NRL Report 6736

# Infrared Characteristics of Ocean Water (1-1/2 to 15 Microns)

DANIEL FRIEDMAN

*Applied Oceanography Branch*
*Ocean Sciences Division*

July 11, 1968

NAVAL RESEARCH LABORATORY
Washington, D.C.

This document has been approved for public release and sale; its distribution is unlimited.

## ABSTRACT

Equations and tabulated values of relevant physical parameters are presented which can be used to calculate the reflectance and emissivity of ocean water in the 1-1/2- to 15-micron range. Using double-beam spectrophotometers, the reflectance of artificial ocean water with respect to the reflectance of pure water was measured and compared with the calculated values for incidence angles of 70, 60, and 34 degrees. The agreement between the calculated and the measured values is well within the limits of experimental accuracy.


## PROBLEM STATUS

This is an interim report, work on this problem is continuing.

## AUTHORIZATION


NRL Problem G01-02A
AIRTASK NO. A37533059/6521/F101-99-01

Manuscript submitted April 12, 1968.

# INFRARED CHARACTERISTICS OF OCEAN WATER
# (1-1/2 to 15 MICRONS)

## INTRODUCTION

Many studies in physical oceanography are concerned with measurements of the infrared energy emitted from and reflected by the water at the air-ocean interface. The following examples illustrate the scope of these investigations: The Naval Oceanographic Office is currently using airborne radiation thermometers to obtain near-synoptic measurements of surface temperature in connection with the Antisubmarine Warfare Environmental Prediction Services (ASWEPS) (1). McAlister (2) reports on the use of an airborne two-wavelength radiometer to obtain measurements of the total heat flux from the ocean surface. Stommel, et al. (3) used an airborne differential radiometer to study the movement of the edge of the Gulf Stream. To properly analyze radiometric measurements of an air-water interface, a knowledge of the emissivity and reflectance of the water surface as a function of wavelength and angle of incidence is required.

Using the basic laws of optical physics, equations have been derived which can be used to calculate the emissivity and the reflectance of an air-water interface. To solve these equations requires a knowledge of the extinction coefficient and the index of refraction. Although this information is available for pure water, Davis (4), in his bibliography of references pertaining to the optical constants of liquid water, pointed out a serious deficiency in the scientific literature on the infrared properties of ocean water.

The objective of this report is to provide equations and tabulated values of the index of refraction and the extinction coefficient which can be used to calculate the emissivity and the reflectance of ocean water from 1-1/2 to 15 $\mu$. To avoid the difficult and time-consuming work required to measure the index of refraction and the extinction coefficient as a function of salinity and wavelength, an alternate approach was developed. Using the data available for pure water as a reference, predictions were made of the changes in these parameters that could be expected to result from the presence of the ions known to exist in ocean water. To check the validity of the above predictions, the reflectance of artificial ocean water relative to the reflectance of pure water was measured for several angles of incidence using double-beam spectrophotometers, and the results obtained were compared with the predicted values.

## DERIVATION OF EQUATIONS

Whenever infrared energy is incident at the air-water interface, a portion is reflected back into the air while the remainder is refracted into the water where it is absorbed. The relative intensities of the reflected and refracted beams depend on the polarization of the incident beam. Using Fresnel's formulas and Snell's law of refraction, we can derive the equations

$$R_1 = \left[\frac{(N^2 - \sin^2\theta)^{1/2} - N^2\cos\theta}{(N^2 - \sin^2\theta)^{1/2} + N^2\cos\theta}\right]^2 \tag{1}$$

and

$$R_2 = \left[\frac{(N^2 - \sin^2\theta)^{1/2} - \cos\theta}{(N^2 - \sin^2\theta)^{1/2} + \cos\theta}\right]^2 . \tag{2}$$

where $R_1$ is the reflectance for energy polarized in the plane of incidence, $R_2$ is the reflectance for energy polarized in the plane perpendicular to the plane of incidence, and $\theta$ is the angle of incidence measured from a plane perpendicular to the surface of the water to the plane of incidence of the beam. For an absorbing medium,

$$N = n - ik, \tag{3}$$

where $n$ is the index of refraction of water, and $k$ is the extinction coefficient of water. Substituting Eq. (3) in Eqs. (1) and (2), the equations for reflectance become:

$$R_1 = \frac{b + c \cos^2 \theta - 2[d(n^2 - k^2) + 2\,ekn] \cos \theta}{b + c \cos^2 \theta + 2[d(n^2 - k^2) + 2\,ekn] \cos \theta} \tag{4}$$

and

$$R_2 = \frac{b + \cos^2 \theta - 2d \cos \theta}{b + \cos^2 \theta + 2d \cos \theta}, \tag{5}$$

where

$$b = (a^2 + 4k^2n^2)^{1/2}$$

$$c = (n^2 - k^2)^2 + 4k^2n^2$$

$$d = [(b + a)/2]^{1/2}$$

and

$$e = [(b - a)/2]^{1/2},$$

in which

$$a = n^2 - k^2 - \sin^2 \theta.$$

According to Kirchhoff's law, the emissivity is equal to 1 minus the reflectance. It should be noted that this law does not apply to transparent fluids. Therefore, caution should be used when applying Kirchhoff's law below about 2.6 $\mu$.

