ing grown in our laboratory in the "standard nitrate" medium developed by Emerson and Chalmers for the growing of *Chlorella* (unpublished). We prefer this completely inorganic medium to the citrate-containing medium used by Kratz and Myers (*5*).

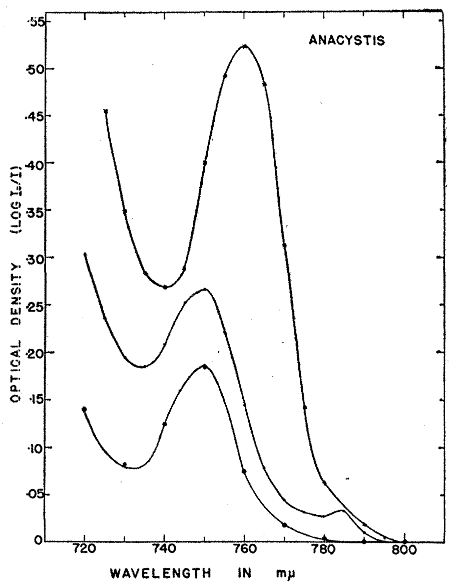

Fig. 1. Absorption spectra of thick suspensions of *Anacystis nidulans* showing the occurrence of pigment "P750" in three cultures of different density.

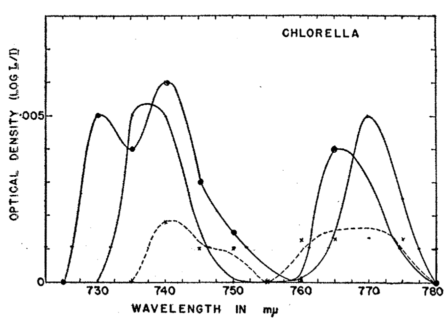

Fig. 2. Absorption spectra of thick suspensions of *Chlorella pyrenoidosa* show the existence of pigments "P740" and "P760" in three different cultures.

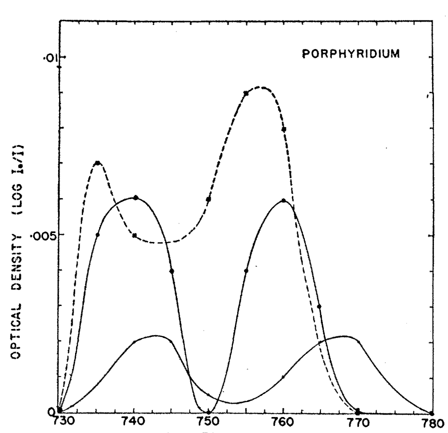

Fig. 3. Absorption spectra of thick suspensions of *Porphyridium cruentum* showing the existence of pigments "P740" and "P760" in three different cultures.

The algal cultures were centrifuged and resuspended, either in their culture medium or in an appropriate carbonate-bicarbonate buffer. The bands were first noted as weak but reproducible wiggles on the absorption curves obtained by the usual methods. Because of their weakness, measurements were made on very thick suspensions, with optical densities of about 2.0 at 680 mμ. In making measurements at low optical densities in very concentrated suspensions, both the stability of the instrument and the accuracy with which it can measure true absorption in a strongly scattering suspension are important. Of the instruments available to us, our 12-cell integrating spectrophotometer (*6*) comes closest to satisfying these requirements. Readings were taken at 5-mμ intervals; the half-intensity band width was 2.0 mμ.

Suspensions of *Anacystis* revealed clearly the presence of an absorption peak at 750 mμ (Fig. 1), which has been mentioned earlier (*2*). In some experiments with this alga, the peak was found at 760 mμ; the cause of this difference is unknown. The presence of a 750-mμ pigment ("P750") in *Anacystis* can be detected also with the Beckman DU spectrophotometer. Contrary to what one would expect from the relatively high intensity of this absorption band, *Anacystis* is the one algal species in which no photoinhibition effect could be noted (*2*).

