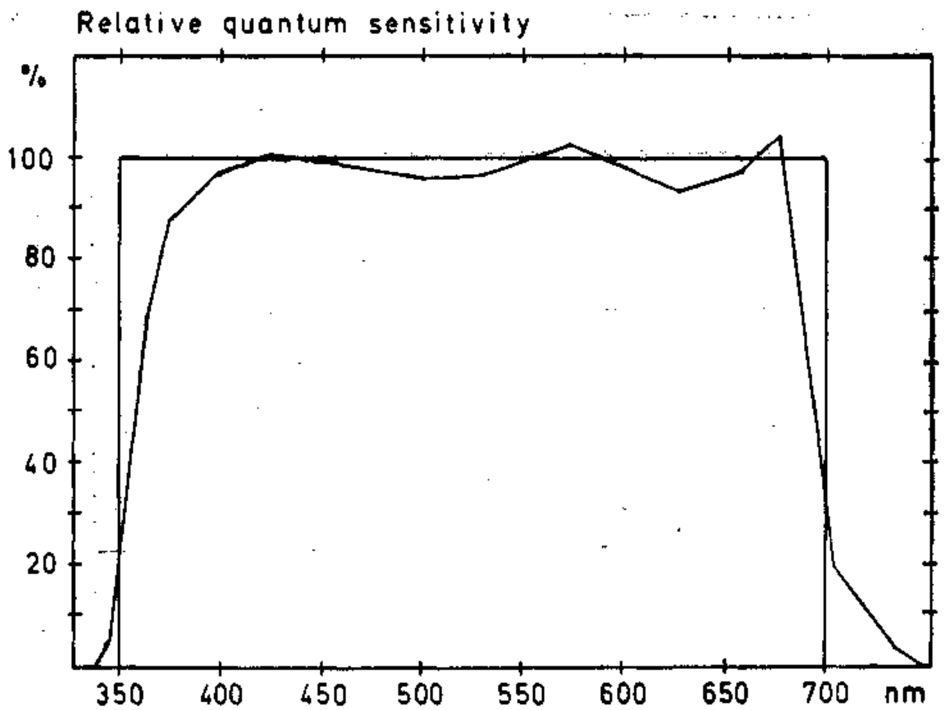

Fig. 7. Relative quantum sensitivity of the quanta meter as a function of wavelength.

(1946) on different water masses made it clear that a definite relationship exists between the *irradiance attenuation* for a certain wavelength and that for the complete visible range. It also follows from the optical classification (Jerlov, 1968), which is based on a large body of experimental data, that the attenuation of the whole visible range can be predicted from measurements in one suitable wavelength band.

In the first place it seems relevant to convert the observation for the blue (465 nm) presented in Fig. 5 into quanta values. A great deal of experimental material has been used to prepare Fig. 8 where percentage of surface blue light is plotted against percentage of quanta (350-700 nm) for different depths. (The numerous data from the two cruises organised by WG 15 has not been included ; they may eventually serve for checking the validity of the established relationship).

The data are readily arranged in the diagram and occurring deviations are as a rule within the interval of experimental errors. The scheme should be independent of solar elevation but there is no observational support for very low elevations (<10°).

The next step would be to arrive at absolute values of quanta at various depths. For St. 192 complete spectral measurements are available and for each wavelength

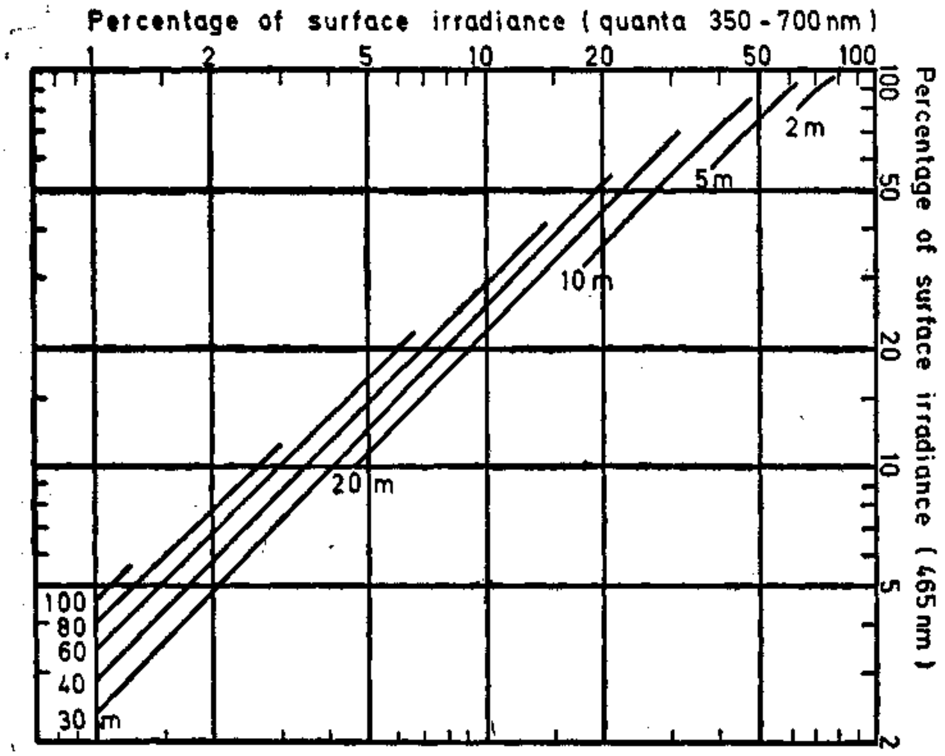

Fig. 8. Relationship between surface irradiance for blue light (465 nm) and that for quanta number (350-700 nm).

λ (nm) the number of quanta N (λ) (per cm² and sec. and △λ is derived from the energy E (λ) cal per cm² and min. and △λ using the formula :

$$N(\lambda) = 3.53\lambda .\ E(\lambda) .\ 10^{14}$$

The calculations yield a surface value (just below the surface)

$$N(350\text{-}700\ nm) = 1100 . 10^{14}$$

This value valid for high solar elevations (~80°) can be accepted for all stations in the Indian Ocean except for St. 227 (65°). The final results representing quanta at different localities as a function of depth are given in Table 2. The series yield information about the depth of the photic zone in different water masses characterized in the first place by their content of particulate matter. The conspicuous decrease in quanta number from the surface to 10 m is due to the strong attenuation of the long-wave part of the spectral range 350-700 nm.

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