extremely dark color of seal meat suggests that the oxygen store exists, at least in part, in the muscle hemoglobin.

The literature on muscle hemoglobin in aquatic mammals is both meager and contradictory. In a review paper on "Respiration in Diving Mammals" Irving[2] estimates the muscle hemoglobin of an aquatic mammal by analogy from Whipple's figures[3] for iron content of dog muscle, and shows that a 70 kg animal could absorb 335 cc of oxygen by this means. He concludes that such a store would, however, be only significant as a store for a fraction of a minute, whereas the endurance of divers requires provision for a number of minutes. But Theorell,[4] who observed that myoglobin occurs in concentrations of 5 to 10 per cent. in the juice pressed from seal meat, states that the necessary oxygen for prolonged diving comes with great likelihood in large part from the exceptionally great myoglobin content of the skeletal muscles, which are so strongly colored that they appear almost blue-black.

I have made some analyses to determine if muscle hemoglobin in the seal is present in concentrations high enough to serve as an oxygen store in diving. The work began with iron analyses of the tissues, as it was thought that the iron content would serve as a rough indication of the relative muscle hemoglobin concentrations. The method of iron determination followed that of Elvehjem and Hart.[5] All tissues analyzed were freed as far as possible from blood hemoglobin by washing in 0.9 per cent. NaCl solution. A single sample of seal meat gave an average of .229 mg Fe per gram of fresh tissue, compared with several analyses of beef muscle by the same method, giving an average of .048 mg Fe per gram of fresh tissue. This experiment indicated that a much larger amount of iron was present in the seal muscle.

In order to determine if the large excess of iron were really present as muscle hemoglobin, samples of tissue from a second seal were washed in 0.9 per cent. NaCl to remove blood hemoglobin, and the muscle hemoglobin was extracted by the dilute NH_4 method of Whipple.[6] The muscle hemoglobin in solution was converted to acid hematin and compared colorimetrically with a blood acid hematin standard. By this method a single sample of seal muscle yielded 7,715 mg of muscle hemoglobin per 100 grams of fresh tissue, compared with an average of 1,084 mg per 100 grams for several samples of beef muscle. In a 70 kg seal, if only 35 per cent. of the body weight represented muscle, there would be 1,890 grams of hemoglobin present, sufficient to combine with 2,530 cc of oxygen. As shown by Table 1, this might amount to 47 per cent. of the total oxygen stores of the animal.

TABLE 1

POSSIBLE OXYGEN STORES OF A 70-KG SEAL

System	Oxygen stored
Lungs	545 cc
Blood	2,055 "
Fluids	245 "
Muscle hemoglobin	2,530 "
Total	5,375 "

SOURCES OF FIGURES IN TABLE 1

Lungs: Average lung capacity of two seals examined after death was 38.9 cc per kg. $38.9 \times 70 \times \frac{1}{5} = 545$.

Blood: Oxygen capacity of seal blood is 29.3 vol. per cent. (Irving, Solandt, Solandt and Fisher[7]). Blood represents 10 per cent. of the seal's body weight (Irving).[8] $70 \times 10 \times 29.3 = 2{,}051$.

Fluids: From Irving.[9]

Muscle hemoglobin: 7,715 mg Hb per 100 gm muscle. If 35 per cent. of the seal's weight is muscle, there are 24.5 kg of muscle. $24.5 \times 10 \times 7{,}715$ mg (7.715 grams) = 1,890 grams Hb. Muscle hemoglobin has the same combining power for oxygen as does blood Hb—1.34 cc per gram hemoglobin. $1{,}890 \times 1.34 = 2{,}532$ cc.

The resting metabolic requirement of a 70 kg seal would be 373 cc of oxygen per minute according to Irving, Solandt, Solandt and Fisher.[10] Assuming 100 per cent. utilization of all oxygen stores, it would be possible for the seal metabolizing oxygen at the basal rate to remain submerged for 14.4 minutes on a store of 5,375 cc of oxygen. This figure compares favorably with the common submersion time, when the animal is active, of about six minutes. But for active 15-minute submersions, such as recorded by Millais, there still seems to be no physiological explanation.

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THE ABSORPTION OF RADIO WAVES IN WATER

IN view of the recent submarine disasters, the question naturally arises as to the possibility of signaling from undersea craft by radio. Some years ago, Mr. Allen Bassett and the author carried out a series of tests in Lake Michigan which have a direct bearing on this problem. We chose for our task the determination of the law of absorption of radio waves in water.

A small transmitter with a loop aerial and an output of about one-tenth watt was set into operation, sealed into a water-tight box and lowered with a rope

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[2] L. Irving, *Physiol. Reviews*, 19: 112, 1939.

[3] G. H. Whipple, *Am. Jour. Physiol.*, 76: 693, 1926.