Absorption spectra of several suspensions of *Chlorella* and *Porphyridium* (prepared from different cultures) showed two absorption bands in the extreme red, at 730 to 740 mμ and at 750 to 760 mμ, respectively. Figures 2 and 3, obtained by correcting the experimental absorption curves for a "tail" of the chlorophyll *a* absorption band (assumed to fade out smoothly on the long-wave side), clearly show the two new bands.

We believe that the pigments ("P740 + P760") producing these absorption bands are responsible for the inhibition effect previously detected in photosynthesis and in the Hill reaction of the same algae, since these absorption peaks coincide with the peaks observed in the action spectrum of inhibition (*3*). The weakness of the absorption bands shown in Figs. 2 and 3 suggests that the pigments are either present in very low concentrations or have very low extinction coefficients.

No evidence has yet been obtained of the chemical nature of the new pigments ("P750" and "P740 + P760"). Some experiments suggest, however, that the pigment "P740 + P760" may be similar to the "phytochrome," which Butler *et al.* (*7*) have found in higher plants. Alternatively, the new absorption bands could be due to microcrystals of the chlorophylls, since the latter are known to absorb in the same spectral region (*8, 9*).

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7 March 1961

Air Entrainment in Turbulent Liquids

Abstract. An experimental technique has been developed for measuring the concentration and distribution of air entrained by turbulence in an agitated liquid. The air content was related to the viscosity, surface tension, and turbulence of the liquid by dimensional analysis.

The concentration and distribution of air in turbulent water have been measured by several investigators both by mechanical sampling (*1*) and by electrical methods (*2*) in laboratory channels set at slopes sufficiently steep that when the turbulent boundary layer intersected the free surface there was sufficient transverse kinetic energy to overcome the stabilizing effects of surface tension and air was entrained into the water. The air bubbles were then

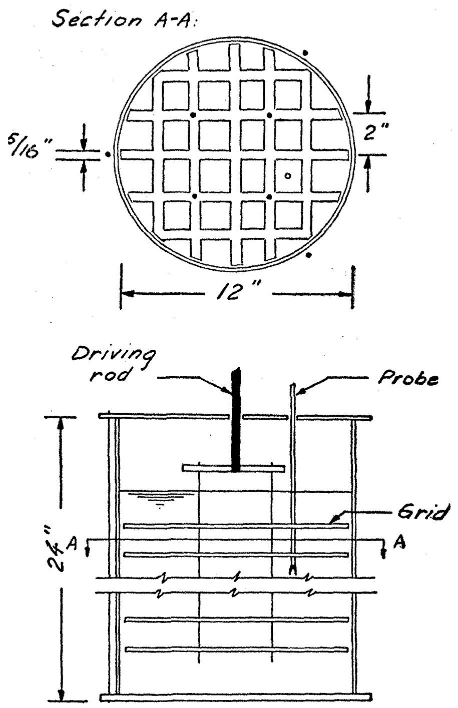

Fig. 1. Grid agitator used to generate homogenous turbulence in a liquid. The driving rod is connected to an eccentric on a variable-speed drive.

carried to some depth in the water by the mechanism of turbulent diffusion.

This report summarizes the results of an experimental study of the mechanism of air entrainment as it is related to significant fluid properties and to turbulence artificially induced by a moving grid in a container of liquid. The surface tension, viscosity, and density of the liquid determine the

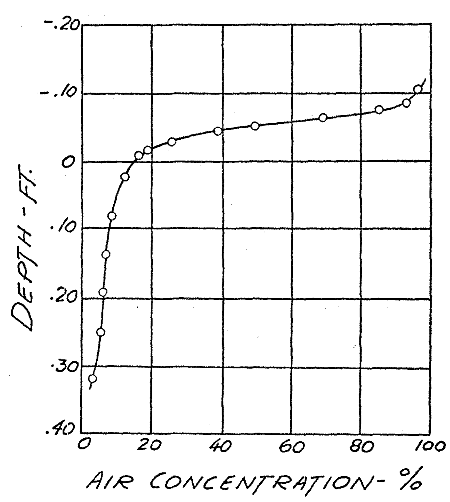

Fig. 2. Typical distribution of air entrained into water through the free surface by turbulence. Negative values of depth result from bulking of the air-water mixture.

