THE UNIVERSITY OF MICHIGAN

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Final Report

ATMOSPHERE BOUNDARY OPTICS

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ORA Project 084690

under contract with:

OFFICE OF NAVAL RESEARCH
DEPARTMENT OF THE NAVY
CONTRACT NO. N00014-67-A-0181-0003
ARLINGTON, VIRGINIA

administered through:

OFFICE OF RESEARCH ADMINISTRATION ANN ARBOR

June 1971

TABLE OF CONTENTS

	Page
LIST OF FIGURES	iii
ABSTRACT	iv
1. INTRODUCTION	1
2. THE INSTRUMENTATION SYSTEM	1
3. SPECTRAL RESPONSE OF INSTRUMENTATION	3
4. ANTICIPATED SPECTRAL RESPONSE OF PLANKTON	3
5. RANGE OF THE SYSTEM	5
6. RECOMMENDATIONS	6
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LIST OF FIGURES

Figure		Page
1.	Block diagram of the plankton spectrum analyzing system.	8
2.	The light source, collimating mirror, and monochrometer with entrance slit.	9
3.	The strip-chart recorder and photomultiplier power supply.	10
4.	Examples of output spectra.	11
5.	Spectral characteristics of chlorophyll A and chlorophyll B.	12
6.	Absorption spectrum of chlorophyll B.	12
7.	Spectral response of system as weighted by absorption spectrum of chlorophyll B.	13
8.	Light intensity distributions of the light source.	14
9.	Light intensity distribution of the collimated light beam.	15

ABSTRACT

This study was conducted to determine the feasibility of detecting plankton over various sea states using absorption spectroscopy with visible light. A qualitative analysis of their presence and a quantitative analysis of their concentrations were to be determined. Over a limited range of 100 feet or slightly more, it appears that a white light source with a collimated light beam should have adequate sensitivity even in daylight. During darkness or with certain improvements, it should be possible to improve the range. The equipment was not field tested, so positive proof of plankton detection and concentration measurement was not obtainable.

1. INTRODUCTION

Absorption spectroscopy offers a method of nondestructive qualitative and quantitative analysis applicable to any transparent material having absorption lines or bands within the wavelength range of the equipment being used. In particular, the detection of plankton above the surface of various sea states should be possible, as they contain chlorophyll, which has absorption bands in the green wavelength region of visible light. The equipment described in this report was assembled to operate in the visible region of the electromagnetic spectrum, so as to be sensitive to the absorption bands of chlorophyll and, therefore, presumably to the sensitive bands of plankton.

2. THE INSTRUMENTATION SYSTEM

The instrumentation system, Figure 1, consists of a white light source, a collimating mirror, a cell for test solutions, a focusing mirror, an Ebert monochrometer, a photomultiplier-type radiation detector with power supply, and a strip-chart recorder.

The white light used was a Marchel Fantasque Model GT575 auto headlight. These units, imported from France, are quartz with iodine vapor and are considerably brighter than similar lights made in the United States.

The collimating and focusing mirrors were spherical front surfaced mirrors. They had a diameter of 4.5 inches and a focal length of 45 inches. The purpose of the collimating lens was to produce a parallel beam of light through the

region to be sampled. The second mirror reflected the parallel light beam and focused it onto the entrance slit of the monochrometer.

A glass test cell was used in the laboratory to introduce absorbing material into the optical beam. India ink in water provided a neutral filter to reduce light intensity during a portion of the testing of the equipment, while the water cell plus a Wratten #58 filter was used to produce transmission in the green portion of the visible spectrum.

The monochrometer was a Jarrel-Ash 0.25 Meter Ebert Monochrometer, Model No. 82-410. This monochrometer has an attachment that provides an electrical tracking voltage proportional to the monochrometer wavelength. Two scan rates, which provide a single scan of the electrical potentiometer for a single scan of the monochrometer available. The first scan rate was one complete scan from 1500 Angstroms to 8400 Angstroms in 6-3/4 minutes, while the second scan required 67-1/2 minutes. The second scan rate was excessively long, based on the intent of the experiment and was not used.

A R132 photomultiplier tube with response S-13 was provided with the monochrometer to produce a voltage that is related to the light output of the monochrometer. The spectral response of the photomultiplier tube and its envelope modify the response of the monochrometer system.

The strip-chart recorder was a Heath Model No. EUW-20M. This is a servo-type recorder with a multi-speed chart drive.

Figures 2 and 3 illustrate portions of the equipment as it was assembled in the laboratory.

3. SPECTRAL RESPONSE OF INSTRUMENTATION

The spectral response of the instrumentation system depends on the spectral characteristics of the output from the light source and all absorptions at various wavelengths throughout the system. A principle limitation of the spectral pass band of the system is the optical absorption in the glass envelope of the photomultiplier tube. The system response below 3000 Angstroms and above 8000 Angstroms will be small, and any large amplitude signals outside these limits should be viewed with suspicion. Figure 4 shows the spectral response curve of the system with a neutral gray water-cell attenuator. The sharp dip in intensity at 7000 Angstroms provides a well-defined reference mark. Also shown in Figure 4 is the light transmission when the Wratten #58 green filter is added in the optical path. In this case the peak light transmission is about 42% at 5300 Angstroms and is reduced to less than 1% at 4800 Angstroms and 6200 Angstroms, respectively.