[4] A. T. H. Theorell, *Biochem. Zeitschr.*, 268: 81, 1934.

[5] C. A. Elvehjem and E. B. Hart, *Jour. Biol. Chem.*, 67: 43, 1926.

[6] G. H. Whipple, *Am. Jour. Physiol.*, 76: 693, 1926.

[7] *Ibid.*, 6: 393, 1935*a*.

[8] L. Irving, *Physiol. Reviews*, 19: 112, 1939.

[9] L. Irving, *Physiol. Reviews*, 19: 112, 1939.

[10] L. Irving, O. M. Solandt, D. Y. Solandt and K. C. Fisher, *Jour. Cell. and Comp. Physiol.*, 6: 393, 1935*a* and 7: 137, 1935*b*.

over the side of a boat to various depths. In the boat there was a loop aerial connected to a receiving set which was tuned to the transmitter and which operated a Wynn-Williams balanced vacuum tube voltmeter, rather than the usual loud speaker. The voltmeter gave a measure of the strength or intensity (I) of the radio wave. As the transmitter was lowered farther and farther into the water, thus increasing the thickness of the layer of water between the transmitter and receiver, the strength of the received signal decreased in the manner shown in Fig. 1. The different curves refer to the indicated wave-lengths (λ) of the radio waves, as marked, and show that the shorter waves are more readily absorbed. Because of the rocking of the boat and the directional properties of the two loop aerials, the intensity of the received signal fluctuated considerably at any one separation of the transmitter and receiver. The intensity readings given in the figure are the maximum values at each point.

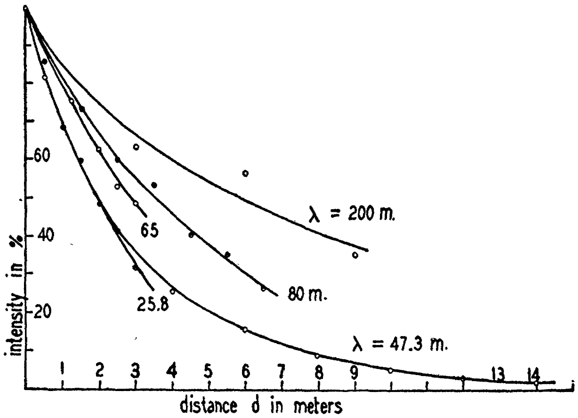

FIG. 1. The intensity I of radio waves after passing through various thicknesses of fresh water. λ = wave-length in meters.

The form of the curves shown in Fig. 1 is typical of absorption processes in general and may be expressed by the well-known exponential law

$$I = I_0 e^{-\alpha d}, \qquad (1)$$

where I is the intensity of the wave after penetrating d centimeters of the absorbing material, I_0 is the original intensity at the transmitter, $e = 2.718$—, the base of the Naperian system of logarithms, and α is the so-called linear absorption coefficient. Large values of α indicate large absorption in unit thickness of the absorber and *vice versa*. If we take logarithms of both sides of equation 1 we have

$$\log_e I = \log_e I_0 - \alpha d, \qquad (2)$$

or, changing to common logarithms,

$$\log_{10} I = \log_{10} I_0 + (-0.4343\alpha) d. \qquad (3)$$

If, then, we plot log I against d we should get a straight line whose slope is negative and is numerically equal to 0.4343 α. The straight lines in Fig. 2, obtained in this manner, prove that the radio waves are absorbed in the exponential manner of equation 1 in water. The values of α computed from the slopes of the straight lines are given in Table 1.

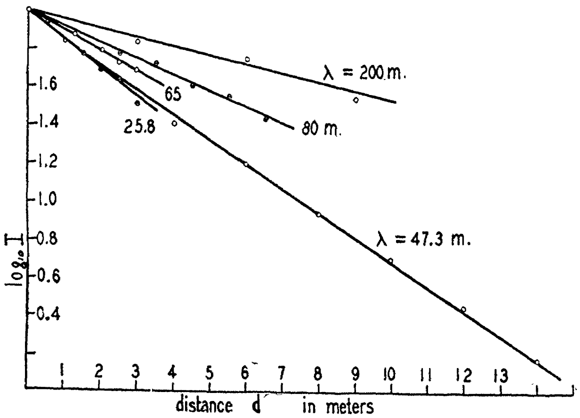

FIG. 2. Proof of the exponential absorption law and determination of the absorption coefficient α.

