NRL REPORT 3774

EXPERIMENTS ON THE TRANSMISSION OF ULTRAVIOLET LIGHT IN CHESAPEAKE BAY WATER

NAVAL RESEARCH LABORATORY

WASHINGTON, D.C.

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W. S. Plymale, Jr., L. H. Dawson, and R. J. Worsley

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Approved by:

J. A. Sanderson, Superintendent, Optics Division

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CAPTAIN F. R. FURTH, USN, DIRECTOR
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ABSTRACT

The transmission of light through water of Chesapeake Bay for several wavelengths between 2900A and 4050A has been studied. A high-intensity mercury arc and a gallium lamp were lowered below the surface of the water and the intensity of radiation at the surface was measured by means of a photomultiplier tube and amplifier. The absorption coefficients for 2975A, 3660A, and 4050A were found to be 0.033, 0.009, and 0.0067 respectively. The values of these coefficients are larger than some previous values found by other observers for samples of ocean water taken farther from land. This was due to the turbidity of the Bay water and to the presence of murky river waters emptying into the Bay.

Some fluorescence in the water was caused by the ultraviolet light from the mercury arc and from the gallium lamp. The brightness of the fluorescent water near the lamp windows was measured at the surface by visual means. In a separate experiment, a dome of ultraviolet-transmitting glass was fitted over the mercury arc to reduce the fluorescent glow. Photometric measurements showed that the brightness could be markedly reduced in this manner.

PROBLEM STATUS

This is an interim report; work on the problem is continuing.

AUTHORIZATION

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NR473-220

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INTRODUCTION

During May of 1950, apparatus was completed to make intensity measurements at the surface on ultraviolet sources lowered into the waters of Chesapeake Bay. The main purpose for such experimentation was to explore the possibility of optical communication between a submerged submarine and aircraft flying directly over the underwater signal. Such a system might possibly be used for identification without detection by visual observers not aware of ultraviolet radiation being transmitted from a submerged source. An area several miles east of Chesapeake Beach was chosen because of boat and dock facilities connected with the Chesapeake Bay Annex.

The water in the Bay was not ideal for making transmission studies in the ultraviolet region of the spectrum, but since the facilities were readily available it was considered worthwhile to complete a number of experiments. As a result, vertical transmission data were obtained for several wavelengths from 2900A to 4050A simultaneously with visible brightness measurements made on the lamps while under water. These visible effects were secondary to the ultraviolet transmission and were due mainly to luminescence produced by ultraviolet excitation of the water near the lamp windows. Some luminous effects were due to disturbance of the water by the lamps and lines but in all cases the brightness levels were low.

With a very sensitive light detector utilizing photomultiplier tubes[1] it was possible to get an idea of how far below surface ultraviolet signals at wavelengths below the visible region could be detected. Also accurate measurements were made of the absorption coefficients in Bay water for certain wavelengths below the visible. These data were compared with best published results[2,3] and found to be consistent except that the absorption coefficients were high for this water.

Although the apparatus was very sensitive and worked well for all the experiments it was not possible to detect ultraviolet light from the lamps at very impressive depths. This was due in part to the absence of any collimating or special optical system, but the high absorption coefficients of the Bay water were the chief deterring factors. The data collected, together with

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[1] *Plymale, W. S., Jr, and Hansen, D. F., " A Stabilized Voltage Supply and Linear Amplifier for Photomultiplier Tubes," NRL Report 3555, October 12, 1949*

[2] *Hulburt, E. O., "The Penetration of Ultraviolet Light into Pure Water and Sea Water," J.O.S.A., Vol. 17, p. 15-22, July 1928*

[3] *Dawson, L. H., and Hulburt, E. O., "The Absorption of Ultraviolet and Visible Light by Water," J.O.S.A., Vol 24, p. 175-77, July 1934*

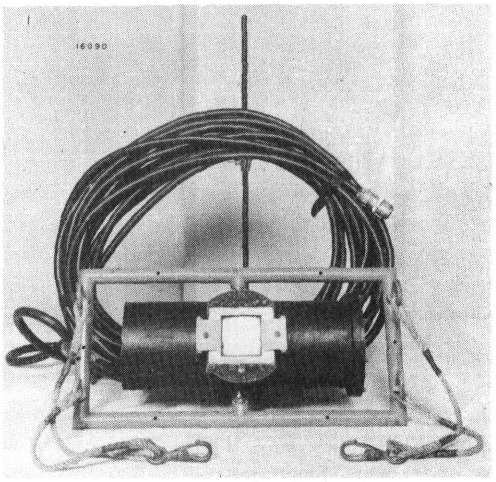

Figure 1 - Underwater lamp with cable for remote control

a brief description of the apparatus used, are given below. No conclusive evidence as to the ultimate use of submerged ultraviolet sources for communication to surface equipment is presented but it may be said that the feasibility of such an idea has definitely not been disproved.