4. ANTICIPATED SPECTRAL RESPONSE OF PLANKTON

As no plankton were available in the laboratory for spectral response determination, their response had to be simulated. All phytoplankton contain chlorophyll A, while some contain chlorophyll B. Therefore, plankton simulation was achieved by weighting the spectral response of the system with the known, Gillam, Stern, and Jones,* absorption characteristics of chlorophyll

*Gillam, A. E., E. S. Stern, and E.R.H. Jones. 1957. An Introduction to Electronic Absorption Spectroscopy in Organic Chemistry. Edward Arnold, Ltd. (publishers), London.

as shown by Figure 5. Figure 6 is a percent transmission profile for chlorophyll B, while Figure 7 shows the response of the system with no chlorophyll attenuation and as it would be when weighted by the addition of chlorophyll in the optical path.

If cholrophyll absorption is a good simulation of plankton absorption, then measurements at a dip like that at 6000 Angstroms would provide a means of quantitative analysis. The absorption spectra of plankton will have to be determined in the field over a sea surface where they are available.

In the conventional absorption spectrometer, the substance being measured is dissolved in a liquid that does not enter into a chemical reaction with the sample. This sample is placed in a transparent cell in one beam of the optical system of the spectrometer. A sample of the pure solvent in an identical cell is placed in a second optical path, and measurements are made by comparing the light intensity through the sample solution with that through the pure solvent. In such an instrument, the output is the ratio of or the difference between the two signals.

In the instrumentation of this report, only one beam is available, and measurements are limited to comparisons between unattenuated spectra and spectra made with absorbing material present. Because of the above, meaningful conclusions can be made only by correlation studies between the two spectra. One possible solution to identification of the spectra of plankton is to produce a Fourier series representation of the plankton spectra and of the unattenuated spectra and look for discrepancies in their relative magnitudes at different harmonics.

5. RANGE OF THE SYSTEM

The range of the system is determined by the signal-to-noise ratio at the photomultiplier tube. Signal is the light from the source that has passed through any attenuating medium in its path (plankton, chlorophyll, or green filter) and has been refracted onto the sensitive element of the photomultiplier tube by the monochrometer. Optical noise is light from any other source that gets to the sensitive element of the photomultiplier tube. Noise can also be generated as an electronic signal in the photomultiplier circuits or in the tube itself.

With the instrumentation used in this work, optical noise and electronic noise cannot be distinguished. However, with optical input cutoff, the remaining internal noise of the system was 0.01 volt. With the quartz iodine lamp uncollimated and at a distance of 10 feet from the entrance slit of the monochrometer, the available signal produced a peak output of 0.21 volt. The resulting signal to noise ratio was approximately 20 to 1 and acceptable over a large part of the span of the monochrometer. In this configuration (no optical beam shaping) the optical beam divergence from the quartz iodine light was about one unit in the horizontal for each six units along the optical path. With such a divergence the light intensity falls to a level at 20 feet, so that the noise-to-signal ratio is 2 to 1 in daylight. Under these conditions the system performance is unacceptable.

A photometric scan of the plane normal to the light beam was made at a distance of 4 feet and again at 9 feet. The results of this experiment are

shown by Figure 8. It is clear that the further from the source, the more uniform the light intensity is over the area of the beam. At 4 feet the uniformity is so poor as to make the instrumentation unusable.

Collimation of the beam by means of a 4.5-inch concave spherical mirror reduced the dispersion of the white light beam, so that a gain of nearly 7 was achieved in the light intensity at a distance of 9 feet over the intensity of the uncollimated system at the same distance from the source. Figure 9 shows the distribution of light intensity over the beam when the collimating mirror was used. While of the same general shape as the distribution pattern for the uncollimated source, the gain in signal strength is obvious.

Under daylight conditions, stray light incident on the entrance slit of the monochrometer produced a noise contribution which, when added to other noise sources, resulted in a limiting signal-to-noise ratio, when the total optical path length was about 100 feet. This, then, would be the limiting range for the system as assembled and tested in this investigation.

6. RECOMMENDATIONS

The minimization of stray light incident on the entrance slit of the monochrometer would enhance the range of the system. Light shielded housings with extended tubes along the optical path for the source, mirrors and entrance slit could possibly double the range. A brighter light source would boost the signal and enhance the signal-to-noise ratio. If the plankton-sensing experiments could be conducted during darkness, much greater ranges could be obtained, as the stray light would be much less.

Once the absorption spectra of plankton have been determined using white light, it may be possible to find a characteristic wavelength for quantitative analysis that coincides with the output of a laser. With a laser as the light source, collimation is a natural result, and a greatly improved range should be achieved.

For field studies of plankton over various sea states, a study region should be chosen where they are known to exist and a corner reflector mounted beyond the region of plankton activity. The collimated beam can then be aimed at the corner reflector and the focusing mirror adjusted to receive the reflected light beam and focus it on the entrance slit of the monochrometer. With this configuration the light beam will pass through the plankton swarm twice, and more absorption will occur. With a laser as light source, the experimental setup would be the same except no mirrors would be necessary.