TABLE 1

Wave-length in meters	Experimental α	Theoretical α
200	0.00117	0.00126
80	.00200	.00198
65	.00240	.00220
47.3	.00290	.00260
25.8	.00364	.00350

By means of the electromagnetic theory it can be shown in a comparatively simple manner[1] that the absorption coefficient α is related to the permeability μ and conductivity σ (e.m.u.) of the absorbing substance and to the frequency (f) of the radio wave in the following manner:

$$\alpha = 2\pi \sqrt{\mu \sigma f}. \qquad (4)$$

The value of μ for water is unity. Our measured value of σ for Lake Michigan water is 2.7×10^{-14} e.m.u. Thus it is possible to calculate a value of α for each of the frequencies used in the experimental work. These theoretical values are given in the same table with those obtained from the slopes of the straight lines and show reasonably good agreement between theory and experiment. We are thus able to state with confidence that, over the range of wave-lengths tested (200 to 25.8 meters), the absorption per unit distance through fresh water increases as the square root of the conductivity

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[1] A. Hund, "Phenomena in High Frequency Systems," p. 333. McGraw-Hill Book Company, 1936. G. P. Harnwell, "Principles of Electricity and Electromagnetism," p. 544. McGraw-Hill Book Company, 1938.

of the water and as the square root of the frequency of the radio wave.

We may now apply equation 1, with the known values of α, to bring into evidence the shortness of the range of transmission of radio waves through water. For example, the intensities of radio waves of wave-lengths 200, 80, 65 and 25 meters will be reduced to 10 per cent. of their value at the transmitter after passing through approximately 20, 11, 10 and 6 meters of Lake Michigan water, respectively. The corresponding distances for a reduction to one one-thousandth of the original intensity (irrespective of the strength of the transmitter) are 58, 35, 30 and 20 meters, respectively. Since the conductivity of sea water is approximately one thousand times as great as that of fresh water, the absorption coefficients of salt water will all be approximately thirty times larger and the distances, for a given ratio of intensities, will be only 3 per cent. of those in fresh water.

It may be concluded: (1) that radio waves can not be expected in appreciable intensity at any great distance from *deeply* submerged undersea craft unless the transmitter has considerable power; (2) that the longer wave-lengths will travel farther than the shorter ones, other conditions being the same; and (3) that greater distances will be reached in fresh than in salt water.

A test was also made in which the receiver was placed near the water, on the shore, while the transmitter was submerged a short distance under the water and moved parallel to the shore line, away from the receiver. Intensity readings were taken every 20 meters up to a distance of 140 meters when the transmitter was brought to the shore and then carried back on the land toward the receiver. Intensity readings were made on the return trip and gave practically the same shape intensity-distance curve as on the outward journey, lying slightly above the water values. Similar results were obtained with the receiver in one boat and the transmitter in or below a second boat. An intensity-depth curve for 47.3 meter waves, for d from 0 to 2.6 meters, was made when the boats were 20 meters apart and yielded an absorption coefficient of 0.00260, in exact agreement (fortuitously) with the theoretical value.

The measurements in these latter tests were not made as carefully as those reported in the first part of this paper and, hence, can not be used with the same degree of conviction in drawing conclusions. We might assume, however, that the radio waves came to the surface within a comparatively short distance from the transmitter and, because of the comparatively high index of refraction of water (around 9, for these waves), were sharply refracted and traveled through the air to the receiver, rather than taking the shorter but much more absortive path directly through the water.

If these conclusions are valid, then it should be possible to signal to considerable distances from a submarine which is submerged only a *short* distance below the surface of the water.

The writer wishes to express his sincere thanks to Mr. M. Romberg for placing his power boat at our disposal and to the South Shore Power Boat Club for the use of its wharf and club house.

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SCIENTIFIC APPARATUS AND LABORATORY METHODS

A SPECTROCOLORIMETER FOR COMPARING THE SPECTRA OF SOLUTIONS OF DIFFERENT DEPTH[1]

IN matching colors and absorption bands it is desirable to have a simultaneous reference. A hand spectroscope mounted immediately above the prisms of a standard colorimeter of the Duboscq type provides two spectra in immediate juxtaposition when the adjustable slit of the spectroscope is placed perpendicular to the line of division of the two fields of light. This allows the instrument to be used as a regular colorimeter with the added advantage that specimens having an interfering color, such as urine- or bile-stained blood, can be more accurately matched and a correction made for the increased absorption of light by these interfering colors. A quick and accurate method is provided

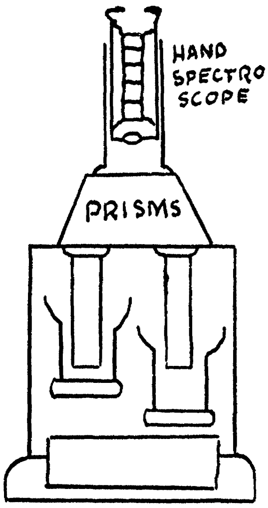

FIG. 1

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[1] From the Littauer Pneumonia Research Fund, New York University College of Medicine, and the Medical Service, Harlem Hospital, Department of Hospitals, New York City, N. Y.