## PREDICTED EFFECTS

Since this study is predicated on the assumption that the infrared properties of ocean water can be derived from the corresponding values for pure water, experimentally determined values of the index of refraction and the extinction coefficient of pure water are required. The values reported by Pontier and Dechambenoy (5), for a wide range of wavelengths, were used in this study. A summary of their data is given in Table 1.

To predict the effect of dissolved ions, a knowledge of the ion concentrations for a representative sample of ocean water is required. The ion concentrations reported by Sverdrup, et al. (6) for typical ocean water (salinity 34.3‰ chlorinity 19.0‰) were used for this study.

A survey of the literature available concerning the effect of dissolved ions on the infrared properties of water uncovered two phenomena that require consideration: the increase in the index of refraction and the shift in the absorption bands. McLellan (7) reports that the results of measurements of the index of refraction increase as a function of chlorinity, for the sodium D line at 25°C. For the assumed typical ocean-water chlorinity of 19.0‰, the increase in the index of refraction was found to be $6 \times 10^{-3}$ and to be a linear function of the salt concentration. Since corresponding measurements for the infrared region have not been reported, it was assumed that this correction also applies to the 1-1/2- to 15-$\mu$ region.

Table 1
Variation of the Index of Refraction $n$ and the Extinction*
Coefficient $k$ as a Function of Wavelength for Pure Water