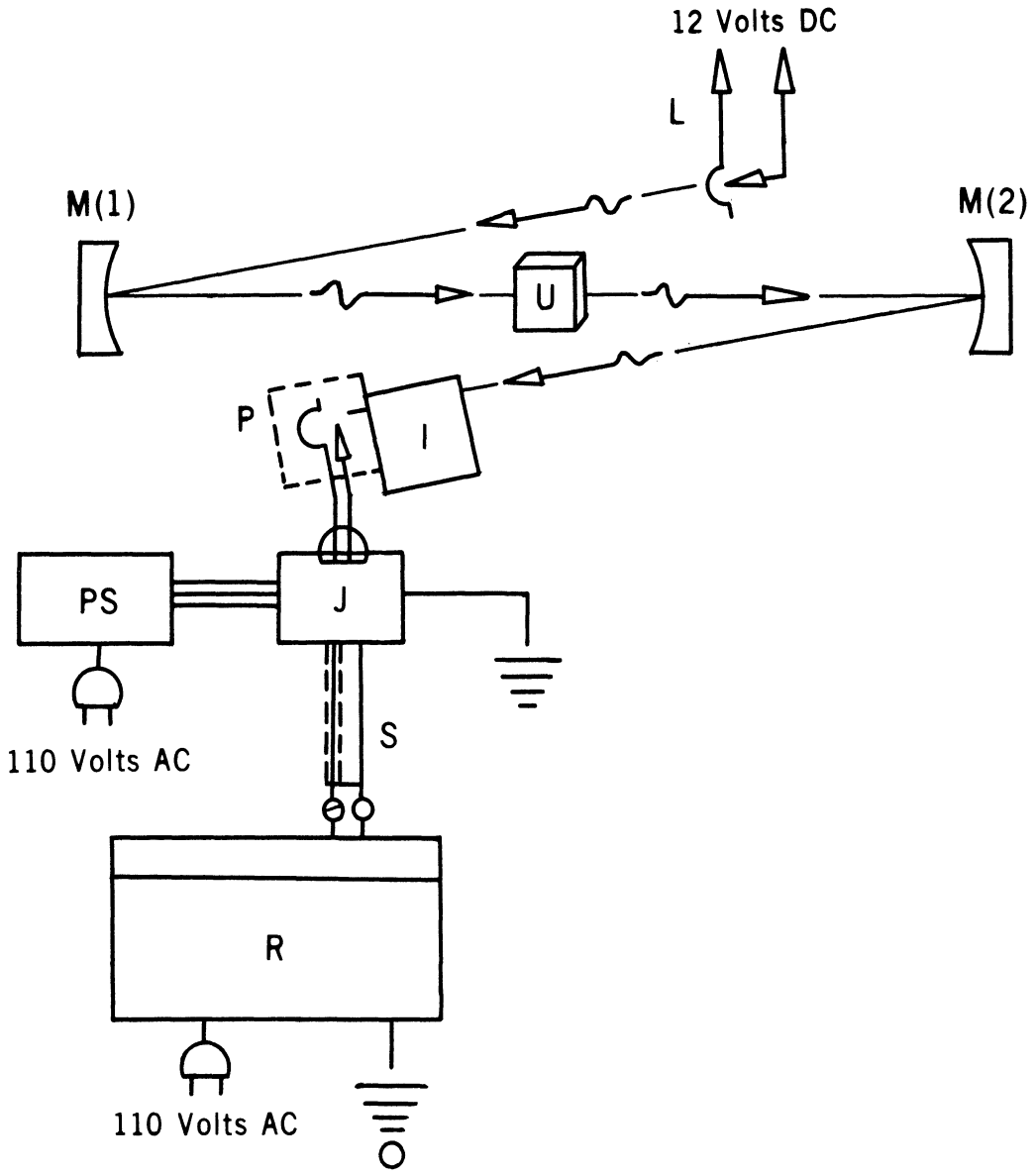

Figure 1. Block diagram of the plankton spectrum analyzing system. L is the quartz iodine light source; M(1) the collimating mirror and M(2) the focusing mirror; U the water cell; I the monochrometer; P the photomultiplier and PS its power supply; J a junction box; and S a shielded cable to take the signal to the strip-chart recorder, R.