amount of air entrained and the size and concentration of the air bubbles within the liquid for any given degree of turbulence. This interrelationship can be expressed as

$$C = \phi\,(\epsilon, \rho, \mu, \sigma, \gamma) \qquad (1)$$

where C is the mean air content by percent of volume in the container, ϵ is the diffusion coefficient, ρ is the density, μ is the viscosity, σ is the surface tension, and γ is the specific weight of the liquid.

The turbulence was generated by a grid agitator moving vertically in simple harmonic motion in a transparent container of the liquid (see Fig. 1). The amplitude and frequency of the stroke and the geometry of the agitator were varied. The liquids used were water, ethyl alcohol, methyl alcohol, and sugar-water solutions at different temperatures. These liquids permitted significant changes in the fluid properties. An electrical probe similar to that developed by Lamb and Killen (*2*) was used to measure the concentration of air at any level. A typical distribution of the air is shown in Fig. 2.

Since the eddy coefficient cannot be readily evaluated, the dimensional analysis of the problem proceeded from the following relationship

$$C = \phi'\,(v, l, d, \rho, \mu, \sigma, \gamma) \qquad (2)$$

where the diffusion coefficient (ϵ) of Eq. 1 has been replaced by v, the mean velocity, l, the stroke, and d, the grid spacing of the agitator.

Application of the π theorem resulted in the following relationship

$$C = \phi''\left(\frac{l}{d}, \frac{vl\rho}{\mu}, \frac{v^2\rho l}{\sigma}, \frac{lg}{v^2}\right) \qquad (3)$$

where the first term in parentheses is a dimensionless geometry parameter and the remaining terms are forms of the familiar Reynolds (R), Weber (W), and Froude (F) numbers.

Equation 3 was evaluated from results of these tests to be

$$C = 0.013\ (R^{0.21}\ W^{0.58}\ F^{0})$$

The exponent of the Froude number averaged near zero, indicating that gravity has a negligible effect on air entrainment for the liquids tested.

Visual observation of the entrainment process indicates that entrainment occurs when the surface undulations form breaking waves. Then turbulent mixing carries the air bubbles deep into the liquid. Decreasing the surface tension results in greater surface action and greater air entrainment; similarly, the greater the turbulence, the greater the air entrainment. Decreasing the viscosity permits more bubbles to be carried into the fluid (*3*).

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Pre-Columbian Littorina littorea in Nova Scotia

Abstract. *Littorina littorea*, an abundant northeast North American gastropod, was thought to have been introduced from Europe about 1840. Shells of that species found in ancient Micmac Indian camp sites in Nova Scotia have been radiocarbon-dated as pre-Columbian. Failure of *L. littorrea* to extend its range southward before 1840 may have been due to oceanographic factors.

Littorina littorea (Linn.) is probably the most abundant intertidal gastropod occurring between the Gulf of St. Lawrence and southern New Jersey. Long native in Europe from the White Sea to Gibraltar and in the British Isles (*1*), it was first recorded from North America about 1857 when Willis reported it from Halifax, Nova Scotia (see *2*). Its subsequent progressive colonization of more southerly localities has been well documented by Morse (*3*), who states that it first occurred at Portland and Kennebunk, Maine, in 1870; at Salem and Provincetown, Massachusetts, in 1872; at Woods Hole, Massachusetts, in 1875; and at New Haven, Connecticut, in 1880. Morse also stated (*3*) that he had received specimens from Bathurst, Bay of Chaleur, Gulf of St. Lawrence, in 1855, and Dawson (see *2*) reported that he had collected it at Pictou on