| Wavelength ($\mu$) | $n$ | $k$ | Wavelength ($\mu$) | $n$ | $k$ | Wavelength ($\mu$) | $n$ | $k$ |
|---|---|---|---|---|---|---|---|---|
| 1.0 | 1.324 | $3.0 \times 10^{-6}$ | 7.4 | 1.299 | 0.0453 | 15.0 | 1.260 | 0.420 |
| 1.2 | 1.320 | $1.13 \times 10^{-5}$ | 7.6 | 1.295 | 0.0460 | 15.5 | 1.293 | 0.428 |
| 1.4 | 1.317 | $2.9 \times 10^{-4}$ | 7.8 | 1.290 | 0.0468 | 16.0 | 1.323 | 0.433 |
| 1.6 | 1.313 | $8.4 \times 10^{-5}$ | 8.0 | 1.285 | 0.0477 | 16.5 | 1.348 | 0.436 |
| 1.8 | 1.308 | $1.5 \times 10^{-4}$ | 8.2 | 1.280 | 0.0484 | 17.0 | 1.369 | 0.437 |
| 2.0 | 1.300 | $1.01 \times 10^{-3}$ | 8.4 | 1.274 | 0.0488 | 17.5 | 1.388 | 0.437 |
| 2.2 | 1.288 | $3.6 \times 10^{-4}$ | 8.6 | 1.268 | 0.0493 | 18.0 | 1.404 | 0.436 |
| 2.4 | 1.269 | $8.8 \times 10^{-4}$ | 8.8 | 1.262 | 0.0500 | 18.5 | 1.418 | 0.434 |
| 2.6 | 1.231 | 0.0056 | 9.0 | 1.255 | 0.0510 | 19.0 | 1.431 | 0.432 |
| 2.74 | 1.168 | 0.0300 | 9.2 | 1.247 | 0.0521 | 19.5 | 1.443 | 0.429 |
| 2.8 | 1.202 | 0.0828 | 9.4 | 1.239 | 0.0538 | 20.0 | 1.454 | 0.426 |
| 3.0 | 1.364 | 0.3060 | 9.6 | 1.229 | 0.0564 | 20.5 | 1.464 | 0.423 |
| 3.02 | 1.383 | 0.307 | 9.8 | 1.218 | 0.0598 | 21.0 | 1.474 | 0.419 |
| 3.17 | 1.482 | 0.1180 | 10.0 | 1.207 | 0.0640 | 21.5 | 1.483 | 0.414 |
| 3.2 | 1.478 | 0.0834 | 10.2 | 1.194 | 0.0696 | 22.0 | 1.492 | 0.410 |
| 3.4 | 1.416 | 0.0250 | 10.4 | 1.180 | 0.0786 | 22.5 | 1.499 | 0.405 |
| 3.6 | 1.382 | 0.0088 | 10.6 | 1.166 | 0.0850 | 23.0 | 1.507 | 0.400 |
| 3.8 | 1.360 | 0.0054 | 10.8 | 1.153 | 0.0956 | 23.5 | 1.514 | 0.394 |
| 4.0 | 1.345 | 0.0065 | 11.0 | 1.142 | 0.1086 | 24.0 | 1.519 | 0.388 |
| 4.2 | 1.334 | 0.0100 | 11.2 | 1.133 | 0.1240 | 24.5 | 1.524 | 0.381 |
| 4.4 | 1.327 | 0.0144 | 11.4 | 1.126 | 0.1416 | 25.0 | 1.528 | 0.376 |
| 4.6 | 1.323 | 0.0196 | 11.6 | 1.120 | 0.1620 | 26.0 | 1.535 | 0.366 |
| 4.73 | 1.322 | 0.0218 | 11.8 | 1.118 | 0.184 | 27.0 | 1.538 | 0.361 |
| 4.8 | 1.322 | 0.0212 | 12.0 | 1.116 | 0.207 | 27.5 | 1.539 | 0.360 |
| 5.0 | 1.319 | 0.0174 | 12.2 | 1.117 | 0.229 | 28.0 | 1.538 | 0.359 |
| 5.2 | 1.312 | 0.0147 | 12.4 | 1.119 | 0.253 | 29.0 | 1.535 | 0.359 |
| 5.4 | 1.300 | 0.0142 | 12.6 | 1.122 | 0.275 | 30.0 | 1.529 | 0.360 |
| 5.6 | 1.282 | 0.0187 | 12.8 | 1.127 | 0.299 | 31.0 | 1.522 | 0.363 |
| 5.8 | 1.254 | 0.0360 | 13.0 | 1.135 | 0.321 | 32.0 | 1.512 | 0.366 |
| 5.92 | 1.230 | 0.066 | 13.2 | 1.145 | 0.339 | 33.0 | 1.502 | 0.371 |
| 6.0 | 1.259 | 0.0980 | 13.4 | 1.156 | 0.354 | 34.0 | 1.489 | 0.376 |
| 6.08 | 1.306 | 0.1215 | 13.6 | 1.168 | 0.367 | 35.0 | 1.474 | 0.383 |
| 6.2 | 1.362 | 0.0863 | 13.8 | 1.180 | 0.379 | 36.0 | 1.456 | 0.391 |
| 6.4 | 1.335 | 0.0584 | 14.0 | 1.193 | 0.388 | 37.0 | 1.433 | 0.400 |
| 6.6 | 1.321 | 0.0496 | 14.2 | 1.206 | 0.397 | 38.0 | 1.408 | 0.410 |
| 6.8 | 1.313 | 0.0456 | 14.4 | 1.219 | 0.404 | 39.0 | 1.382 | 0.421 |
| 7.0 | 1.308 | 0.0444 | 14.6 | 1.233 | 0.411 | 40.0 | 1.355 | 0.432 |
| 7.2 | 1.303 | 0.0446 | 14.8 | 1.246 | 0.416 | | | |

*Reprinted from Pontier and Dechambenoy (5), Courtesy Annales de Geophysique.

Williams and Millett (8) report shifts in the vibrational frequencies of the infrared absorption bands of water which result from the presence of dissolved ions. Although there are a number of such bands in the 1-1/2- to 15-$\mu$ region, only one absorption band was found to be strong enough and broad enough to require consideration, namely, the absorption band which starts at about 9$\mu$ and extends beyond the 15-$\mu$ limit of this study. The procedure used to predict the values of the index of refraction and the extinction coefficient for ocean water in the 9- to 15-$\mu$ region was as follows: The magnitude of the absorption band was determined from transmittance measurements. The values for $n$ and $k$ for pure water (Table 1) were plotted as a function of wavelength, the wavelength scale was modified in accordance with the results obtained from the transmittance measurements, and a new set of values was read from the chart using the modified scale. An additional correction of $6 \times 10^{-3}$ was added to the values obtained for $n$ in accordance with the prediction procedure previously mentioned.

The transmittance measurements required to determine the absorption-band shift were made using a Model 621 Perkin-Elmer grating spectrophotometer and an absorption cell with Irtran-2 windows and an 18-1/2-$\mu$ sample thickness. To improve the accuracy of the results and to check on the possibility of nonlinear effects, shift measurements were made using three salt concentrations. The solutions used to approximate ocean water of different salinities were prepared using the following procedure: A formula was developed for an artificial ocean water which would have the same concentration of significant ions (sodium, magnesium, chlorine, and sulfate) as the typical ocean water reported by Sverdrup, et al. (Table 2). A solution made according to this formula was considered to have a relative salt concentration of 1.0. The other solutions were prepared using one-half and twice the salt concentrations shown in Table 2. All solutions were prepared using triple-distilled water and clean glassware to keep contamination to a minimum.