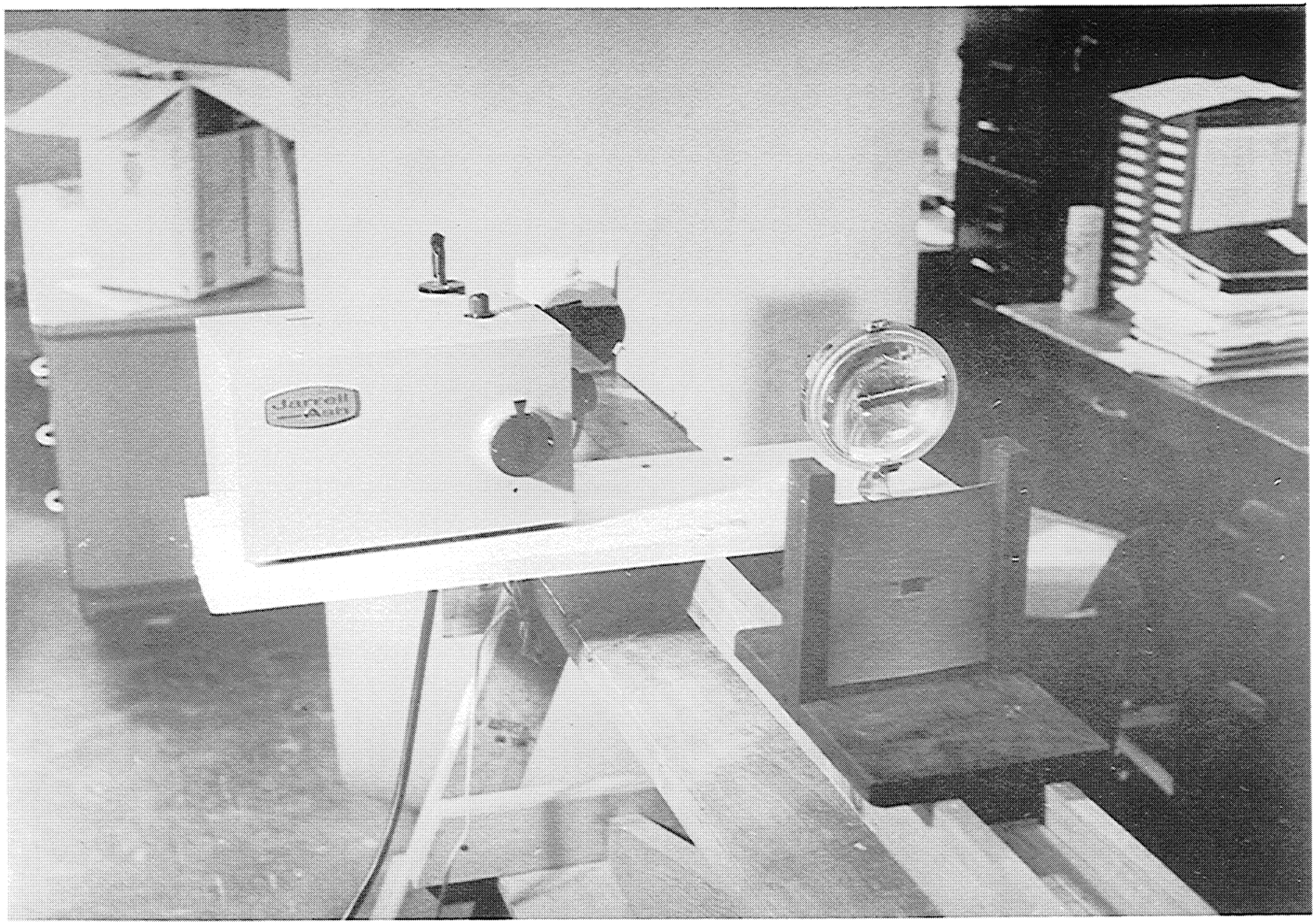

Figure 2. The light source, collimating mirror and monochrometer with entrance slit.

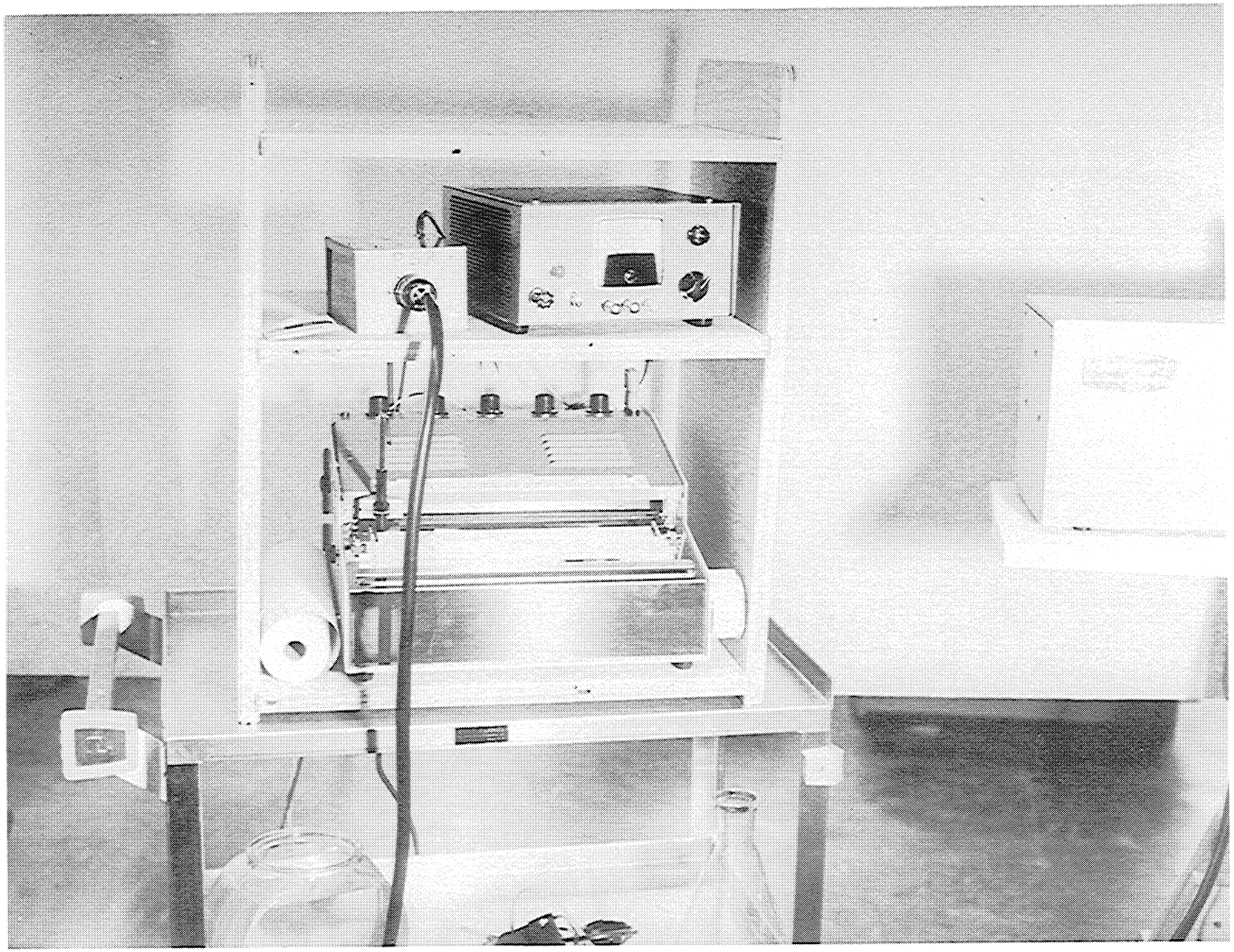

Figure 3. The strip-chart recorder and photomultiplier power supply.