APPARATUS

The apparatus consisted of two main units, an underwater ultraviolet source and a detecting apparatus on the deck of a boat. The source used in most of the experiments was a mercury AH5 lamp (250 watts) housed in a specially built watertight compartment with a quartz window. This underwater lamp is illustrated in Figure 1, which also shows the rubber cable through which the lamp and shutter were controlled from the boat.

In Figure 2 is seen the AC power supply and amplifier for the multiplier tube. A 1P21 tube, used at 3660A and 4050A, and a 1P28, used at 2975A, were placed in a pick-up box which could be attached to an arm extending about five feet over the surface of the water. A cone was designed to be used to reduce stray light effects above the water, but at night this precaution proved to be unnecessary.

In Figure 3 is shown another lamp and housing for experiments in the 2975A region. A gallium lamp with a special filter was enclosed in a watertight case with a quartz window in one end. No shutter was used with this lamp, but the lamp itself could be turned on and off through the cable.

A detailed description of the gallium lamp and specially developed filter is given in other reports.[4] The filter itself was made up of a viscous layer of nickel sulfate-sorbital complex contained between a plate of polished fused silica and a plate of Corex 9863. The lamp with vibrator unit was identical to the one previously used for land experiments. It was developed primarily for atmospheric transmission work, but afforded a good source for studies of sea-water transmission in the 2975A region.

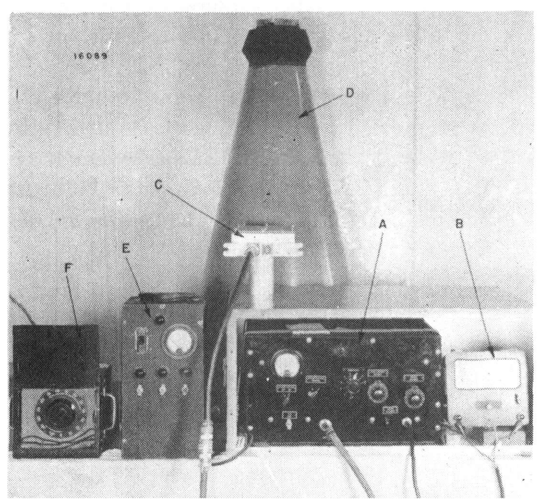

Figure 2 - Power supply and amplifier unit for photomultiplier tubes. A - Control panel, B - Meter, C - Pickup box with shutter, D - Cone, E - Switch box, F - Variac.

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4 *Summary Technical Report of Division 16, NDRC, Chapter 6, Vol. 4, Washington 1946*

TRANSMISSION MEASUREMENTS AND EXPERIMENTAL RESULTS

The actual measurements were made over a period of several months owing to weather and other conditions. All data were taken at night with skies from dark and overcast to clear and moonlit. In most instances the approximate illumination was noted but in some experiments low-brightness measurements were made with a visual photometer. These measurements included water and deck brightnesses as well as low-level photometer readings taken directly over the submerged ultraviolet lamps. As was to be expected, a certain amount of luminescence occurred near the lamp windows and this low-intensity glow was measured directly until the lamps were submerged a number of meters.