Table 2
Composition of Artificial Ocean Water
(Salinity 34.3‰, Chlorinity 19.0‰)

| Chemical | Grams/100 cc of Ocean Water |
|---|---|
| $MaCl_2 \cdot 6\,H_2O$ | 0.52 |
| Na Cl | 2.75 |
| $MgSO_4 \cdot 7\,H_2O$ | 0.70 |
| Ca $Cl_2$ | 0.15 |

Figure 1 shows the results obtained from the transmittance measurements described above. The relative transmittance scale used in Fig. 1 is arbitrary, chosen solely for convenient presentation. The expected absorption-band shift, as well as the well-known sulfate absorption band in the 9-$\mu$ region, can be seen in the curves of Fig. 1. It should be noted that the data obtained are plotted as a function of frequency (reciprocal wavelength) and that the shift appears to be one of constant frequency, not one of constant wavelength. Since the phenomenon being evaluated is a vibrational frequency shift, this is to be expected. To obtain better resolution of the absorption shift, an expanded scale measurement was made of the 10-1/2- to 12-$\mu$ region. The results obtained are shown in Fig. 2. Although there is considerable scatter in the data, the absorption-band shift seems to be a linear function of the salt concentration and to have a value of -4 $cm^{-1}$ for the typical artificial ocean-water salt concentration used in this study (relative salt concentration = 1.0).

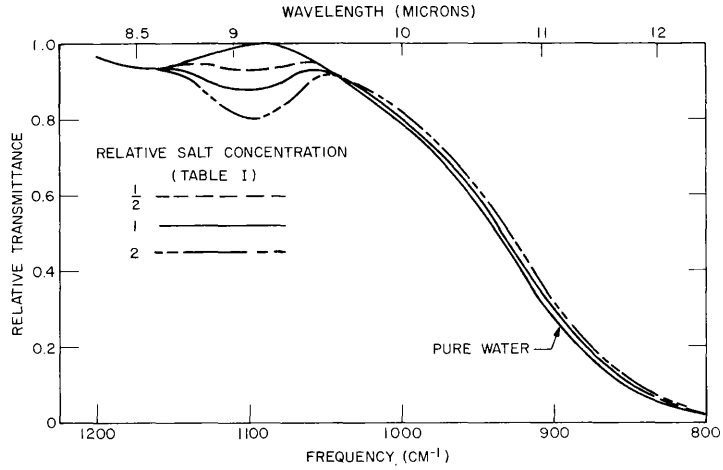


Fig. 1 – Relative transmittance of pure and artificial ocean water (water sample thickness 18.5 $\mu$, temperature 25°C). Note the sulfate absorption band at 9$\mu$ and the absorption-band shift starting at about 9.7$\mu$.

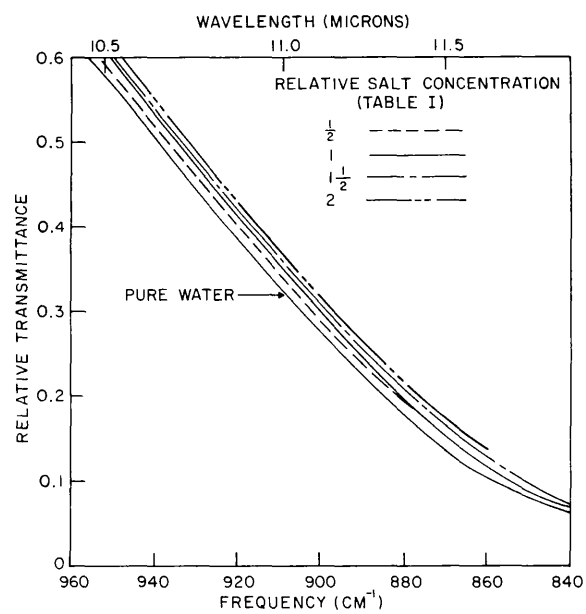


Fig. 2 – Expanded scale presentation of the relative transmittance of pure and artificial ocean water (sample temperature 25° C) shown in Fig. 1.

Using the procedures outlined in this discussion and the -4 $cm^{-1}$ absorption-band shift, a set of predicted values for the index of refraction and the extinction coefficient of ocean water in the 9- to 15-$\mu$ range were calculated. The results of these calculations are in Table 3.