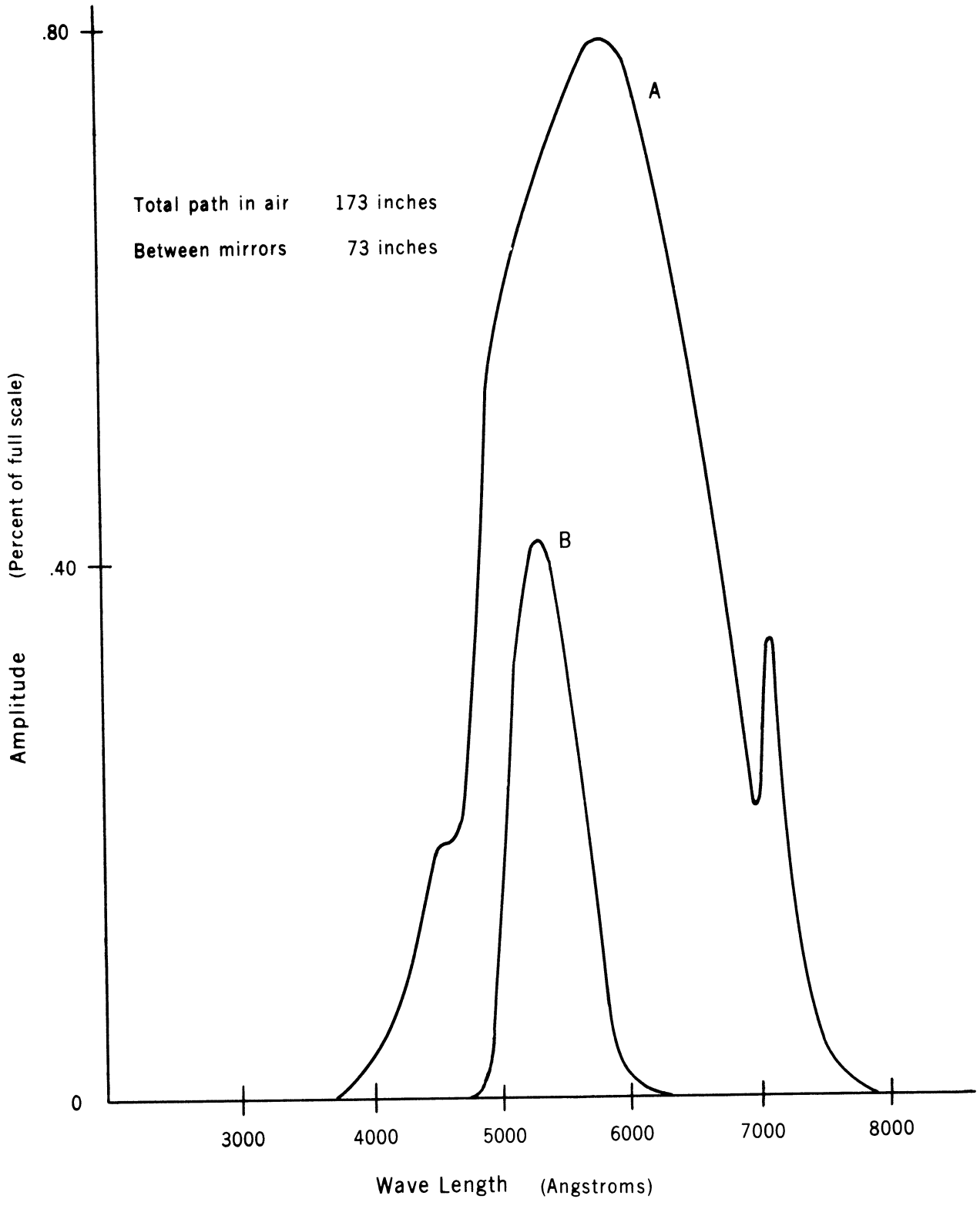

Figure 4. Output spectra. (A) With a cell containing India ink in water; (B) with a Wratten Felter #58 (green) in addition to the water cell.