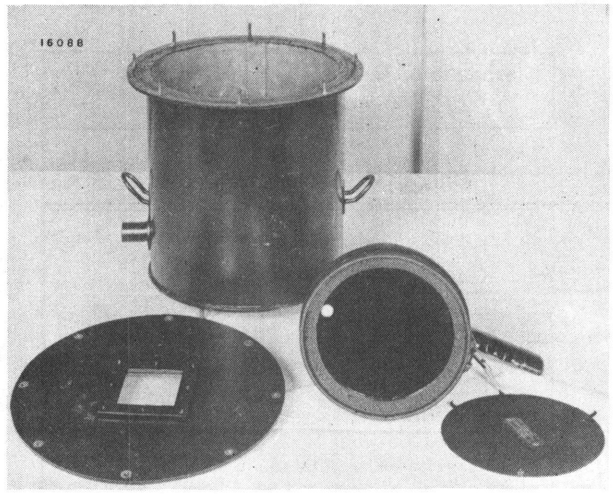


Figure 3 - Gallium lamp and housing for experiments at reduced depths

The first successful experiment was made on June 7 on the edge of the channel in the Bay. An AH5 lamp was used with a Corning "black light" No. 5860 filter placed over the quartz window. Since a 1P21 multiplier tube was used as detector, the transmission results were predominantly in the 3660A region. The sensitivity curve for the 1P21 tube and the transmission curve for the No. 5860 glass are plotted in Figure 4 and the results of the experiment are tabulated in Table 1.

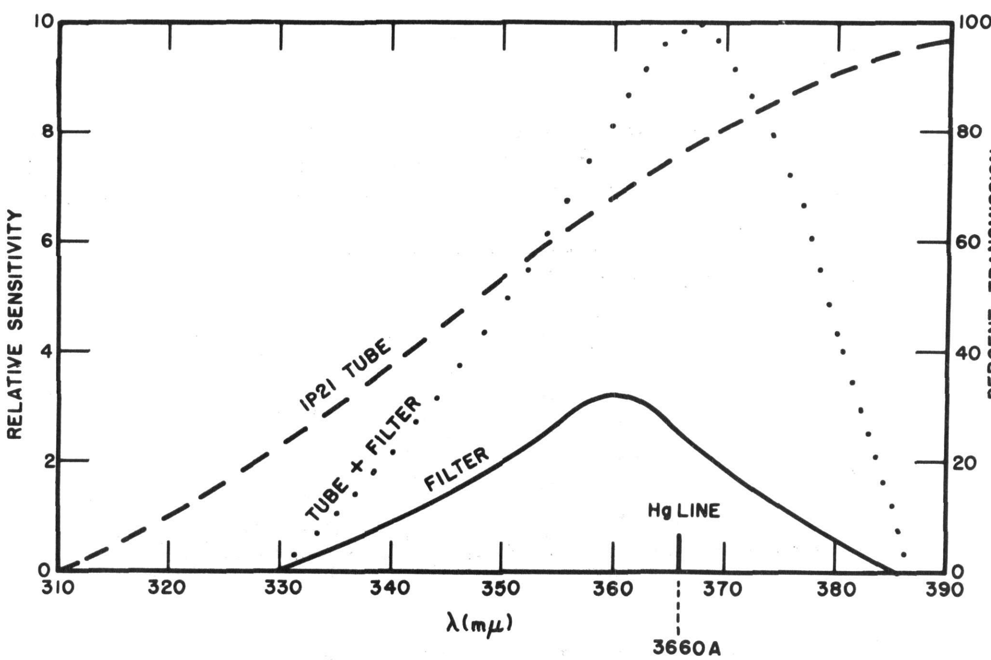


Figure 4 - Transmission and sensitivity of 1P21 - filter combination

TABLE 1

Variation of Insensity with Depth for the 3660-Angstrom Region*	
Depth (Meters)	Meter Deflection
4	537,500
5	45,000
6	3,750
7	550
8	16
9	2.5
9.5	1.5

*
Brightness of surface of water = 0.01 microlambert (lamp off)

Filter used - Corning No. 5860, 5.0 mm
Phototube used - 1P21

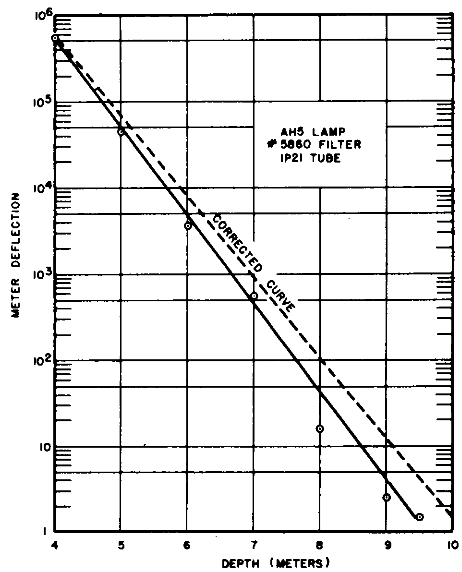


Figure 5 - Plot of deflection vs. depth for 3660A line

A plot of the points is given in Figure 5. Since the submerged lamp did not have a collimating lens, the deflection curve was corrected to allow for the inverse-square effect. When this curve was corrected around the point of minimum recorded depth, it was possible to get a straight line more accurately representing the absorption effects of the water. From this corrected curve the absorption coefficient and at a wavelength centered at 3660A was computed from the formula

$$D = D' \, 10^{\alpha(x'-x)}$$

where D and D' = deflections at depths x and x' respectively. This attenuation coefficient α is given as 0.009 cm^{-1} in Table 4.