Table 3
Variation of the Index of Refraction $n$ and the Extinction Coefficient $k$ as a Function of Wavelength for Ocean Water (salinity = 34.3‰)

| Wavelength ($\mu$) | $n$* | $k$* | $k'$† |
|---|---|---|---|
| 9.0 | 1.262 | .051 | — |
| 9.2 | 1.254 | .052 | — |
| 9.4 | 1.247 | .053 | — |
| 9.6 | 1.237 | .055 | — |
| 9.8 | 1.227 | .059 | — |
| 10.0 | 1.216 | .063 | — |
| 10.2 | 1.197 | .068 | — |
| 10.4 | 1.185 | .076 | — |
| 10.6 | 1.175 | .084 | — |
| 10.8 | 1.162 | .093 | — |
| 11.0 | 1.151 | .105 | — |
| 11.2 | 1.142 | .120 | — |
| 11.4 | 1.134 | .137 | — |
| 11.6 | 1.128 | .157 | — |
| 11.8 | 1.125 | .178 | -.001 |
| 12.0 | 1.123 | .201 | -.003 |
| 12.2 | 1.123 | .223 | -.004 |
| 12.4 | 1.125 | .247 | -.004 |
| 12.6 | 1.128 | .269 | -.004 |
| 12.8 | 1.132 | .293 | -.004 |
| 13.0 | 1.139 | .315 | -.004 |
| 13.2 | 1.148 | .333 | -.005 |
| 13.4 | 1.158 | .349 | -.005 |
| 13.6 | 1.170 | .362 | -.005 |
| 13.8 | 1.182 | .375 | -.005 |
| 14.0 | 1.194 | .385 | -.005 |
| 14.2 | 1.208 | .394 | -.005 |
| 14.4 | 1.220 | .402 | -.005 |
| 14.6 | 1.234 | .409 | -.005 |
| 14.8 | 1.247 | .414 | -.005 |
| 15.0 | 1.260 | .419 | -.005 |

*Corrected for changes in "$n$" and for the absorption-band shift.
†Additional correction for changes in the intensity of absorption.

## RELATIVE REFLECTANCE

The validity of the prediction procedures discussed in the previous section was determined using measurements of the reflectance of artificial ocean water with respect to the reflectance of pure water (relative reflectance). This procedure was chosen because it tended to cancel, at least to a first-order approximation, the effect of polarization sensitivity, beam convergence, and similar secondary effects.

The predicted values of relative reflectance were calculated using the following procedure: The reflectance for pure water was calculated using Eqs. (4) and (5) and the data contained in Table 1. It was assumed that the observed reflectance would equal the arithmetic average of the reflectances calculated using Eqs. (4) and (5). The predicted parameters obtained using the procedures outlined in the previous section were used to calculate the reflectance of artificial ocean water. The relative reflectance was obtained by dividing the predicted artificial ocean water reflectance by the predicted pure water reflectance.

Figure 3 shows the Model 621 grating spectrophotometer and tilt table used to experimentally determine the relative reflectance. The Model 21 Perkin-Elmer prism spectrophotometer, visible in the background, was also used in this study. Figure 4 shows the radiation source and the sample trays. All measurements were made at 25°C.

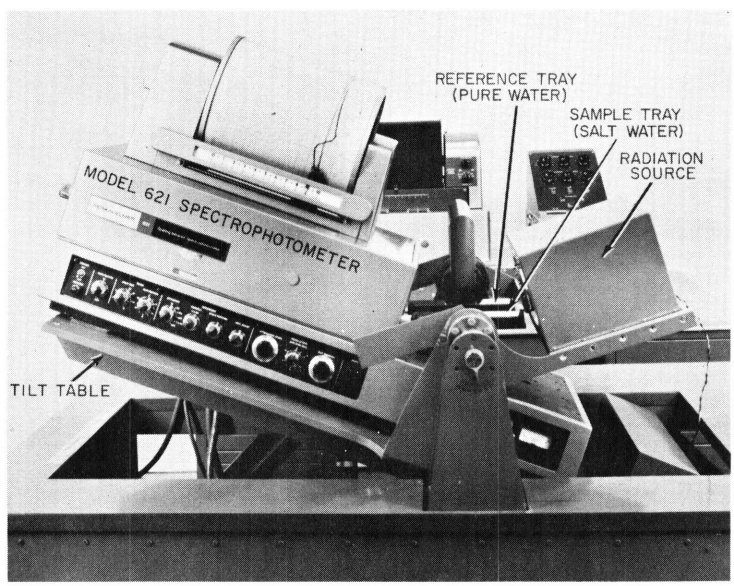


Fig. 3 – Assembly of the spectrophotometer and the tilt table used to measure the relative reflectance

Figure 5 shows the predicted and the measured values of the relative reflectance for an angle of incidence of 70 degrees. To improve the accuracy of the measurements, and to check on the possibility of nonlinear effects, tests were run at four salt concentrations. Figure 6 shows the essential linearity of the relative reflectance for two typical wavelengths. Each of the data points in Fig. 5 is the value obtained for a relative salt concentration of 1.0 using a straight-line approximation such as shown in Fig. 6.

The results in Figs. 5 and 6 indicate that the agreement between the predicted and the measured values in the 1-1/2- to 11-1/2-$\mu$ range is well within the limits of experimental accuracy. Beyond 11-1/2 $\mu$, however, the agreement is not as good and the two instruments do not give consistent values. Since this region is close to a grating change in the Model 621 spectrophotometer, it was assumed that the Model 21 data were more reliable. Further studies in this region, to check the assumption, are being considered. The lack of agreement beyond 11-1/2 $\mu$ was assumed to result from a reduction in the intensity of the absorption band. Although no reference to such a phenomenon could be

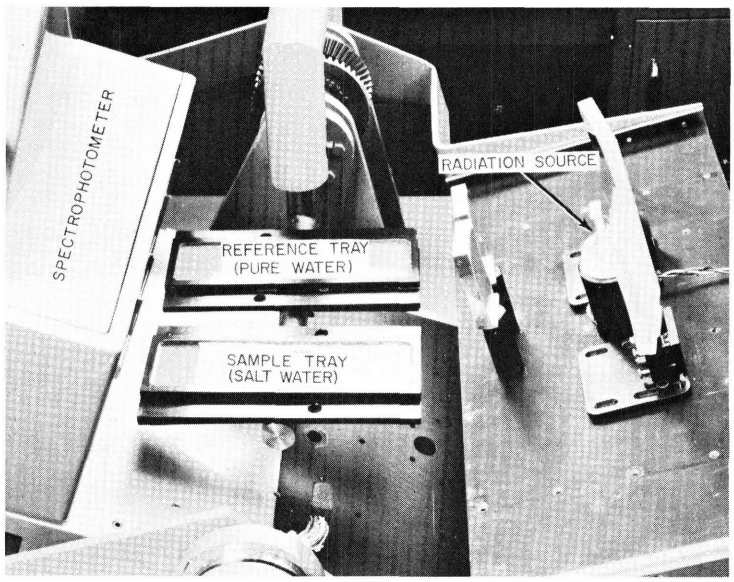


Fig. 4 – Closeup of the radiation source, sample trays, and spectrophotometer

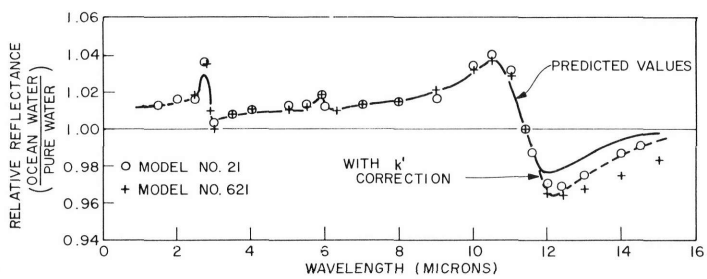


Fig. 5 – Relative reflectance of artificial ocean water at a 70-degree angle of incidence (sample temperature 25° C). These data were obtained with a Model 621 grating spectrophotometer and a Model 21 prism spectrophotometer. Although the grating instrument has better resolution, the inherently large sensitivity to changes in polarization of the reflected radiation cast doubt on the reliability of the Model 621 data above 13 $\mu$.

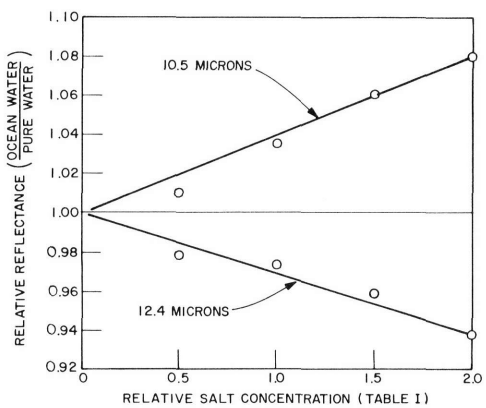


Fig. 6 – Effect of relative salt concentration on the relative reflectance for two typical wavelengths at a 70-degree angle of incidence (sample temperature 25° C)

found in the literature, it seemed reasonable to assume that the presence of dissolved salts would change the intensity as well as the vibrational frequency of an absorption band. The magnitude of the intensity change (numerically represented by a change in the extinction coefficient) required to provide good agreement between the predicted and the observed values is very small. Table 3 lists the extinction coefficient corrections $k'$ which were calculated to provide the best agreement between the predicted and the measured relative reflectances. It should be noted that these corrections are too small to be measured using conventional absorption-measuring techniques. The predicted curve using the $k'$correction is shown as a dashed line in Fig. 5.

Figure 7 shows the predicted and the measured values of the relative reflectance for an angle of incidence of 60 degrees. Since the Model 621 spectrophotometer would not operate properly at the tilt angle required for this measurement, only the Model 21 data are shown in Fig. 7. It should be noted that the use of the correction $k'$ yields much better agreement between the predicted and the observed values. Figure 8 shows the effect of changing the salt content for two typical wavelengths.

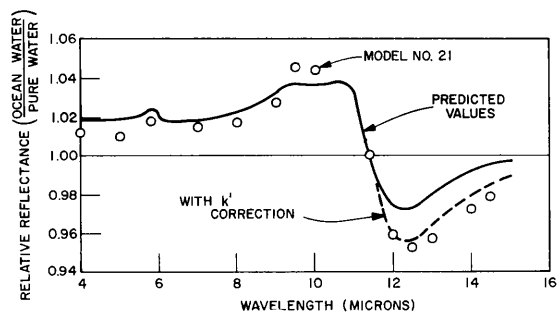


Fig. 7 – Relative reflectance of artificial ocean water at a 60-degree angle of incidence (sample temperature 25°C). The value for $k'$ applied in Fig. 5 to obtain a correct curve is also used here to adjust the relative reflectance curve.

As the result of physical limitations imposed by the tilt table shown in Fig. 3, the smallest angle of incidence obtainable was 34 degrees. Figures 9 and 10 contain the corresponding results obtained for a 34-degree angle of incidence. Here too, the use of $k'$ improves the accuracy of the predictions. The larger scatter observed is probably attributable to the low beam energy caused by the very low reflectance of water at small angles of incidence.

It should be noted that all the measurements contained in this report were made at 25°C and that the data in Table 1 were obtained at 35°C. Since data at low temperatures are not available, the infrared properties in Table 3 and Table 1 should be used with caution when low water temperatures are being considered.

## CONCLUSIONS AND RECOMMENDATIONS

1. In the infrared region between 1-1/2 and 8.8 $\mu$, the extinction coefficient for pure water can be used to provide a good approximation to the extinction coefficient of ocean water for any chlorinity up to 38‰. The index of refraction for pure water, plus a correction for the dissolved ion effect, can be used to provide an equivalent approximation

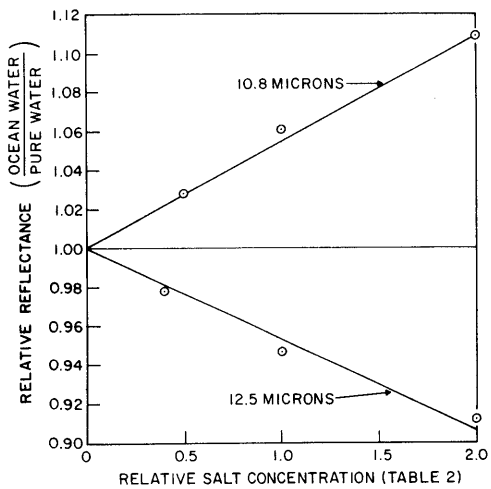


Fig. 8 – Effect of relative salt concentration on the relative reflectance for two typical wavelengths at a 60-degree angle of incidence (sample temperature 25° C)

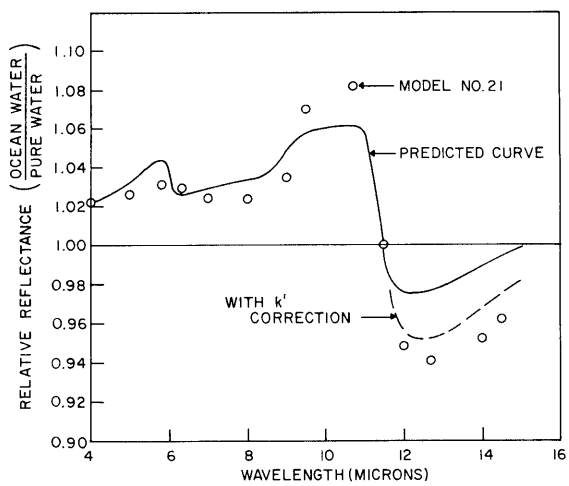


Fig. 9 – Relative reflectance of artificial ocean water at a 34-degree angle of incidence (sample temperature 25° C)

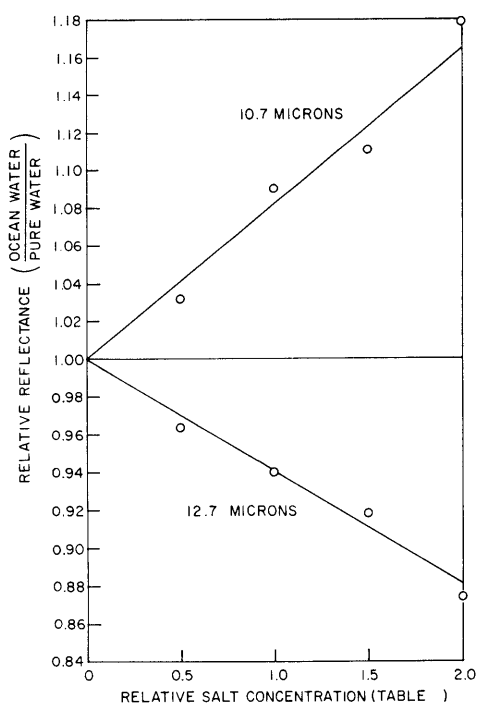


Fig. 10 – Effect of relative salt concentration on the relative reflectance for two typical wavelengths at a 34-degree angle of incidence (sample temperature 25° C)

to the index of refraction of ocean water. For a chlorinity of 19.0‰, the correction recommended is $6 \times 10^{-3}$ and is a linear function of the salt concentration (chlorinity < 38‰).

2. In the infrared region between 9 and 11.6 $\mu$, the values for the index of refraction and the extinction coefficient given in Table 3 are recommended for 19‰ chlorinity ocean water. For other values of salt concentration, a linear interpolation or extrapolation between the values contained in Table 3 and Table 1 is recommended.

3. In the infrared region between 11.8 and 15 $\mu$, it is recommended that the additional correction $k'$ be used pending further studies. For other salt concentrations some interpolation or extrapolation may be necessary.

## REFERENCES

1. Wilkerson, J.W., Geo-Marine Technology 2(No. 8):9 (1966)

2. McAlister, E.D., Ocean Industry 2(No. 5):35 (1967)

3. Stommel, H., et al., Science 117:639 (1953)

4. Davis, P.W., "A Bibliography of Certain Optical Properties of Liquid Water in the Infrared Region (1-2000 microns)," NRL Bibliography 25, Aug. 1965

5. Pontier, L., and Dechambenoy, C., Ann. Geophys. 22:633 (1966)

6. Sverdrup, H.U., Johnson, M.W., and Fleming, R.H., "The Oceans," New York:Prentice-Hall, 1942, p. 173

7. McLellan, H.J., "Elements of Physical Oceanography," New York:Pergamon Press, 1965, p. 129

8. Williams, D., and Millett, W., Phys. Rev. 66:6 (1944)

**This page intentionally left blank.**

Security Classification

**DOCUMENT CONTROL DATA - R & D**

*(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)*

| | |
|---|---|
| 1. ORIGINATING ACTIVITY *(Corporate author)*<br>Naval Research Laboratory<br>Washington, D.C. 20390 | 2a. REPORT SECURITY CLASSIFICATION<br>Unclassified<br>2b. GROUP |

3. REPORT TITLE

INFRARED CHARACTERISTICS OF OCEAN WATER (1-1/2 to 15 MICRONS)

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

An interim report on one phase of the problem.

5. AUTHOR(S) *(First name, middle initial, last name)*

Daniel Friedman

| | | |
|---|---|---|
| 6. REPORT DATE<br>July 11, 1968 | 7a. TOTAL NO. OF PAGES<br>15 | 7b. NO. OF REFS<br>8 |
| 8a. CONTRACT OR GRANT NO.<br>NRL Problem G01-02A<br>b. PROJECT NO.<br>AIRTASK NO. A37533059/6521/<br>c. F101-99-01<br>d. | 9a. ORIGINATOR'S REPORT NUMBER(S)<br>NRL Report 6736<br>9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* | |

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

| | |
|---|---|
| 11. SUPPLEMENTARY NOTES | 12. SPONSORING MILITARY ACTIVITY<br>Dept. of the Navy (Naval Air Systems Command, Code AIR-53303)<br>Washington, D.C. 20360 |

13. ABSTRACT

Equations and tabulated values of relevant physical parameters are presented which can be used to calculate the reflectance and emissivity of ocean water in the 1-1/2- to 15-micron range. Using double-beam spectrophotometers, the reflectance of artificial ocean water with respect to the reflectance of pure water was measured and compared with the calculated values for incidence angles of 70, 60, and 34 degrees. The agreement between the calculated and the measured values is well within the limits of experimental accuracy.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801



Security Classification

Security Classification

| 14. KEY WORDS | LINK A ROLE | LINK A WT | LINK B ROLE | LINK B WT | LINK C ROLE | LINK C WT |
|---|---|---|---|---|---|---|
| Infrared oceanography | | | | | | |
| Ocean water (infrared characteristics) | | | | | | |
| Artificial ocean water | | | | | | |
| Index of refraction | | | | | | |
| Extinction coefficient | | | | | | |
| Reflectance | | | | | | |

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)



Security Classification