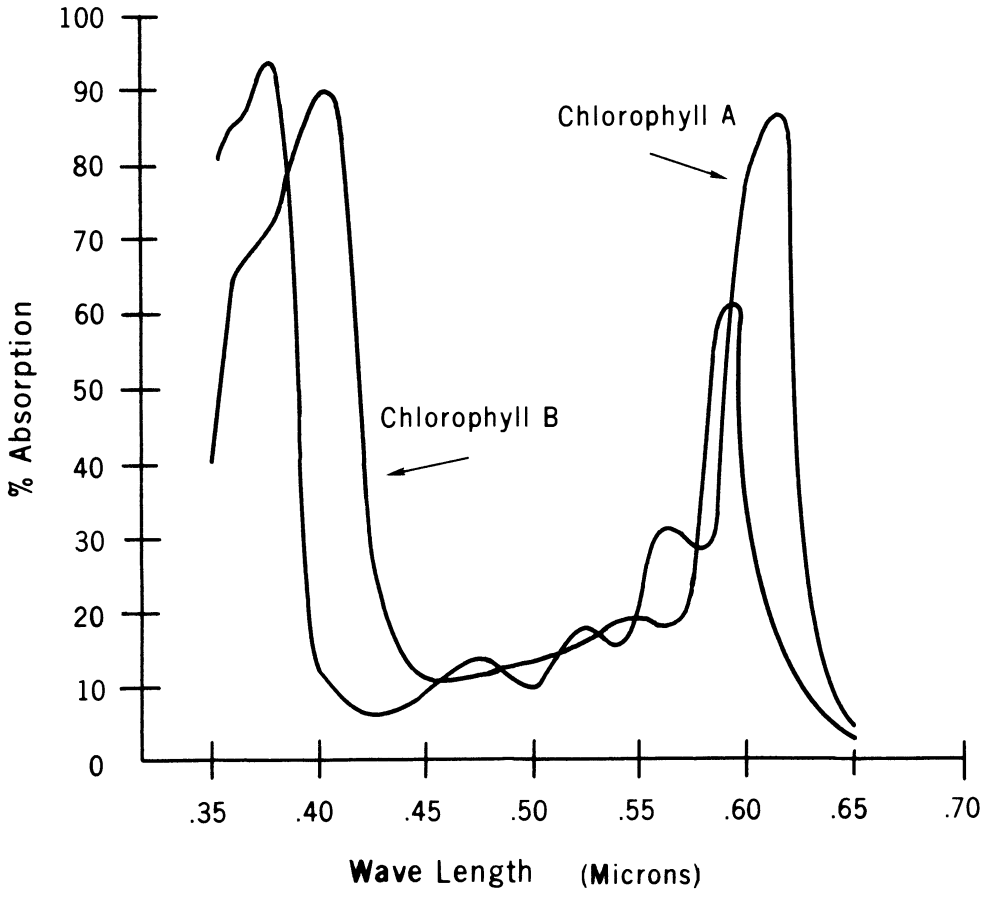

Figure 5. Spectral characteristics of chlorophyll A and chlorophyll B.

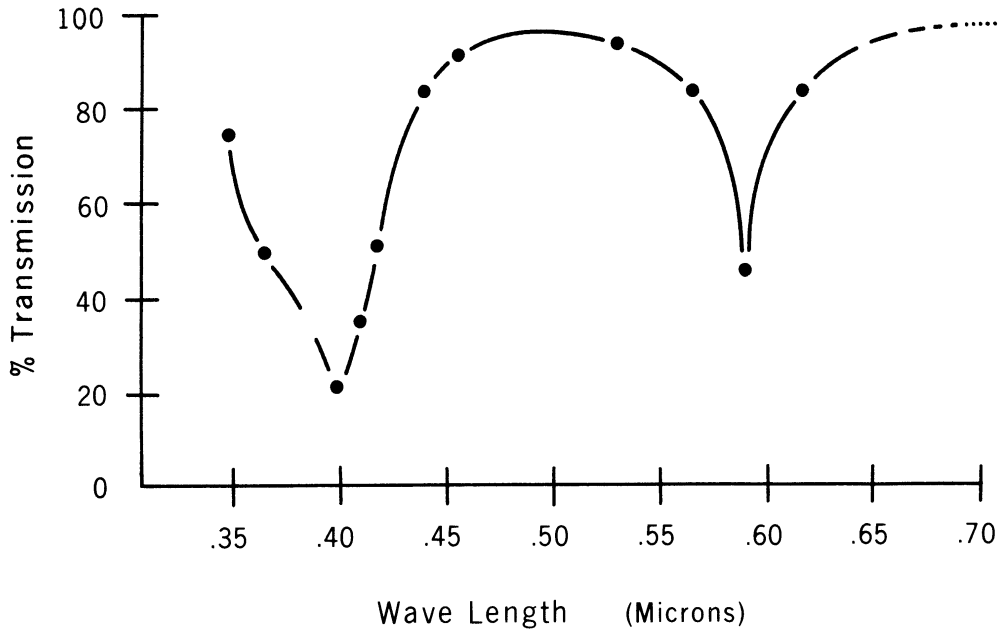

Figure 6. Absorption spectrum of chlorophyll B.