Another experiment was made with the same lamp and phototube combination, but a filter stack to isolate the 4050A mercury line (Figure 6) was placed over the lamp window and pickup box. No stray light effects were noticeable through the second filter even though the cone was omitted and there was some starlight.

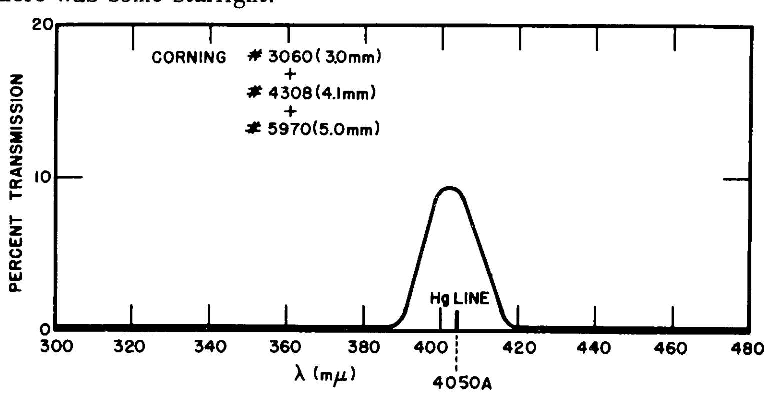


Figure 6 - Transmission curve for filter stack used to isolate the 4050A line

TABLE 2

Deflection and Brightness Values for the 4050 Angstrom Region*		
Depth (Meters)	Meter Deflection	Lamp Brightness (μL)
4	46,875	
5	11,870	0.31
6	4,250	0.20
7	130	0.11
8	12	0.03
9	2	0.014
10	1.5	0.012

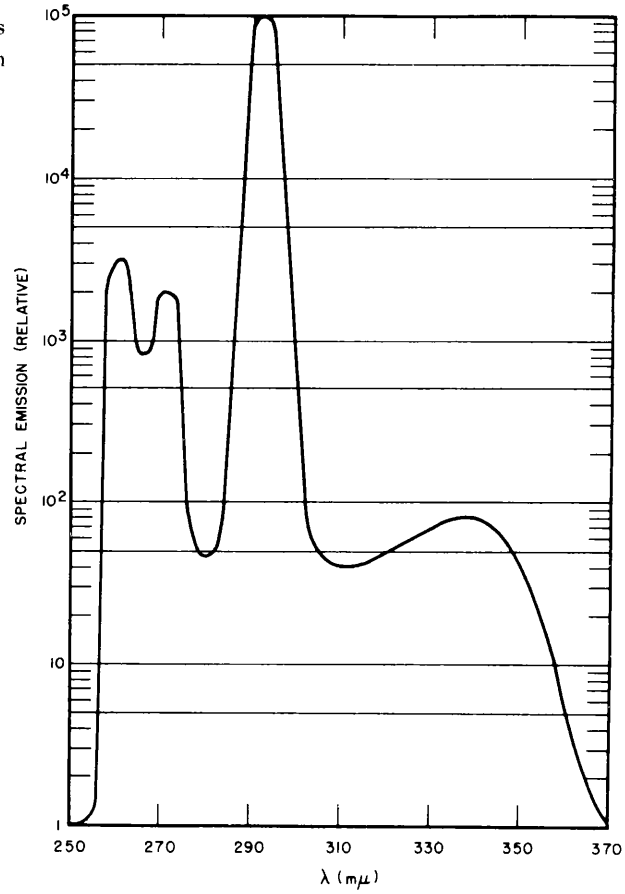
* Brightness of surface of water 0.009 μL.
Filters used - Corning Nos. 3060 + 4308 + 5970 (Two sets) Phototube used - 1P21

Direct brightness measurements on the lamp were made under various conditions and at different depths by C. A. Pearson of NRL . The photometer was of the visual or Rochester type widely used in night-sky photometry. Laboratory calibrations on the instrument were made by C. A. Pearson and M. Koomen of NRL, and all brightness values shown are taken from these calibration data. The results of the experiment for a wavelength of 4050A are given in Table 2.

On a very dark, overcast night a third set of measurements was made with the photoelectric apparatus and gallium lamp illustrated in Figure 3. The spectral emission curve of this lamp and filter was determined in the laboratory and may be seen plotted on a logarithmic scale in Figure 7. The "G-filter" has a specially chosen transmission band to limit the energy to a region from 2600A to 3500A. As ordinarily described,[5] the lamp-filter source is invisible beyond 50 feet in the atmosphere and has the advantage of being easily cut on and off for signaling purposes.

In Table 3 are listed the measurements on deflection and brightness for the gallium lamp to a depth of 220 cms.

Figure 7 - Spectral energy curve for gallium lamp and "G-filter"



[5] *Dawson and Hulbert, op. cit.*

TABLE 3

Instrument Deflection and Lamp Brightness Values in the 2975 Angstrom Region*

Depth (cm)	Meter Deflection	Lamp Brightness (μL)
50	468,750	1.65
100	43,750	0.49
120	15,000	0.31
140	4,000	0.29
150	500	0.22
170	200	0.08
190	70	0.09
200	13	.11
210	5	—
220	2.5	.10

* Brightness of surface of water = 0.03 μL
Brightness of white paper on deck = 0.08 μL
Phototube used - 1P28

TABLE 4

Comparison of Absorption Coefficients for Bay and Sea Water

Wavelength (Angstroms)	α(cm^{-1}) Chesapeake Bay	α(cm^{-1}) Sea Water*
2540		0.067
2800		0.039
2975	0.033	
3030		0.017
3130		0.009
3660	0.009	0.0013
4050	0.0067	
4360		0.0006

* Values taken from Hulburt. Op. Cit.

A graph representing these points is given in Figure 8. By the use of the formula described above, it was possible to get a reasonably accurate value for the absorption coefficient in the 2975A region of the spectrum.

From data taken to the present time, it is possible to present three ultraviolet absorption coefficients for Chesapeake Bay water. The data were recorded for three representative wavelengths, and may be compared with some published values for sea water more typical of that in the open seas. The values for α in the second column of Table 4 are given for wavelengths around a mean value indicated in column one. It is, however, certain that only the 3660A and the 4050A lines figured in the computations for α at these wavelengths.

It must be emphasized that the absorption coefficients given in the second column of Table 4 are computed from Bay water not far removed from river outlets. The measurements were made during the summer months when vegetable and other matter was perhaps at the

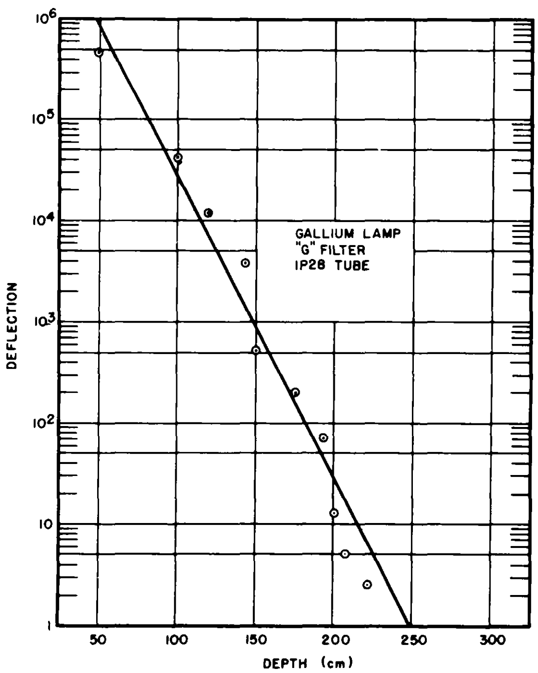


Figure 8 - Plot of deflection vs. depth for source illustrated in Figure 3

highest level. An appreciable amount of fluorescence due to agitation was noticed in the water. Also the ultraviolet excitation from the lamp was sufficient to produce effects that warranted a separate study on brightness and visibility.

BRIGHTNESS MEASUREMENTS ON THE SUBMERGED LAMP AND THE WATER SURFACE

Since the 3660A wavelength is intermediate in the so-called near ultraviolet region, it was the wavelength chosen to make special studies on brightness and lamp visibility under certain conditions. The visual photometer mentioned in the preceding section was used to make extensive brightness measurements during a boat trip planned solely for visual observations. A 5-mm piece of Corning No. 5860 glass was placed over the lamp window and photometer measurements were made directly on the lamp as it was lowered. A dome containing a large thick piece of similar glass (Figure 9) was then placed over the lamp and another run made to see how much the visibility of the lamp had been reduced. The results are given in Table 5.

It can be seen from the table that the dome effectively reduces the brightness of the water over the window of the submerged lamp. Since the glass in the attached dome has a maximum transmission near 3660A, the decrease in instrument deflection is much less in proportion to the decrease in the amount of fluorescent light that reaches the surface. By the use of a filter with higher ultraviolet transmission over the window it would be possible to get even higher transmission at 3660A while containing the fluorescent light in the dome.

No accurate statements can be made as to the visibility of the underwater lamps except under the conditions described. The diameter of the luminous area caused by fluorescence was from approximately one to two feet with the brightest point at the center. All the photometer readings were taken by matching the field to this brightest region. The measurements were made by an observer a few feet from the surface of the water.

The brightness values given in the tables are considered very low insofar as photometry is concerned. No doubt the underwater lamps would be difficult to see from any appreciable

TABLE 5

Photometric Reduction of Visible Light from Submerged Lamp by Use of Ultraviolet Dome*

Depth (Meters)	Brightness (Microlamberts)	
	Dome Off	Dome Attached
2	18.0	5.0
3	7.4	1.43
4	0.98	0.51
5	0.22	0.15
7	0.12	0.090
8	0.12	0.086

* Brightness of water surface 0.086 μL (low moonlight)

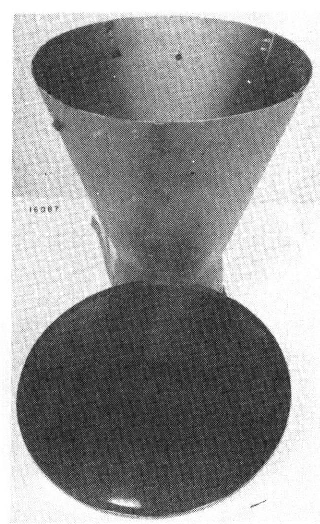


Figure 9 - Attachment for reducing glow near lamp window

distance, especially as the angle of observation is increased. It would require, however, a separate group of experiments to determine lamp visibilities under varying weather conditions and with different observers farther removed. All photometrists making readings with a low-intensity photometer directly off of the deck would be considered in such a series of experiments as only one observer.

CONCLUSIONS

It has been pointed out that all these experiments were made in water not typical of that in the open seas. A recent paper gives reports on measurements of penetration depths of sunlight into clearer sea water such as that in the East Mediterranean and the Sargasso Seas.[6] Photoelectric detectors were used, and the intensities of ultraviolet radiation were measured to various depths. The results as published seem in contrast to those given in the above tables. For example, in the East Mediterranean it was found that the radiation at a wavelength of 3100A was reduced 14 percent per meter depth and at a wavelength of 3750A the corresponding reduction was only five percent. In Chesapeake Bay water the reduction in intensity at 3660A was approximately 85 percent per meter.

It may therefore be permissible to present such contrasting results as representative of the extreme cases of ultraviolet transmission in sea water. If any conclusion may be drawn, it could be that depths from five to ten times those recorded for the Bay are possible elsewhere in clearer water. Furthermore, it seems probable that a lamp-filter combination with a very strong band in the 3400- to 3600-Angstrom region would be most desirable for signaling from underwater craft.

PRESENT STATUS OF THE PROBLEM

From the standpoint of acquiring extensive basic scientific facts about the transmission of ultraviolet light in sea water the work is, of course, very incomplete. At the present time, the work is necessarily in the initial stages and the apparatus is being improved to make measurements in deeper water farther from shores and from inland waters.

Further investigations of more powerful and better suited lamp-filter sources are necessary to determine with accuracy, the possibilities of underwater signalling by optical means. Such investigations are now under way while additional experiments are being made with the apparatus described above.

[6] *Jerlov, N. G., "Ultraviolet Radiation in the Sea," Nature, Vol. 166, p. 111, July 15, 1950*

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