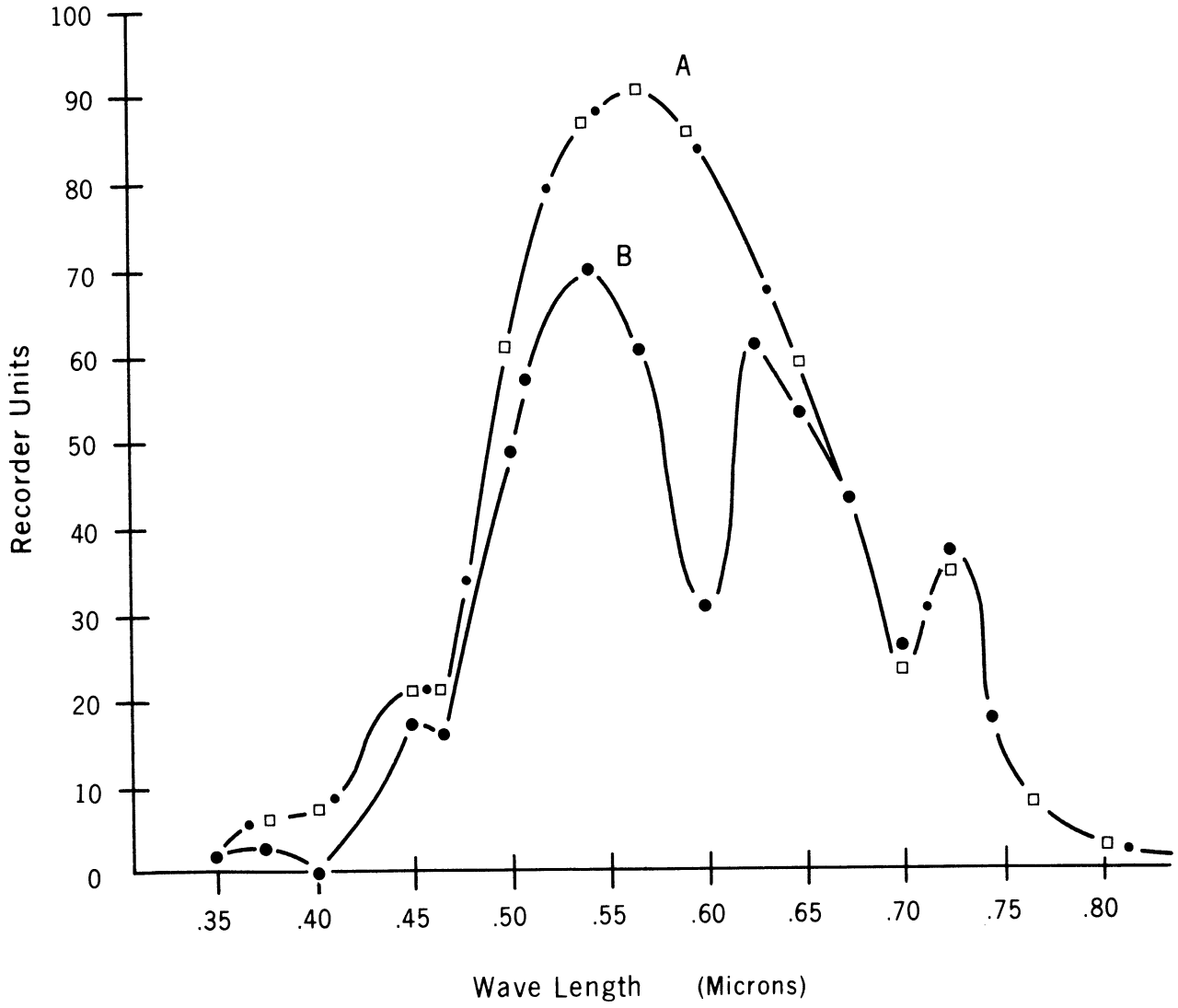

Figure 7. Spectral responses of system. (A) With no absorbing material; (B) as weighted by the absorption spectrum of chlorophyll B.

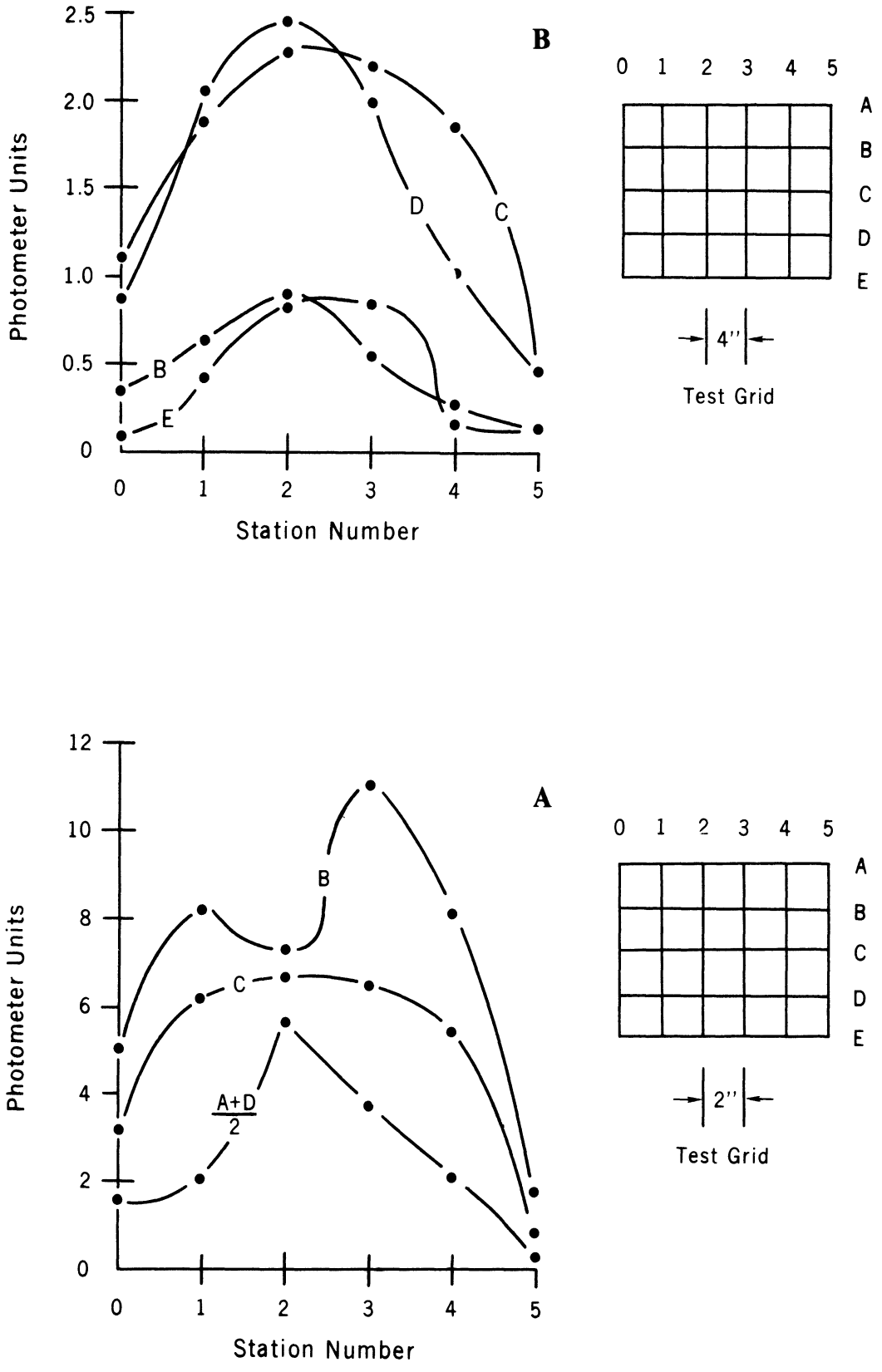

Figure 8. Light intensity distributions from the quartz iodine-vapor light source on a plane normal to the beam. (A) At a distance of 4 feet; (B) at a distance of 9 feet.

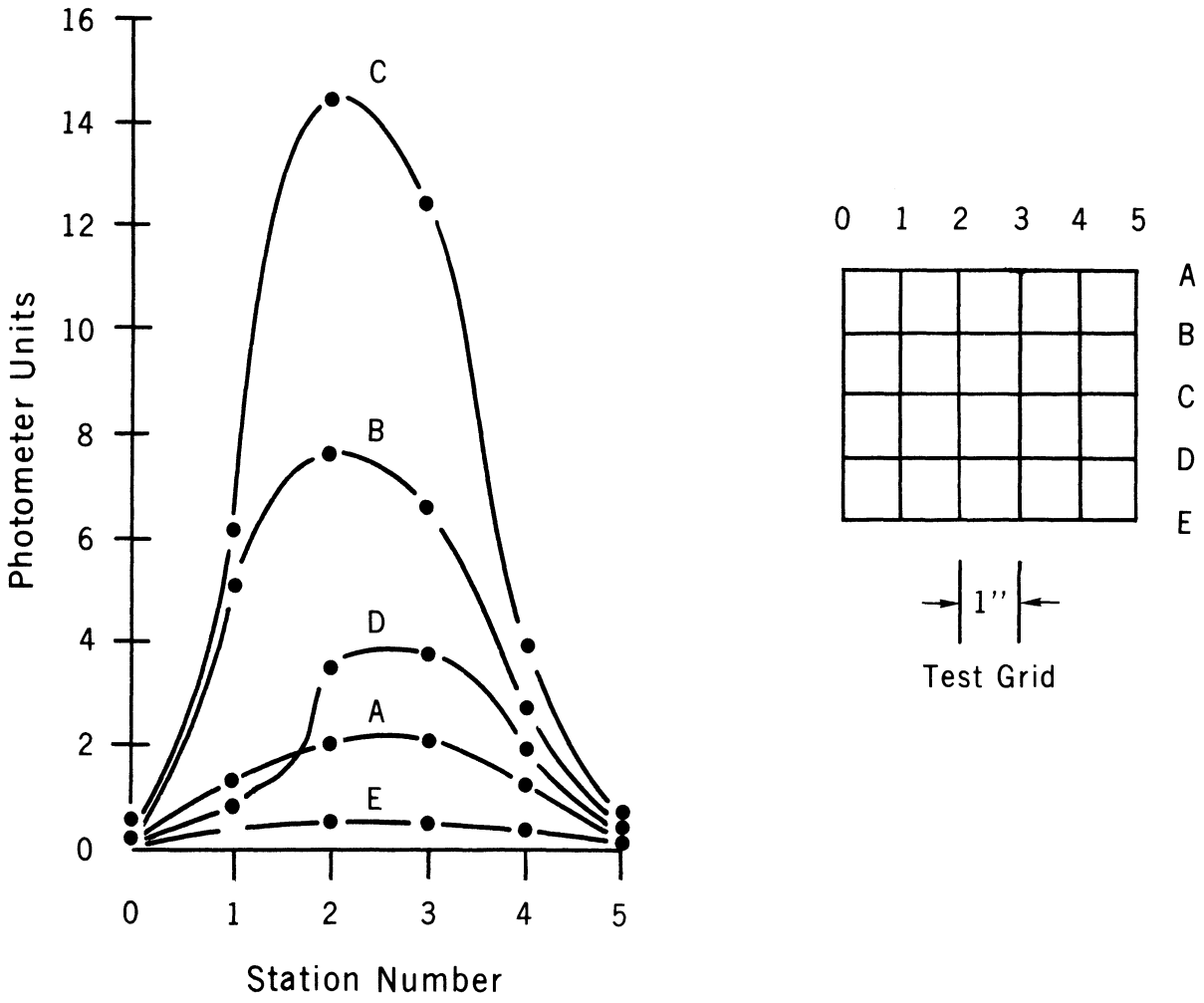

Figure 9. Light intensity distribution of the light beam after collimation by the 4.5-inch spherical mirror. Distribution measured at a distance of 9 feet.

UNCLASSIFIED

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)	2a. REPORT SECURITY CLASSIFICATION
The Regents of The University of Michigan Ann Arbor, Michigan 48104	Unclassified
	2b. GROUP

3. REPORT TITLE

ATMOSPHERE BOUNDARY OPTICS

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

Scientific—Final (1 November 1966 - 30 June 1968)

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

Albert W. Stohrer and Alan L. Cole

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1971	15	1

8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)
N00014-67-A-0181-0003	084690-1-F
b. PROJECT NO.	
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)
d.	

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
TECH, OTHER	Office of Naval Research Department of the Navy Arlington, Virginia

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DD FORM 1 NOV 68 1473

UNCLASSIFIED

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT