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WATER CLARITY METER  
OPERATING AND MAINTENANCE INSTRUCTIONS

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## TABLE OF CONTENTS

	Page
1.0 Purpose	1
2.0 Description	2
2.1 Method of Measurement	2
2.2 General Physical Description	3
2.3 Detailed Description of Components	5
2.31 Underwater Mechanical Assembly	5
2.311 Frame	5
2.312 Receiver Mount Assembly	6
2.313 Projector Mount Assembly	7
2.314 Housings	7
2.315 Pressure Transducer Assembly	8
2.316 h-Meter Assembly	8
2.317 Baffle Assembly	9
2.318 Junction Box	9
2.32 h-Meter	11
2.321 Mechanical Assembly	11
2.33 $\alpha$ -Meter	12
2.331 Projector Optical-Mechanical System	13
2.332 Receiver Optical-Mechanical System	14
2.34 h-meter and $\alpha$ -Meter Electrical Circuits	15
2.341 Photometer Circuits	15
2.342 Underwater Electrical Chassis	21
2.35 Depth Measurement	21

## TABLE OF CONTENTS (Continued)

	Page
2.36 Underwater Cable	23
2.37 Deck Illuminometer	25
2.38 Deck Control Unit	27
2.39 Recorder	30
3.0 Operation	31
3.1 General Precautions	31
3.2 Preparation of Equipment	33
3.3 Deck Check-Out	34
3.4 Data Taking Procedure	34
3.5 Post Operational Routines	35
4.0 Theory of Operation	36
4.1 h-Meter and k Determination	36
4.2 $\alpha$ -Meter	37
5.0 Reduction of Data	41
5.1 Depth, Z	41
5.2 Deck Illuminance, E	41
5.3 Relative Underwater Scalar Irradiance, h	42
5.4 Attenuation Coefficient for Collimated Light, $\alpha$	42
5.5 Computation of Attenuation Coefficient for Diffuse (Ambient) Light, k	43
6.0 Alignment and Calibration Procedures	44
6.1 Optical Alignment of $\alpha$ -Meter	44
6.2 Calibration of Depth Transducer	49
6.3 Calibration of Logarithmic Photometer Chassis	50

TABLE OF CONTENTS (Continued)

	Page
7.0 Maintenance	56
7.1 Mechanical Precautions and General Maintenance	56
7.11 Water Seals	56
7.12 Use of Nitrogen and Desiccant	58
7.13 Pressure Transducer	58
7.14 h-Meter Removal	60
7.2 Electronic Maintenance	61
7.21 Vacuum Tube Replacement	61
7.22 Replacement of Regulating Diodes	62
7.23 Miscellaneous Maintenance	63

## LIST OF ILLUSTRATIONS

<u>Figure</u>	<u>Title</u>
Frontispiece	Water Clarity Meter
1	Assembled Instrument
2	Deck Control Unit - Panel
3	Deck Control Unit - Underside
4	Deck Control Unit - Underside
5	Deck Illuminometer
6	Instrument with Housings Removed
7	Pressure Transducer Assembly
8	Junction Box - Open
9	h-Sphere Assembly
10	h-Sphere Assembly with Electronics
11	Underwater Electrical Chassis
12	Multiplier Phototube Assemblies
13	Pressure Transducer - Schematic Diagram
14	Alignment Telescope
15	Alignment Tool

LIST OF DRAWINGS

<u>Drawings</u>	<u>Title</u>
3-540-10	Optical Assembly (Schematic)
3-545-1	U. W. Circuit and Cabling Diagram
3-545-2	Control Panel Circuit
3-545-3	Photometer Chassis
3-545-4	Lamp Control Circuit for Optical Alignment
3-546-1	Assembly - Water Clarity Meter
3-546-2	Assembly - with Alignment Tube
3-546-4	Receiver Tube Assembly
3-546-5	Projector Tube Assembly

1.0 PURPOSE

The Water Clarity Meter, (WCM) developed and constructed by the Visibility Laboratory in the spring of 1958, has as its purpose the measurement of those optical properties of natural ocean waters which will permit the determination of the optical clarity of these waters in the visible portion of the spectrum. It is essential that at least two properties be measured to allow the determination of the transmittance of optical signals through the water (i.e., the contrast transmittance). The properties which were selected in this instance are the attenuation coefficient for collimated light,  $\alpha$ , and the attenuation coefficient for diffuse (ambient) light,  $k$ .

The data obtained from the Water Clarity Meter can be used to determine the depth profiles of these attenuation coefficients with sufficient accuracy for hydrographic survey purposes. Such survey data may be used for the computation of sighting ranges for underwater swimmers and underwater television equipment using natural illumination.\*

\* For a treatment of the computation of sighting ranges by swimmers see S. O. Duntley, Nomographs for Calculating Visibility by Swimmers, I. Natural Light, Report No. 3-1, U. S. Navy Bureau of Ships, Contract NObs-72039, Task 3, 10 May 1958.

## 2.0 DESCRIPTION

### 2.1 Method of Measurement

In order to determine the values of the two selected parameters  $\alpha$  and  $k$  as a function of depth it is necessary, with this equipment, to measure a total of four quantities. These are the relative value of the scalar irradiance,  $h$ ; the depth,  $Z$ , of the underwater unit; the illuminance,  $E$ , incident on the water surface concurrently with the  $h$  measurement; and the beam attenuation coefficient,  $\alpha$ , which is determined by direct measurement. The value of  $k$ , the diffuse attenuation coefficient, is obtained at any depth  $Z$  from the slope of a plot of  $\ln h$  vs  $Z$ .  $h$  must be corrected for the temporal variations in surface illumination such as those caused by the movement of clouds or changes in the position of the sun by using the information provided by the deck illuminometer.

The measurement of  $h$  is accomplished by sensing the totality of the flux received by a diffuse sphere. This sphere is mounted on an extremity of the underwater unit in order that the light field in which it is immersed is not appreciably disturbed by the presence of the remainder of the instrument. As these data are to be used only for the determination of  $k$  it is not necessary to measure  $h$  in absolute units. The primary photosensing device is a multiplier phototube which is used in conjunction with a logarithmic photometer circuit mounted on deck. The output indication of the  $h$ -meter is consequently proportional to the logarithm of the scalar irradiance of the light field present at depth  $Z$ .

The measurement of depth is accomplished through the use of a variable potentiometer-type pressure transducer. This unit is located so that it is sensitive to the pressure of the environment of the underwater unit and can therefore be calibrated directly in depth.

The surface illumination is determined by means of a gimbal mounted photo-voltaic cell equipped with a Lambert collector surface. The unit then, measures the incident illumination on a horizontal plane and is calibrated to read directly in lumens per square foot (foot-candles).

The measurement of  $\alpha$  is accomplished by determining the transmittance of a one-half meter column of water. This is done by passing a narrow (5 millimeter) beam of light from a projection system through a carefully baffled region of water to a receiver appropriately equipped with optics to collect flux from a very narrow scattering angle. The primary sensing device here again is a multiplier phototube which is connected to a logarithmic photometer circuit similar to that used by the  $h$  measuring portion of the equipment. The output of the photometer is calibrated to read  $\alpha$  directly in reciprocal feet ( $\text{ft}^{-1}$ ).

All four outputs,  $X$ ,  $h$ ,  $Z$ , and  $E$  are fed to a single strip chart recorder in order to obtain a permanent record. It is possible to select any one of the four to be continuously recorded, to sequence manually between the four, or to feed the signals into a synchronously driven commutating arrangement for automatically sequencing (commutating) the four outputs into a single record.

## 2.2 General Physical Description

The underwater unit is designed to provide housings for the lamp, phototubes, optics, and pressure transducer. It is so arranged that all portions of the equipment critical as to alignment are held within a stiff protective steel structure consisting of an I-beam, four hoop-shaped frames, and a longitudinal stress bar. The plastic diffuser ball for  $h$  measurement is of necessity outside of the main protective frame, but it is enclosed in a heavy wire guard designed to protect it from superficial damage while still allowing essentially unobstructed view of the surrounding light field. The overall dimensions of the underwater unit are 60 inches (length) by 14 inches (height) by 10 inches (width). It weighs 184 pounds.

The physical features of this portion of the equipment can be readily seen in the frontispiece and in Figure 1. The cylindrical housing in the left portion of Figure 1 encloses the multiplier phototube-cathode follower assembly for the  $h$  meter at its left end, a junction box for the entering cable and the pressure transducer in its central portion, and the multiplier phototube-cathode follower assembly for the  $\alpha$ -meter and the  $\alpha$ -meter receiver optics in its right half. This housing is mounted on a pad welded to the upper flange of the I-beam. The position of the housing on this flange has been carefully adjusted to align the window at its right end parallel with the window at the left end of the lamp housing. This is necessary in order that the light beam not change its position when the instrument's environment is changed from air to water. Further adjustment of the position of the housing should not have to be made unless there has been major damage to the equipment.

In the central portion of Figure 1 the baffle assembly can be seen. This has been so arranged that it can be readily removed and replaced without requirement for alignment or adjustment. The cylindrical housing in the far right portion of the instrument encloses the lamp for the  $\alpha$ -meter along with the projection optics. This housing is also affixed to a plate welded to the flange of the I-beam. Its alignment, again, should not require adjustment, barring major physical damage to the instrument.

The short cable running from the lower left hand portion of Figure 1. to the cover of the junction box in the upper center of the photograph serves as a means of connecting the equipment to the major length of underwater cable.

A plug is permanently mounted to the cover plate of the junction box in such a fashion that removing the cover plate disconnects the equipment quickly and completely. It should be noted that two sets of slings are provided to enable the equipment to be operated in either a horizontal attitude or a vertical attitude. The selection will depend upon the requirement for detailed data in the vertical profile and to a certain extent on the local conditions extant at the time of measurement.

Five hundred feet of a specially manufactured underwater cable is used to both support the instrument and provide the necessary electrical conductors.

The Deck Control Unit shown in Figures 2, 3, and 4 provides the power, the controls and the necessary electronics for operating the entire equipment. This unit is housed in a water tight fiber-glass case with removable cover. The complete case measures 13 inches (height) by 20 inches (width) by 26 inches (depth) and weighs 93 pounds. The underwater cable terminates in a connector which plugs into a mating receptacle shown in the lower center of Figure 2. Connectors for recorder signal (upper left), recorder power (right center), main power input (right of Variac), and illuminometer input (upper left) can also be seen in this photograph. Meters are provided for monitoring line voltage,  $\alpha$ -meter lamp voltage, and incident illumination. Switches provide for controlling the power to or the sensitivity of the several instruments which together make up the WCM. The logarithmic photometer electronic circuits for the h and  $\alpha$ -meters and the various DC power supplies are housed in this unit and can be seen in Figures 3 and 4. A synchronously driven commutator allows the four outputs E,  $\alpha$ , Z and h to be recorded in sequence thus recording all information on a single chart. Alternatively one may select any one of the four output functions to be recorded by itself.

The Deck Illuminometer shown in Figure 5 consists of a gimbal mounted photovoltaic cell with a light collection surface of white matte plastic. It has its own protective carrying case fitted with spare filters, spare white matte plastic and a supply of mercury to use for changing the characteristics of the stabilizing pendulum. The illuminometer with case weighs approximately 11 pounds.

The output from the Deck Control Unit is fed to a standard Leeds and Northrup Speedomax Model G recording potentiometer. It has a paper speed of 2.5 inches per second, a span of 10 millivolts and a full scale pen travel time of 4 seconds. The recorder is approximately 20 inches high by 18 inches wide by 12 inches deep and weighs 80 pounds.

## 2.3 Detailed Description of Components

### 2.31 Underwater Mechanical Assembly

For a general physical description of the underwater portions of this instrument refer to paragraph 2.2 General Physical Description. The underwater part of this instrument, exclusive of the plastic diffusing sphere, is designed to withstand a maximum pressure of 500 feet of water. In reading the following material reference should be made to Figures 1 and 6 and Drawing No. 3-546-1.

#### 2.311 Frame

The frame can be seen in the figures. Its overall dimensions are 52 3/4 inches (length) by 13 1/2 inches (height) by 10 1/4 inches (width). It has as the main structural member a 3-inch, 5.7 lb/ft standard steel I-beam which runs the length of the instrument along the bottom. It serves to give rigidity to the frame in order to maintain the optical alignment. Inset into and welded to this I-beam along its top surface are four steel pads 3/8 inch thick. The two large pads at either end serve as supporting and locating surfaces for the projector and receiver mounting bases. Each of these plates has four 3/8 - 16 NC tapped holes for the mounting bolts which secure the projector and receiver mounting bases. In the central area are two smaller plates which serve as bases for mounting the baffle assembly. These plates each have two 3/8 - 16 NC tapped holes for securing the baffle assembly with bolts.

Extended along the top of the frame is a 52 3/4 inch by 2 inch by 1/4 inch steel stress member which receives the compression forces when the instrument is suspended horizontally with a sling. It also serves as a guard and adds stiffness to the frame.

The four hoop-shaped members are welded to the I-beam and stress bar. Their function is to support the stress bar, to act as guards around the instrument, and to add to the stiffness of the frame. They are made from 1/2 inch steel plate.

At each end of the stress bar and the I-beam are 1/2 inch diameter holes through which may be mounted shackles for suspending the instrument. The entire frame has been "metal sprayed" with a covering of zinc. This was done to avoid corrosion of the steel and to prevent galvanic action between the steel and adjoining metal units. This finish has a light matte texture which is desirable from an optical standpoint.

At the end of the frame, surrounding the plastic diffuser sphere, is mounted a wire cage which protects the sphere without materially disturbing the light field. This wire cage is constructed of 3/16 diameter rod, type 321 stainless steel, which has been sandblasted and chrome plated to give an optically desirable light matte surface.

### 3.312 Receiver Mount Assembly

This assembly can be seen near the left end of the instrument in Figure 6. It mounts directly to the pad on the I-beam and is held in place with four 3/8 - 16 NC stainless steel bolts. This assembly is constructed entirely of brass parts silver soldered together. The parts are rabbeted and jointed together in a manner such that the silver solder is not subjected to any stresses when the unit is submerged.

This assembly provides a vertical face plate for accurately mounting the receiver housing and a similar vertical face plate for mounting the h-meter and plastic sphere assembly. It forms an enclosure within which is housed the pressure transducer, a connector which connects and disconnects when the h-meter assembly is removed and replaced, and serves as a junction box for the leads which go to the projector lamp. This unit when assembled together with the h-meter assembly and the receiver housing forms a watertight enclosure.

The enclosure consists of a 6 inch inside diameter 1/8 inch wall brass tube which lies between the two vertical face plates. Through the upper portion of this tube extends a packing gland housing, and an opening and boss for mounting the pressure transducer assembly. The main electrical power and signal cable passes through this packing gland into the enclosure. Sealing is accomplished in this gland by means of a rubber packing and a nut which applies pressure to the rubber packing through a back-up ring. Attached to the lower portion of this enclosure is a 1 1/4 inch, 1/8 wall brass tube which extends through the base plate and also through the mounting pad and the I-beam when the assembly is in position. Located at the lower end of this 1 1/4 inch tube is a second packing gland similar to but somewhat smaller than the main cable packing gland. This gland lies in a horizontal position and seals with a two conductor cable which serves to carry power to the projector enclosure for the projector lamp. Protruding from the vertical face plate against which mounts the receiver housing is a shelf-like platform upon which are two rings, each of which has three adjusting screws. These screws position and support the optical receiver assembly. Pressed into each of the vertical face plates are two .2500 inch stainless steel dowel pins which locate the receiver housing and the h-meter assembly when they are assembled to this unit.

### 2.313 Projector Mount Assembly

This assembly can be seen at the right end of the instrument in Figure 6. It mounts directly to the pad on the I-beam and is held in place with four 3/8 - 16 NC stainless steel bolts. This assembly is constructed entirely of brass parts silver soldered together. The parts are fitted and jointed together in a manner such that the silver solder is never subjected to any major stresses.

This assembly provides a rigid vertical face plate against which is mounted and sealed the projector housing to form a water tight enclosure for the optical projector assembly. Projecting from this face plate is a shelf-like platform upon which are mounted two rings each of which has three adjusting screws. These screws position and support the optical projector assembly. Mounted against the back side of the vertical face plate is a packing gland through which passes the two conductor cable which supplies the power for the projector lamp. This cable comes from the receiver mount assembly and lays along one side of the I-beam passing through holes in the hoop members of the frame. At the projector end it goes upward through holes in the pad and base at the projector mount assembly and enters the packing gland to the projector lamp. Sealing is accomplished by tightening a nut to apply pressure through a back-up ring and a rubber packing around the cable. Pressed into the vertical face plate are two .250 inch diameter stainless steel dowel pins which locate the projector housing when it is assembled to this unit.

### 2.314 Housings

The two housings shown in Figure 6, when mounted against the vertical face plates of the receiver and projector mount assemblies provide the water tight enclosures for these optical units. The housings are identical in construction but should not be interchanged. They are identified by a letter stamped into the metal flange which locates against the vertical face plate. There is a similar letter stamped into the upper corner of the corresponding face plate.

The housings are approximately 6 inches in diameter and 10 inches long. A 6 inch I.D. x 1/8 inch wall seamless brass tube is secured with silver solder to a mounting flange at one end, and to a 1/2 inch thick circular plate at the other end. These parts are fitted and jointed in such a way that the silver solder is not required to withstand any major stresses when the instrument is submerged. The mounting flanges have four 5/16 - 18 NC tapped holes which are used to mount the assembly against the face plate with four 5/16 - 18 NC stainless steel machine screws. Two 1/4 inch holes are located at the top of this flange which mate with the two dowel pins on the face plate to properly locate the housing when it is

is in position. Machined into this flange is a groove into which is placed a rubber "O" ring to form a seal when the housing is mounted. In the center of the plate at the other end of the housing is a 1 inch diameter hole around which is a circular groove for a rubber "O" ring seal. Against this seal, in a 1/16 inch recess, is a 1/4 inch thick plastic window. It is retained by a cap held by four 6 - 32 NC stainless steel screws. Mounted over this window is a removable cup-like baffle system which prevents light outside the system from striking the window directly. This could result in unwanted scattered light entering the system. This baffle is retained by two knurled nuts and is removable by hand to allow access for cleaning the window. It is vented in such a fashion as to be free flooding for both operating orientations of the Water Clarity Meter.

### 2.315 Pressure Transducer Assembly

This assembly provides a means of mounting the Bourne pressure transducer and isolating it from the sea water environment while allowing it to sense the external pressure. The unit is mounted in the upper portion of the receiver mount assembly. Figure 7 is a photograph of this assembly.

The threaded nipple on the transducer screws into a hole in the center of one end of a brass adapter and seals against a small "O" ring. This hole extends through the adapter. Over the other end of the adapter is placed a surgical finger cot held in place by an "O" ring which is stretched over the finger cot. The "O" ring lies in a "V" groove near the end of the adapter, and presses the finger cot to the adapter to effect a seal. This assembly is placed from the inside of the receiver mount assembly, finger cot end first, through a hole in a boss on the upper side of the receiver mount enclosure. Before inserting, an "O" ring is placed against the assembly to lie against the flange on the adapter located at the end near the pressure transducer. The "O" ring lies against the side of the flange which is away from the pressure transducer. The assembly is held in place with a nut which screws onto threads on the adapter from the outside. Tightening this nut squeezes the "O" ring to form a seal and locks the assembly in place. Onto the threads left exposed after the nut is tightened is screwed a chrome plated brass guard. This guard serves to protect the finger cot from damage. It has a hole in the end to allow the entrance of water. The cavity formed by the finger cot, the hole through the adapter, and the bourdon tube in the pressure transducer is filled with silicone oil which transmits the pressure of the water through the finger cot to the pressure transducer.

### 2.316 h-meter Assembly

See Section 2.32 for a detailed description of the h-meter.

### 2.317 Baffle Assembly

The baffle assembly is mounted between the projector and receiver systems and helps to prevent external light from entering the optical system. It has seven large baffles spaced  $1 \frac{31}{32}$  inches apart. Each baffle is six inches in diameter,  $\frac{1}{32}$  inch thick, and has a one inch knife edge hole in the center through which passes the light beam. The baffles are mounted on four brass rods with cylindrical spacers between the baffles. At each end of this baffle system is an angle bracket for mounting the baffles to two pads on the I-beam. This assembly can be seen in Figure 6.

### 2.318 Junction Box

The junction box provides a means for separating the instrument from the 500 feet of cable with which it is supplied. This junction box can be seen opened in Figure 8 and again with the instrument in Figure 1.

The body is composed of a 4 inch outside diameter,  $\frac{1}{8}$  inch wall, brass tube having an end plate silver soldered to one end, and a mounting flange for securing the cover silver soldered to the other end. At the top of this housing is mounted a packing gland and at the bottom is a  $\frac{1}{2}$  inch piece of brass in which are two  $\frac{1}{2}$  inch holes for securing the sling that supports the instrument when it is suspended. This  $\frac{1}{2}$  inch piece of brass extends through the wall of the junction box housing and forms a clevis to which the supporting cable is attached within the enclosure. These parts are all silver soldered together and are joined in such a manner that the silver solder is not required to withstand any major stresses.

The cable which leads from the electronic topside gear to the instrument enters the junction box through the packing gland. Sealing is accomplished with a rubber packing which lies around the cable within the packing gland body. Pressure is applied to this rubber packing through a back-up ring by tightening the packing nut at the end of the gland. The electrical leads of the cable terminate at a female Amphenol connector mounted within the junction box housing. A  $\frac{3}{16}$  inch diameter stainless steel wire rope, which lies in the center of the cable and is the major load carrying element of the cable, is made up around a plastic thimble which is secured to the clevis directly opposite the packing gland with a  $\frac{5}{16}$  inch diameter stainless steel pin. The load imposed by the instrument is transmitted from the sling to the clevis and directly to the steel messenger in the cable. Thus, neither the junction box housing nor the packing gland are subjected to any load carrying stresses.

A cover plate bolts to the flange on the housing and makes up against an "O" ring which lies in a groove in the flange to form a water tight seal. Mounted on this cover plate is a second packing gland and the male half of the Amphenol connector. The short cable which runs from the instrument proper to the junction box passes through this gland to the connector. Removing the cover disconnects the connector and separates the instrument from the main cable. The female part of the connector is mounted in the housing in a manner which allows it to "float" slightly to allow for any small misalignment. Dummy covers are provided for both the junction box housing and the cover plate and should be mounted over these assemblies to protect them from physical damage and moisture whenever they are to be separated for any length of time.

## 2.32 h-Meter

The measurement of the scalar irradiance,  $h$ , is accomplished by sensing the totality of the flux received by a white diffuse light collecting sphere. This sphere is mounted on an extremity of the underwater unit in order that the light field in which it is immersed is not appreciably disturbed by the presence of the remainder of the instrument. This assembly can be seen removed from the instrument in Figures 9 and 10, and again, mounted on the instrument, in Figure 1.

As the data from the h-meter is to be used in determining the sighting ranges for underwater swimmers, the phototube has been provided with a Wratten No. 106 gelatin filter to correct its spectral response to that of a human observer. The spectral quality of the ambient light will change with depth due to the selective attenuation of the water; regardless of this the h-meter will indicate the efficacy of the light in producing a stimulus in the eye of the so-called photopic "standard observer".

The description of the electronic circuit used for measuring the light flux collected by the h-sphere is contained in section 2.34 below.

### 2.321 Mechanical Assembly

The 5-inch diameter sphere was fabricated at the Visibility Laboratory from a diffuse white Plexiglass which was selected as having the proper optical properties for this application. It is a hollow sphere having a minimum wall thickness of about 1/16 inch and it will safely withstand the pressures encountered at depths to 200 feet of sea water. A Plexiglass flange is cemented to the base of the sphere for mounting it to the instrument. Through the center of this flange is a 1 1/16-inch diameter hole which continues through the wall into the inside of the sphere.

A wire cage is mounted directly to the frame of the instrument and surrounds the h-sphere to protect it from physical damage. This cage was necessarily made of lightweight rod and will protect the sphere from incidental contact with its surroundings; but it will not afford protection from damage which would occur, for example, if the instrument were allowed to swing against the side of the ship when lowering or retrieving it.

The housing which supports the h-sphere and contains the h-meter light sensing phototube is formed from a 6-inch diameter, 1/8-inch wall, brass tube with a heavy mounting flange silver soldered at one end. This flange secures to the outward vertical face of the receiver mount with four 5/16 - 18 NC stainless steel Allen cap screws and seals to this surface by means of an "O" ring. Mounted to the outboard end of the large tube is a 6-inch diameter plate held in place by six stainless steel screws and sealed to the inside of the tube with an "O" ring.

Extending outward from the center of this 6-inch diameter plate is a short brass tube which supports a circular flange against which the base of the h-sphere mounts and seals against an "O" ring. The flange at the base of the h-sphere is held against this surface by a split ring fastened in place with six stainless steel machine screws.

A 1-inch diameter x 1 3/8-inch long, clear plastic rod passes through the center of the 6-inch diameter plate, the small brass tube, the flange on which the sphere mounts and the hole in the bottom of the sphere. The outward end of this rod lies flush with the inside surface of the sphere, and the inward end lies just inside the inside surface of the 6-inch diameter plate. An "O" ring groove is machined into this plate around the hole through which the plastic rod passes. The "O" ring in this groove forms a seal with the plastic rod. This is a safety seal to prevent water from entering the instrument in the event that the sphere is damaged or collapses while the unit is submerged. Mounted on the inside surface of the 6-inch diameter plate are two semi-circular clips which fit into an annular groove near the inward end of the plastic rod. These clips properly position the rod and also are sturdy enough to prevent its driving into the enclosure in a piston-like action if the h-sphere collapses, allowing external water pressure to act upon the outer end of the plastic rod.

Extending from the inside face of the 6-inch diameter plate is a shelf upon which is mounted the encapsulated phototube assembly. Secured to the end of this shelf is a 4 3/4-inch diameter circular aluminum disk, upon which is mounted the electronic components which accompany the underwater unit. Also mounted on the inside face of the 6-inch diameter plate is a solenoid and the movable neutral density filter which it operates. When the h-filter switch on the Deck Control Unit is closed, the solenoid pulls the spring loaded filter out from the space between the end of the plastic rod and the phototube, and consequently out of the light path. When the solenoid is not energized the spring pulls the filter into the light path.

### 2.33 $\alpha$ -Meter

The  $\alpha$ -meter portion of the Water Clarity Meter basically measures the transmission,  $T$ , of a beam of light  $r$  feet in length ( $r = 1/2$  meter or 1.64 feet) and 5 millimeters in diameter.  $\alpha$  is then determined by solving the equation  $T = \exp(-\alpha r)$  for  $\alpha$ . Thus  $\alpha = (1/r) \ln(1/T)$ . It is calibrated to read  $\alpha$  directly in reciprocal feet. A detailed discussion of its theory of operation will be found in section 4.2 below.

The light source for the measurement has a lamp whose power is carefully stabilized by means of a voltage regulating circuit, in order that the light flux from the lamp will remain constant regardless of fluctuations in line voltage or temperature. The flux from the lamp is projected by means of a specially designed optical system through the water to the receiver in such a manner that all the flux in the system stays within a cylinder 5 millimeters in diameter. The receiver optical system is sensitive to a cylindrical volume slightly larger (8 millimeters) in diameter which completely surrounds the projector beam. The receiver is essentially insensitive to flux coming

from outside this volume but to provide further assurance of freedom from stray light a system of baffles is interposed between the projector and receiver. These baffles are so designed that they allow the free passage of water through the instrument but prevent sunlight from reaching the projector or receiver windows.

The receiver sensor consists of a multiplier phototube, so shielded that it is sensitive only to flux coming through its optical system. The phototube is connected in a logarithmic photometer circuit described in section 2.34 below.

The phototube is fitted with a Wratten 65A gelatin filter. The product of this filter's transmission, the spectral response of the 6472 multiplier phototube and the output of the lamp as a function of wavelength, produces an overall instrument spectral sensitivity that is in the blue-green region of the spectrum. This selection was made to provide data on the beam transmittance using light of approximately the same spectral quality as the natural light available below the surface. Due to the selective absorption of sea water, the light which penetrates the first few feet of water will become blue-green in color. The deeper the measurement the more sharply filtered the light becomes. It is not possible, therefore, to select a single filter that will satisfy the objective, but it is felt that the use of the 65A represents a reasonable compromise.

### 2.331 Projector Optical-Mechanical System

(See Drawings 3-540-10 and 3-546-5)

The projector optical system is housed within a 1 3/4-inch diameter tube approximately 9 inches long. The system consists of a lamp, a condensing system of two lenses, a field stop, a projection lens system of two achromatic lenses and an aperture stop, and miscellaneous spacers and lens cell mounts. The assembly is held in position by six adjusting screws which enable the assembly to be adjusted so that its optical axis is perpendicular to the windows of the watertight enclosures and coincident with the optical axis of the receiver assembly.

The lamp used as a light source is a GE No. 1493 having a double contact bayonet base. The socket has been modified with a clamp which securely locks the lamp to prevent its being moved inadvertently as this would affect the calibration of the instrument. The lamp socket is held to the end plate of the assembly with two hex-head screws which can be reached with a slim, end-wrench. Enough clearance has been allowed so that when these screws are loosened the lamp can be moved a small amount in a plane perpendicular to the optical axis. This adjustment is made to obtain the maximum amount of light flux passing through the system from the filament. The 1 1/4-inch housing tube is open above and below the lamp to allow convection cooling of the lamp.

The two condensing lenses image the lamp filament approximately 8 mm beyond the field stop and serve to properly fill the field stop aperture with light flux. The condensing lenses are fixed in position and require no adjustment.

The field stop is a 0.022-inch diameter circular hole with a knife edge chamfer. It is machined in a diaphragm as part of a cylindrical mount. It is held in place by a set screw through the wall of the 1 1/4-inch housing tube which locates in a "V" groove on the outside of the field stop cylinder. The field stop is thus positively located and requires no adjustment. This field stop, when the projector lenses are properly located, produces an image 5 millimeters in diameter in the plane of the receiver aperture stop. In conjunction with the projector aperture this determines a cylindrical beam 5 millimeters in diameter throughout its length from the projector to the receiver aperture stops.

The projector aperture stop is a 0.187-inch diameter knife edge hole in a diaphragm which is located between the two achromatic projector lenses. These three parts mount in a cell which is held in the 1 1/4-inch tube by two screws. These two screws pass through elongated slots in the 1 1/4 inch tube which allows for a focusing type adjustment to image the field stop in the plane of the receiver aperture.

### 2.332 Receiver Optical-Mechanical System

(See Drawings No. 3-540-10 and No. 3-546-4)

The receiver optical system is housed within a 1 3/4-inch diameter tube approximately 6 1/2 inches long. The system consists of an aperture stop, an achromatic lens, two light baffles and a field stop. Mounted on the end of the assembly behind the field stop is a housing in which is encapsulated the multiplier phototube. The assembly is held in position by two sets of three adjusting screws which enable the assembly to be positioned so that its optical axis is perpendicular to the windows of the watertight enclosures and coincident with the optical axis of the projector assembly.

The aperture stop is the first element in this system. It is a knife edged hole 0.318 inch in diameter through which the 0.5 cm diameter (0.197 inches) beam enters the system. This aperture together with the field stop limits the light flux received to narrow limits about the 0.5 cm diameter cylinder of light flux between the projector and receiver units. This stop is 3 millimeters larger than the projector beam diameter to allow for slight misalignment and any flexure of the instrument during use.

The achromatic lens is located immediately behind the aperture stop. It images the projector aperture stop in the plane of the receiver field stop and this image lies within the hole in the field stop when the instrument is in proper optical alignment and the light beam is traversing a water medium.

Between the lens and field stop are two light baffles which are thin disks with knife edge holes of such a diameter as to be slightly larger than the acceptance cone of the receiving system. They serve to stop any stray scattered light which may be present within the receiver system from reaching the opening in the field stop.

The field stop is a knife edge hole, 0.106 inch in diameter, in the center of a thin disk. The image of the projector aperture formed by the receiver lens lies within this opening. The 0.106 inch diameter hole is a little larger than this image to allow for slight optical misalignment and any flexure which may occur during use of the instrument. The field stop fixes the angle of acceptance of the receiver at  $1.8^\circ$  total.

The light flux, which meets the restrictions of the receiver system and passes through the field stop, impinges upon the cathode of a 931-A type multiplier phototube. This phototube with some of its associated electronic components is potted within a 2 x 2-inch square mu-metal box 3 1/2 inches long. One side of the mu-metal box has an opening through which the light accepted by the receiver optical system may enter to fall upon the cathode of the phototube. About this opening is mounted a cylindrical extension which fits closely about the outside of the back end of the receiver housing tube and clamps securely by tightening one screw. This supports the phototube assembly and properly positions it behind the field stop of the receiver unit.

## 2.34 h-Meter and $\alpha$ -Meter Electrical Circuits

### 2.341 Photometer Circuits (Drawing 3-545-3)

The major electronic circuits of the Water Clarity Meter are the dual photoelectric photometers used for the light flux measurement in the h- and  $\alpha$ -meter. Physically, they are located on a single chassis to enable the two instruments to use a single low voltage power supply. This conserves space and makes for easier maintenance.

The primary sensing element in these photometers is a type 6472 multiplier phototube. It is operated with a quasi-constant anode current and its dynode multiplier voltage is allowed to vary as required to maintain this current constant when the light flux on the photocathode varies. The output indication is obtained by sensing this voltage with a nonlinear "voltmeter", whose response is essentially proportional to the logarithm of the reciprocal of the light flux.

The use of this logarithmic type of photometer has several distinct advantages over a linear device. The first is that in natural environmental situations the available light is going to vary over many orders of magnitude due, in the case of the h-meter, to changes in the amount of solar radiation

and the large attenuation suffered by this radiation as it penetrates into the sea. A linear device would require many changes in full scale sensitivity to be able to handle this situation, and then not as well as a logarithmic device because of the latter's second advantage. This is, that the accuracy of the reading of the logarithmic instrument is the same regardless of the position of this reading in the full scale range of the device. With a linear instrument, on the other hand, the accuracy would be a function of the full scale sensitivity and the absolute accuracy of any reading would therefore vary according to where the reading occurs with respect to full scale. A third consideration in favor of the logarithmic instrument is that the data in both the  $\alpha$ -meter and the h-meter are utilized in logarithmic form in the reduction calculations. Thus in the  $\alpha$ -meter the value of  $\alpha$  is proportional to the logarithm of the flux and, consequently, the output scale of the logarithmic device is linear in  $\alpha$ . Similarly, it is the slope of the logarithm of h versus depth plot that determines k from the h-meter readings. A fourth and very important advantage of the circuit is that by operating the multiplier phototube at constant anode current the possibility of fatigue or, in fact, permanent physical damage to the phototube from excessive anode currents is reduced. In operating such tubes at constant dynode voltages it is easily possible, by momentarily exposing the device to large amounts of flux, to obtain destructive anode currents in the order of amperes, if the power supplies will permit it. At the very least the large values of current in the last dynode stages will cause a temporary change in the secondary emission ratio, which will make the sensitivity of the tube decay or "fatigue" with time when subjected to these high light levels. This, of course, results in an undesirable nonlinearity which cannot be easily taken into account in calibration.

The principle operation of the two photometers is the same, the major difference lies in the fact that the h-meter photometer covers a range of 5 log cycles ( $10^5$ ) in light flux, whereas the  $\alpha$ -meter covers a maximum range of 1 log cycle ( $10^1$ ). The circuit is basically a modification of that developed by Sweet for use as a photographic densitometer. For an excellent detailed explanation of the operation of the circuit, reference should be made to Sweet's paper.\*

The circuit functions as follows: The anode current,  $i_a$ , in a multiplier phototube is proportional to the product of the light flux on the photocathode, F, and the gain of the dynode multiplier. The gain of the multiplier phototube is found empirically to be proportional to the voltage applied to the dynodes, V, raised to some exponent, m.

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\*H. H. Sweet, "An Improved Photomultiplier Tube Color Densitometer," J. Soc. Mot. Pict. Eng., Vol. 54, pp. 35-62, January, 1950.

This may be expressed by the equation

$$i_a = K'' FV^m \quad (1)$$

where  $K''$  is a constant of proportionality.

If we now devise a circuit that will maintain the anode current constant (or approximately so) by automatically decreasing the dynode voltage as the flux is increased, we can rewrite equation (1) as

$$\frac{1}{F} = (K''/i_a) V^m = K' V^m \quad (2)$$

where  $K' = K''/i_a$  is a new constant. Now we may define a new function,  $D$  (analogous to the optical density of films or filters), as

$$D = \log \frac{1}{F} \quad (3)$$

and if we take the logarithm of equation (2) we obtain

$$D = \log \frac{1}{F} = \log K' + m \log V$$

or

$$D = K + m \log V \quad (4)$$

where  $K = \log K'$ . If the light flux is caused to change by some factor, the corresponding changes in "density" and dynode voltage may be computed. Thus

$$\Delta D = D_1 - D_2 = m \log \frac{V_1}{V_2}$$

If we allow  $\Delta D$  to be 5 (i.e., a change in  $F$  of  $10^5$ ), the ratio of the dynode voltages for the two extreme conditions will be

$$\frac{V_1}{V_2} = \log^{-1} \frac{5}{m}$$

In the case of the multiplier phototubes used in the WCM, the exponent,  $m$ , is approximately 7. The voltage ratio is consequently only about 5 for this 100,000 : 1 change in light flux.

Another important consideration is the linearity of the relationship between D and V. We can determine this by taking the derivative of equation (4).

$$\frac{dD}{dV} = \frac{m}{2.303} \cdot \frac{1}{V}$$

or

$$\frac{dV}{dD} = \frac{2.303}{m} V. \quad (5)$$

Here we see that the change in voltage required per unit density change is proportional to the dynode voltage. Thus, far from being linear, the slope of the dynode voltage versus density characteristic, again, will vary by a factor of about 5 from one end to the other of the scale.

From the above discussion we can gain an insight into the requirements of the logarithmic photometer circuit. The device may be considered as an electronic servo. The output of the multiplier phototube is sensed and compared to a reference. If the anode current is larger than the desired reference value, the grid bias applied to the series control tube (6AV5) increases negatively, thereby reducing the current flow through it and the dynode voltage divider in series with it. This reduces the gain of the multiplier to the point where the anode current is almost back to the desired value. The difference between the actual and the "desired" value of anode current produces the required change in the voltage drop in the phototube-anode-load resistor to generate the bias change in the series control tube.

The output indication of the circuit is a sample of the dynode voltage. As was seen above, this voltage does not, in its unaltered form, have the required characteristic of a voltage which is proportional to the density. It is possible, however, by means of a scheme which causes the sensitivity of the device that senses the dynode voltage to change inversely with this voltage (see equation (5)) to obtain the proper response. In analyzing the performance of this variable sensitivity voltmeter, we may start with the large (120K ohm) resistance connected to the negative dynode voltage supply lead (attached to the phototube cathode). This provides a current, which is essentially proportional to this dynode voltage, to a lower resistance network connected to ground through the recorder shunt (6 ohms). This network consists of a 10K ohm resistor in parallel with a series of shunts that become operative at various voltages. The voltage at which these shunts are cut-in is determined by the "cut-in" calibration potentiometers, and the size of the shunt which is introduced is controlled by the "effect" calibration potentiometers. The negative voltages determined by the "cut-in" potentiometers are applied to the anodes of silicon diodes (1N457's). Their cathodes are connected together and tied to the junction of the 120K ohm and 10K ohm resistors mentioned above. In the absence of the diodes the voltage at this junction would vary from about -23 volts to -110 volts in covering the 5 log cycle range of light flux. The diodes are biased to start conducting or "cut-in" at certain points in this voltage interval; and by virtue of the

shunting effect of the resistors they introduce, the voltage at this junction is constrained to vary quasi-linearly with the "density" function,  $D$ . The current through the 10K ohm resistor and the 6 ohm recorder shunt will, therefore, vary in a like fashion.

Because the minimum dynode voltage is not zero when the maximum flux is applied to the photometer, it is necessary to provide a "bucking" current through the recorder shunt which is equal and opposite to the current from the dynode voltage measuring circuit. This current is obtained from the positive low voltage supply and the amount of it is controlled by the "Bucking" control in the h-meter circuit and the "Zero Set" control located on the Deck Control Unit in the  $\alpha$ -meter circuit.

It is necessary in the calibration procedure to adjust the portion of the dynode voltmeter current which flows through the recorder shunt. This adjustment has the effect of changing the slope or sensitivity of the voltmeter. In the case of the h-meter this adjustment is made by the "Sensitivity" control mounted on the photometer chassis panel. In the  $\alpha$ -meter this adjustment can be made by changing the size of the fixed resistor mounted between terminals 33 and 26 on the photometer chassis terminal strip.

The current through the recorder shunts is adjusted by the calibration procedure to be 1/3 milliampere for each log cycle of light flux change. As the full scale span of the recorder is 10 millivolts, the size of the shunts is automatically determined by the number of log cycles span required of the photometer. Thus, in the h-meter with a 5-log span this shunt is 6 ohms and in the  $\alpha$ -meter where spans of 1.0, 0.7 and 0.5 logs are used, the resistances of the shunts are 30 ohms, 42.85 ohms and 60 ohms respectively. In the  $\alpha$ -meter the selection of the shunts is made by the switch labeled " $\alpha$  Range Selector Switch" on the panel of the Deck Control Unit.

To prevent the voltage supplied to dynodes from becoming excessive when the phototubes are in the dark, the control grids of the 6AV5 series control tubes are clamped by two diodes, which ensures that they will not become more positive than -14 volts. This is beneficial in two ways. In the case of the h-meter, high voltage available from the power supply would cause instability due to heating of some of the components and ionization of the residual gas in the phototube. Secondly, in both the h- and  $\alpha$ -meters, 6AV5 grid biases less than this -14 volt value cause the 6AV5 anode voltage to drop below its screen voltage and the resulting large screen current overloads the low voltage (+85V) power supply to the point that it loses regulation and its voltage output falls below a satisfactory operating value.

There is a single voltage-regulated low-voltage power supply which services both photometers. It delivers +85 volts to the 6AV5 screens, the 5719 anodes, and the "bucking" current circuits, and -104 volts to the "cut-in" potentiometers, the 6AV5 grid clamp diodes, the 5719 cathode resistors (100K ohm) and the ninth dynodes of the 6472 multiplier phototubes. The circuit is that of a conventional series-control regulated power supply.

Each photometer has its own high voltage supply for its phototube dynodes. The h-meter has a full wave voltage doubler connection with selenium high voltage rectifiers. The output is 1630 volts. The  $\alpha$ -meter has a full wave connection with 1N256 silicon rectifiers. Its output is 500 volts.

Both photometers have identical circuits for the 6472 multiplier phototubes, the 5719 cathode followers, and the 6AV5 series control tubes. The phototubes and the cathode followers have been encapsulated together in an epoxy resin to prevent damage to the components and to maintain a high insulation resistance, regardless of the humidity of the environment. The latter is necessary in view of the extremely high (200 megohm) anode load resistor that is required in the phototube. The function of the cathode followers is to present a high impedance (compared to the 200 megohms) to the phototubes and a low impedance to the signal leads in the underwater cable. The heaters in the cathode followers are operated at lower than rated voltage to obtain a low value of grid current (necessary for the condition of high input resistance) and a long tube life. The case for the multiplier phototube assembly used in the  $\alpha$ -meter is made from mu-metal to reduce the effects of orientation in the earth's magnetic field. This was not found to be necessary in the h-meter, as the small variations which are encountered are not significant on the 5-log scale.

The diode compensated dynode voltage voltmeters are different in the two circuits because of the requirement for a 5-log range in the h-meter and a 1-log range in the  $\alpha$ -meter. The former requires the use of 4 cut-in circuits with diodes and "effect" resistors in order to allow sufficient freedom in the control of the voltmeter characteristic. The  $\alpha$ -meter requires only one compensating circuit with control of the cut-in voltage alone. The "effect" resistor here is a fixed 40K ohm resistor, as no adjustment was required with the  $\alpha$  phototubes which were tried.

## 2.342 Underwater Electrical Chassis

(See Figure 11 and Drawing 3-545-1)

The underwater electrical chassis consists of two zener-diode type voltage regulating circuits and the necessary components to provide carefully regulated voltages for operating the  $\alpha$ -meter projector lamp, the cathode follower heaters and the pressure transducer. This unit also has an Amphenol "Blue Ribbon" connector No. 26-4100-16P mounted to the main disk with stand-off bushings to facilitate removal of the h-sphere assembly to which this chassis is attached. This connector and its mating unit (No. 26-4200-16S), mounted in the receiver mount assembly, also act as junction points for the underwater cable and the wiring to the components in the underwater equipment.

Both diode regulating circuits consist of a zener diode, to perform the regulation function, and a selected forward biased diode, to compensate for the small but important temperature coefficient of the zener diode.

The regulator for the  $\alpha$ -meter lamp consists of a 10Z5.6 (International Rectifier Corporation) 10 watt zener diode and a 3AT2 (International Rectifier Corporation) forward biased diode. The total voltage drop across these two units is 6.40 volts. The normal current through them is 0.55 amperes. Although these diodes will safely withstand several times this current, they will not handle the current they would have to carry if the lamp is removed from its socket or burned out. Therefore, a small relay is inserted with its pickup coil in series with the lamp current, and its contacts arranged to introduce a resistance approximately equal to that of the lamp when the lamp current drops to zero.

The diode regulator for the cathode follower heaters consists of a 1N1590 3-watt zener diode and a 1N1124 temperature compensating forward biased diode. The total voltage drop across these diodes is 6.45 volts and their normal current is 0.3 amperes. A 175 microfarad, 15 volt tantalum electrolytic capacitor across the regulator serves to reduce the ripple appearing on the regulated voltage. This factor is important for the pressure transducer as its output is applied to the recorder and ripple to the recorder may cause recorder "dead band". As the cathode follower heaters draw about 130 milliamperes each, either or both of these tubes may be disconnected without exceeding the maximum dissipation of the zener regulator or disturbing the operation of the remaining units connected.

### 2.35 Depth Measurement

The measurement of depth,  $Z$ , is accomplished by measuring the ambient pressure of the water surrounding the instrument. The pressure transducer is a Bourns Model 304 pressure potentiometer having a range of 0 - 100 psig. Assuming a value of 64.0 pounds per cubic feet for the density of sea water, the depth for the maximum calibrated pressure is 225 feet. The manufacturer states that the transducer may be subjected to a 20% over-pressure without affecting the calibration. Therefore the maximum depth to which the WCM should ever be subjected when the transducer is installed is 270 feet. This is generally consistent with the design limits of the strength of the various underwater enclosures. The circuitry associated with the pressure transducer, however, has been designed to give a full scale deflection on the recorder when a depth of 200 feet is attained as this is considered the maximum operating depth of the WCM.

Due to the inherent friction which occurs between the wiper arm of the potentiometer and the resistance element, a small, but measurable, pressure must be applied to the transducer to effect a change in its output indication. In many applications of this unit it is subjected to a vibration which "breaks loose" the arm and tends, therefore, to eliminate or at least reduce this source of error. Unfortunately in this application there is unlikely to be sufficient vibration to accomplish this. The manufacturer states that this static friction error will have a maximum value of 2% or 4.5 feet for the transducer in question. There is in addition another 0.5% maximum hysteresis

error which when added to the static friction error means one can expect a maximum difference in reading between the value obtained on lowering and that obtained on raising the instrument of about 11.2 feet in the absence of any vibration. There is also to be considered the nonlinearity of the resistance element itself, which is specified to be no greater than  $\pm 1\%$ . The maximum expected departure from the correct depth would be  $\pm 7.9$  feet. The actual transducers shipped with the Water Clarity Meter were always within  $\pm 5$  feet and over most of the range were considerably closer than that. The exact temperature characteristics of the unit have not been measured by the Visibility Laboratory, but it is inferred from the manufacturer's specifications that the error caused by a change in the temperature of the transducer of  $22^{\circ}\text{C}$  would be about  $1\%$  or 2.25 feet.

Figure 7 shows, in schematic form, the circuitry used in conjunction with the pressure transducer to measure and record depth. It consists of a DC power supply, a temperature compensated voltage regulator, the pressure transducer itself, a voltage divider network and the recorder.

The power supply is also used to supply the  $\alpha$ -meter lamp filament and the heaters for the cathode follower tubes, which are encapsulated with the multiplier phototubes. In fact the approximately 0.65 milliamperes used by the pressure potentiometer represents a negligible portion of the 3.6 amperes total supplied by the rectifier. In order that changes in these other loads not affect the calibration of the depth measurement, a temperature compensated voltage regulator consisting of a 325.6 zener diode and a 1N1124 forward biased temperature compensating diode is utilized. The total drop across the regulator is about 6.45 volts and is independent of line voltage or normal temperature variations. When the lamp is turned off or fails, additional resistance is automatically switched into the circuits to keep the current through the regulating diodes approximately constant. Should the heater in one or both of the cathode followers fail, the additional current shunted through the regulator will not cause the total current to exceed the capacity of the regulator.

It should be noted that the resistance of the cable is an appreciable and important part of the regulator circuit. Operating the underwater equipment without the cable may result in damage to the zener diode.

The voltage applied to the 10,000 ohm pressure potentiometer is the 6.45 volts from the regulator circuit. In order that the measuring circuit not load the potentiometer and thereby affect the accuracy of the measurement, it is necessary that the resistance of the voltage divider network be 50 to 100 times the resistance of the potentiometer. As full scale is 200 feet and the maximum capacity of the transducer is 225 feet (100 psig), only  $8/9$  or 0.889 of the 10,000 ohm resistance is used at "full scale". This corresponds to a maximum output of 5.74 volts. As the full scale span of the recorder is 10 millivolts, the voltage division ratio must be 574. These above conditions are satisfied by having a voltage divider consisting of a 640,000 ohm dropping resistor in series with a 1133 ohm shunt. The shunt is composed of a 1000-ohm-fixed and a 250-ohm-variable resistance. The variable resistance

allows for the adjustment of the calibration of the depth measurement system.

In order that the beryllium copper bourdon tube sensing element in the transducer be protected from the corrosive effects of sea water, this portion of the transducer is filled with silicone oil. Figure 8 is a photograph of the transducer assembly showing the rubber finger cot which holds the oil and acts as a flexible pressure transmitting membrane between it and the sea water. The heavy brass cap protects the finger cot and helps keep it in place. A hole in the end of the cap allows the free passage of water into the region around the finger cot.

### 2.36 Underwater Cable

A specially fabricated underwater cable, procured from the Vector Manufacturing Company, Houston, Texas, was used to provide both physical support for the underwater equipment and the necessary electrical conductors for its operation. The cable is laid up around a core of 3/16 inch, 7 x 19 stainless steel wire rope. This in itself has a breaking strength of 3900 pounds exclusive of any additional strength obtained from the remainder of the cable. Surrounding the wire rope is a neoprene jacket about 0.055 inch thick, which forms a resilient bed for the electrical conductors. Thirteen insulated wires are then placed around this core with their lay opposite to that of the wire rope. As two of these wires are Copperweld (copper-clad steel), they provide a stiffening action tending to prevent the cable from unlaying or twisting, as it is payed out under load. Another two of the wires are shielded and since these shields are insulated they are also used as individual conductors, providing a total of 15 conducting paths. A neoprene outer jacket about 0.115 inch thick is extruded over the conductors, making the total diameter of the cable approximately 0.730 inch. It weighs 0.328 pounds per foot.

The cable is made up in a length of 500 feet terminating at the upper end in a Cannon RNK-L15-1" B & AN right angle plug and at the lower end in a watertight junction box shown in Figure 8. The electrical conductors terminate in the junction box in an Amphenol "Blue Ribbon" No. 26-4200-16S female connector. The cover of the junction box carries the mating (No. 26-4100-16P) male connector so that removing the cover from the junction box immediately disconnects the cable. The connector in the junction box is "floating", being held in place by loose, but captive, rivets. This provides an automatically self-aligning arrangement for the two connectors. Pin 15 on both connectors has been removed to provide a greater leakage path between pin 16 and all others. Pin 16 carries the high voltage for the h-meter multiplier phototube, and as this can get as high as 1300 volts, it was desirable to increase the length of the insulation paths as much as possible.

The insulation on all wires is rated for 600-volt service except for two leads which are rated at 1500 volts. These are used for the high voltage for the multiplier phototubes in the h- and  $\alpha$ -meter circuits. The table below lists all the conductors, in order progressing around the cable, and numbered according to the system used on Drawing No. 3-545-1.

<u>Conductor Number</u>	<u>Color</u>	<u>Size (AWG)</u>	<u>Insulation (volts)</u>	<u>Resistance (ohms)</u>	<u>Use</u>
1	orange	18	600	3.0	$\alpha$ -meter lamp
2.	orange	18	600	3.0	cathode follower heat- ers and pressure transducer
3	blue	18 copper weld	600	6.0	$\alpha$ -meter lamp voltmeter
4	yellow (shielded)	20	600	5.0	$\alpha$ -meter signal lead
5	is the shield of #4		300	5.5	pressure transducer signal ground
6	white	20	1500	4.9	$\alpha$ -meter multiplier phototube high voltage
7	yellow	20	600	4.9	+85V DC cathode fol- lower plate supply
8	orange	18	600	3.0	h-meter filter solenoid
9	orange	18	600	3.0	ground
10	blue	18 copper weld	600	6.0	h-meter filter solenoid
11	yellow (shielded)	20	600	4.7	h-meter signal lead
12	is the shield of #11		300	5.5	ground
13	white	20	1500	4.9	h-meter multiplier phototube high voltage
14	yellow	20	600	4.9	-105v DC for multi- plier phototubes
15	yellow	20	600	4.9	pressure transducer signal

The stainless steel core terminates at its lower end in a plastic thimble, which is pinned into a clevis secured to the bottom of the junction box. The strain is transmitted from the instrument by a sling of 5/32 wire rope to a plate on the bottom of the junction box. This plate and the clevis are machined from a single piece of stock which extends through the wall of the junction box; thus no distortion of the box occurs when a load is put on the cable. It is necessary, when securing the cable gland at the top of the junction box, to ensure that there is no slack in the wire rope inside the box. If there should be slack, the load will then be transmitted from the rubber jacket of the cable to the gland and through the shell of the box to the underwater instrument. This will tend to unduly stress the jacket and the electrical conductors and may deform the box. Although the box is of fundamentally strong design, sufficient distortion could cause it to leak.

### 2.37 Deck Illuminometer

The Deck Illuminometer measures the illumination incident on the sea surface. Obviously, if this changes, the flux incident on the h-meter will change proportionally. If the effect of these changes is not removed by adjusting the recorder h values, an erroneous value of k will result. As there will be some variability or noise in the h-meter record, there exists a point below which it is no longer significant to attempt such corrections. For example: changes of  $\pm 0.1$  log observed in the h-meter readings at shallow depths, due to refraction of sunlight from surface waves, represent a variation of over  $\pm 20\%$  from the mean value. Under these conditions a change of 10 or 15 percent in the value of the surface illumination would probably have little effect on the total accuracy of k determination, unless a careful statistical smoothing of the data were undertaken.

In the situation where the h-meter is at considerable depth, the h record, when depth and surface illumination are constant, would be inherently smooth. However, if the sun is intermittently covered by clouds, the large resulting variation in surface illumination will have considerable effect on h- and thereby on the accuracy of k determination, if the h variations are ignored.

The primary sensing element in the illuminometer is a photovoltaic cell manufactured by General Electric Company under their catalog number 3PV10-FAA. This is a hermetically sealed unit mounted on an octal tube socket for ease in mounting and removal. The diameter of the active photo-sensitive surface is 1 5/32 inches. In order that the output be amenable to calibration in readily specifiable units, the photocell is fitted with a Wratten No. 102 gelatin filter which approximately corrects its spectral sensitivity to that of the human eye.

In order that the instrument measure illumination it is necessary that the light collection surface have a sensitivity that varies as the cosine of the angle from the normal. To accomplish this the photocell is covered with a thin plate of diffuse white plastic, whose outer surface has been lightly abraded. The total effect is very close to that of a Lambert or "cosine law" collector. The fact that the purpose of the illuminometer is to obtain a

measure of the illumination on the sea's surface, means that the plane of the collecting surface must be maintained horizontal. To accomplish this the photovoltaic cell is mounted on gimbals and the center of gravity of the cell housing placed below the gimbal supports. The unit is thus pendulously stabilized with the period of the illuminometer oscillation much shorter than the period of the roll and pitch of the survey vessel. The small stainless steel enclosure at the bottom of the cell housing may be filled with the mercury supplied in a small plastic bottle housed in the illuminometer carrying case. The effect of the mercury is to lower the center of gravity of the pendulum, thus slightly increasing its period; but more important, it increases the restoring force per unit angular displacement from the vertical. This may decrease the total angular error by overcoming the static bearing friction at smaller angular displacements between the normal to the collection surface and the true vertical. Oscillation of this collection surface about the horizontal will appear on the recorder chart as oscillations of the pendulum's frequency, perhaps modulated by the roll of the vessel. These oscillations will be particularly noticeable when the sky is clear and the sun is low in the sky. It will be necessary to determine in the field the optimum amount of pendulum mass. The friction of the cone-type bearings can be adjusted within limits by moving the pivot screws in the gimbal supports. These screws are of stainless steel and the mating surfaces are of aluminum bronze. All other exposed surfaces are of stainless steel or are chrome plated to reduce the corrosive effects of shipboard environment. In addition the chromium plating serves to materially reduce the temperature reached in the cell housing by reflecting most of the incident radiation. This is of considerable concern as the internal resistance of the photovoltaic cell, and therefore its effective sensitivity and linearity, is appreciably affected by temperature. Furthermore, and perhaps most important, the characteristics of the cell may be permanently altered and the cell damaged, if the cell temperature exceeds  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ).

The electrical circuit of the illuminometer is extremely simple and can be seen on Visibility Laboratory Drawing No. 3-545-2 in the right center of the diagram. The output leads from the photovoltaic cell are of very fine insulated wire, arranged to afford the minimum interference with the free movement of the cell. These wires terminate in an extension jack modified with a shorting contact. The purpose of this contact is to short-circuit the cell at all times when it is not in use. Sufficient shielded cord is provided to allow the illuminometer to be mounted in an appropriate location removed from major obstructions in its sensitive upper hemisphere. Inside the deck control panel the current from the cell passes through a  $0.10^{\circ}$  microampere panel-meter in series with a 100 ohm precision resistor. The voltage drop across this resistor is applied to the input terminals of the 10 millivolt recorder. Thus full scale (100 microamperes) on the meter corresponds to full scale ( $100 \times 10^{-4}$  or 10 millivolts) on the recorder. As the recorder has an accuracy of about  $\pm 0.25\%$  and the panel meter accuracy is only  $\pm 2\%$ , any discrepancy between the two instrument readings should be attributed to error in the meter. A three-position switch on the panel of the Deck Control Unit allows the sensitivity of the illuminometer to be changed. The right hand knob position shorts the output of the cell; the center position shunts the meter and recorder-resistor with a calibration

resistor adjusted to give full scale sensitivity of the meter and recorder of about 10,000 foot-candles (lumens per square foot); the third (left hand) switch position removes this shunt and provides the maximum sensitivity of the illuminometer. This position may be useful in situations where the illumination level is always in the approximate lower third of the 10,000 foot-candle scale. As the absolute level of illumination is not necessary for the correction of the h readings, the accuracy of the absolute calibration of the illuminometer is not significant. The linearity of response is of importance and is judged more than adequate for the intended use of the data.

### 2.38 Deck Control Unit

All controls and equipment not required to be housed elsewhere are contained in the Deck Control Unit. It is designed to enable the operator to control and determine quickly the condition of the various components which make up the Water Clarity Meter.

The panel is fastened to the box with nine quick release fasteners along three sides and a piano hinge at the top. Care must be taken on opening the unit to prevent excessive flexure of the 1/8-inch aluminum panel. The inverted panel should be supported to prevent damage to the equipment and cables and to minimize bending of the panel. The use of a mirror will be found helpful when operating the panel in its inverted position. It is also recommended that the outer case be held down, as the panel is lifted, in order to prevent the case from raising to follow the heavy panel.

The AC voltage input enters the equipment through a motor base connector on the lower right hand side of the panel (see Figure 2). Immediately above is the main power switch, which interrupts both sides of the AC line (see Drawing No. 3-545-2). A five ampere fuse protects the entire equipment including the recorder. The power supplied to those circuits which are considered sensitive to voltage changes is passed through a 5 ampere Variac to allow for its adjustment. The equipment is designed to operate from a regulated source of power, such as that supplied by a Sorenson Model 1000S line voltage regulator. However, if no such supply is available, it is possible to adjust the input voltage by means of the Variac to obtain 115 volts indication on the small AC panel voltmeter.

A blower is located in the lower right hand corner of the equipment. It takes air in around the flat cover plate, through a filter, and passes it over the heat producing components. The air is exhausted through screened ports, located on the upper right vertical side of the box immediately below the panel.

A major portion of the space in the control cabinet is taken up by a chassis containing the two photometer circuits for the  $\alpha$ - and the h-meters. This chassis can be seen in the right hand side of Figure 4. The controls needed for operation of the  $\alpha$ -meter photometer are mounted directly on the exterior of the panel of the Deck Control Unit. These are the "  $\alpha$  Range

Selector Switch" and the "Zero Set". The adjustments mounted on the photometer chassis or its panel, which are visible in Figures 3 and 4, are used only in the calibration procedure for the photometers. Connections are made to the photometer chassis by means of a barrier terminal strip. A fanning strip is used on the end of the cable going to the chassis to prevent incorrect connections from being made in servicing and to facilitate reassembly. To enable the photometer circuit to be operated after removing it from the Deck Control Unit for servicing, a jumper cable has been provided which terminates at one end in a similar barrier terminal strip and at the other in a similar fanning strip. The details of the photometer portion of the control unit are covered in Section 2.341,  $\alpha$ -meter and h-meter Photometer Circuits.

Another sub-assembly, shown on the left side of Figure 4, contains two low voltage DC power supplies. The first of these is a half wave silicon diode (Type 1N256) rectifier, supplying about 46 volts at 130 milliamperes which actuates the h-filter solenoid. The circuit for this is shown in the left center of Drawing 3-545-2. It is fused for 0.25 amperes. The switch in the lower left of Figure 2 interrupts the DC supplied to the solenoid. In its unenergized position the solenoid-operated filter is in the optical path, reducing the sensitivity of the h-meter. The panel light is on when the switch is in the "on" position, indicating that the filter is in place. Closing the circuit to the filter solenoid pulls the neutral density filter out of the way and increases the sensitivity of the h-meter. In this condition the h-filter lamp is off.

The second power supply on this sub-assembly performs three functions. It supplies: 1) power for operating the lamp, 2) power for the heaters in the cathode followers, and 3) the potential applied to the depth transducer. The power transformer delivers approximately 100 volt-amps at 24 volts. Its primary is fused for 1.5 amperes. The rectifier consists of four silicon diodes (International Rectifier Corporation, Type 25H15) in a full wave bridge connection. These diodes are mounted on aluminum heat sinks and are operated well under their maximum rating. They should, therefore, provide trouble-free operation. The filter consists of 4000 microfarads of capacitance directly across the output of the rectifier. This large capacitance reduces the ripple fed the underwater cable and equipment to an acceptably low value and produces a sufficiently large DC voltage to operate the underwater lamp with the voltage drop encountered in 500 feet of cable. A switch on the panel allows the power to the  $\alpha$ -meter lamp to be interrupted. When the lamp is turned off, the reduced load on the power supply results in a higher voltage output. The output from the supply is 26.2 volts at 3.6 amperes when the lamp is on, and 32.3 volts at 0.50 amperes when the lamp is off. A resistance of 1.0 ohm is used in series with the lead to the lamp, which adjusts the current to the zener diode regulator in the underwater lamp circuit to its proper value. Similarly, 21 ohms is used in series with the cathode follower heaters and pressure transducer circuitry to limit its current to its design value. As the lamp and cathode follower heaters use one common conductor in the underwater cable, compensation is necessary for the reduction in the voltage drop in this common lead and for the increase in voltage output from the supply when the lamp is shut off. For this purpose an additional 22.3 ohms is

inserted in series with the 21 ohms mentioned above to maintain a constant current to the regulator circuit. This is accomplished by the same switch that controls the lamp power.

The "Function Selector" switch on the left center control panel has five positions. Starting from the left, the first four present the outputs from the depth transducer, the h-meter, the  $\alpha$ -meter, and the deck illuminometer directly to the recorder for continuous recording. By switching to these positions the operator can obtain a record of any sequence and duration of the functions desired. The fifth position of the "Function Selector" switch is labeled "Seq" and starts the operation of the function sequencing assembly. In this position a 3 rpm Bodine synchronous motor drives a series of six cam-operated microswitches, automatically presenting the output of each of the four instruments to the recorder in sequence. The order is E,  $\alpha$ , Z, and h. A complete cycle of operation takes 20 seconds. To reduce ambiguity the timing is divided approximately as follows: E (4 seconds), h (8 seconds), Z (4 seconds), and  $\alpha$  (4 seconds). The longest trace was chosen to represent h, which shows the greatest random variability (at least near the surface) and, consequently, benefits most from the longer period for averaging purposes. The logic behind the sequence chosen is as follows: the illumination information, E is used to correct h and should, therefore, occur next to E in time sequence; the depth information, Z, is used in conjunction with both h and  $\alpha$  data and should appear adjacent to both these functions. A post on one side of the function sequencing assembly holds five small arms on which are mounted the microswitches with their actuators. Mounted on the motor shaft in the center of the assembly are five cams which operate the microswitch actuators. The length of time each switch is closed is determined, primarily, by the notch cut in the cams. A slight adjustment can be made by changing the arm position, thus causing the actuator to engage for a slightly longer or shorter time. Rotating the cams allows the four functions to be delivered in the desired sequence to the recorder input terminals. One microswitch-and-cam combination is used for each of the functions E, h, and  $\alpha$ . The Z output requires two microswitch-and-cam combinations, as the "ground" lead in this circuit is not common to the remaining functions and must also be interrupted. The sixth microswitch-and-cam combination (mounted next to the motor) is used to ensure that the sequencing assembly always stops in the same spot when the operator changes the position of the "Function Selector" switch. This was done for two reasons. First, it is important that the sequencing assembly not stop on the Z position as that would leave the ground circuit to the recorder open and cause the equipment to malfunction. Second, it was thought desirable to always start the automatic sequencing at the same function for ease in immediate identification of the functions. The choice of E was arbitrary, as either h or  $\alpha$  could have been chosen as a starting point by adjustment of the sixth cam. As a result of the use of the sixth microswitch-and-cam combination, the motor may continue to run for a length of time up to 16 seconds after switching the "Function Selector" switch from "Seq" to one of the other functions. The recorded data, however, will immediately be correct for the selected function.

The underwater cable plugs into a cannon type FNK-L 15-31SL receptacle mounted in the lower center of the panel of the Deck Control Unit. This receptacle is a quick-disconnect 15 pin connector.

Removal of a small cover plate, labeled "Depth Calibrate", allows access to a screwdriver adjusted potentiometer. This potentiometer can be adjusted in the field to compensate for changes in circuit parameters. Such changes should only be attempted, when a more accurate means of determining depth other than the pressure potentiometer, is available.

### 2.39 Recorder

The recorder provided is a Leeds and Northrup Model G Speedomax recorder. Any standard strip chart recording potentiometer, having a full scale span of 0-10 millivolts and appropriate chart speed, would suffice for this application. The unit provided was modified from a 16 point thermocouple potentiometer and, consequently, some of the mechanism contained in the recorder is not used. As modified, the recorder has a full scale span of 10 millivolts over  $9 \frac{15}{16}$  inches with no provision for overtravel at either end of the scale. The chart paper provided is Leeds and Northrup chart No. 489 with 100 divisions evenly graduated. Horizontal time graduations are provided every  $\frac{1}{2}$  inch. The chart speed is  $2 \frac{1}{2}$  inches per minute and can be changed by procuring appropriate change gears from the Leeds and Northrup Company.

The recorder receives its power through a cable provided with an AN 3108A-16S-4P right angle plug to match a mating receptacle on the panel of the Deck Control Unit. Turning the main power switch on the latter unit provides power to the recorder. Two switches are mounted on top front of recorder. The right-hand switch controls all power to the recorder. The left-hand switch turns on the chart drive motor. The recorder is fused by plug type fuses mounted inside the cabinet on the rear top. The working battery for the potentiometer is a standard  $1 \frac{1}{2}$  volt Burgess No. 4FH (MIL BA-35) dry cell. The recorder has an automatic standardizing feature, but should also be manually standardized frequently, during the operation of the equipment. It would be desirable to manually standardize at the start of every run and not less than once every two to three hours of operation of recorder. The battery should be replaced when the standardizing mechanism indicates "renew battery".

The pen and its support must be carefully swung out of the way or removed entirely before attempting to change the chart-paper roll. Care should be exercised on closing the paper drive and re-roll unit to ensure that the glass ink well and pen are not damaged by the sprocketed upper-drive roller.

The input signal is fed to the recorder by means of a two-wire shielded cable, fitted with an AN 3108 A-12S-3P right angle plug at the Deck Control Unit end and with spade lugs (coded to match coding on the terminal strip in the recorder) at the recorder end.

### 3.0 OPERATION

The following material tries to anticipate the proper operational procedures to be used in gathering data with the Water Clarity Meter. As there has been little opportunity for operational experience with the equipment it is likely that changes in the procedure will suggest themselves as more experience is gained.

#### 3.1 General Precautions

Every effort has been made to render the Water Clarity Meter as rugged as thought necessary for the general abuse a field instrument must withstand. However, it is a precision instrument and its optical, electrical and mechanical components should receive the care normally afforded such instruments.

It is strongly suggested that the underwater portion of the instrument be placed in the case provided when it is not in use, and that all the other components be stowed in their cases whenever they are not to be used for any appreciable period of time.

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CAUTION!

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Some of the voltages used in the photometer circuits are very dangerous. The output from the h-photometer voltage doubler supply is 1630 volts DC, and under some circumstances the voltages supplied to the h-meter multiplier phototube can approach this value. Before disconnecting the underwater cable from the panel or before opening or disassembling any of the equipment, the main power switch should be turned "off". When in the course of maintenance or calibration procedures the instrument must remain open when turned "on", extreme caution must be exercised to remain clear of any exposed wiring.

The following precautions should be observed in the operation and storage of the instrument:

1. Do not store or operate instrument exposed to extreme heat or direct strong sunlight for extended periods. The multiplier phototubes have a maximum storage temperature of  $75^{\circ}\text{C}$  ( $167^{\circ}\text{F}$ ) and should be kept well below this figure to assure the permanence of their calibration. The black enclosures of the underwater equipment may reach unusually high interior temperatures when exposed to high tropical sun, for example. The dark current in the h-multiplier

phototube will increase with increasing ambient temperature with the result that the h-meter will not be able to attain its maximum sensitivity. The unit should not be calibrated under these conditions.

2. The Deck Illuminometer should not be subjected to conditions which will cause the temperature of the photovoltaic cell to exceed 60°C (149°F).
3. Never operate the equipment without the underwater cable interposed between the Deck Control Unit and the underwater equipment. The resistance of the 500 feet of the various conductors is an important part of the circuit and damage will consequently result from the use of an improperly designed jumper cable.
4. The underwater cable may be permanently damaged by kinking, or bending around a too small radius. The use of sheaves and nigger-heads 15 inches or greater in diameter is suggested to prevent undue stress on the electrical conductors. Smaller diameters when the cable is under load may result in permanently stretching these conductors.
5. Do not allow heavy objects to be placed on, nor fall on the cable. In addition to the danger of damaging the electrical conductors, the neoprene jacket is depended upon for the water-tight integrity of the equipment. Any failure of the jacket due to cuts or abrasion, for example, may result in quickly filling the equipment with water as no water-tight seals for the individual conductors could be used.
6. The AC power supply for the equipment should preferably be regulated and at a constant frequency of approximately 60 cps. If the power is not regulated it should not exceed the limits 105 to 125 volts and should not have other large and variable loads tied into the same source. The variations in line voltage must be slow enough to allow the operator to compensate for them with the Variac on the Deck Control Unit.
7. Do not leave the Deck Illuminometer exposed to high levels of illumination with the cable plugged into the Illuminometer but not plugged into the Deck Control Unit. This results in the cell being open circuited, a condition that is not desirable at high light levels.
8. Particular care must be exercised to protect all mating surfaces of the water-tight enclosures that constitute pressure seals. Nicks and dents in these surfaces will result in loss of pressure integrity.

9. Never attempt to lift or move underwater instrument by applying force to h-sphere, as this is a relatively fragile portion of the equipment. It will withstand the normal stresses to which it will be subjected, but should be protected by its wire cage except when it is necessary to remove it for servicing.

### 3.2 Preparation of the Equipment.

1. Place recorder and Deck Control Unit in convenient location where one operator can operate both units.
2. Place Deck Illuminometer in a position where it will not be shadowed by bulkheads, masts, guys, etc., and where there will be no traffic by it to interfere with its light field.
3. Figure 8 cable on deck by nigger-head. Feed underwater end around nigger-head through snatch block with large sheave attached to boom for underwater equipment and connect to junction box. Attach other end of cable to panel receptacle on Deck Control Unit.
4. Attach sling to underside of junction box and to underwater instrument. Use long sling for horizontal operation and short sling for vertical operation.
5. Ascertain that all underwater pressure seals have been properly secured. Use Dow-Corning DC-4 silicone grease on all "O" rings before closing any underwater enclosures.
6. All equipments must be interconnected with the cables provided.
7. Connect power cable to a source regulated AC power at 115 volts 60 cps.
8. Switch on all equipment and allow 15 minutes for warmup. Adjust line voltage to read 115 volts on panel meter. Read the lamp voltage on the "Lamp Volts" voltmeter. It should be 6.0 volts.
9. Check recorder paper supply, condition of ink and pen, standardize recorder with pen at least slightly off mechanical stops until further standardizing does not result in pen movement.

### 3.3 Deck Check-Out

1. If doubt exists about  $\alpha$ -meter optical alignment due to shipment of equipment, if it has been subjected to severe blows in handling, or if previous data has been suspect, check alignment by following appropriate procedure in Section 6.1 below.
2. Check  $\alpha$ -meter calibration by placing filter holder adapter on receiver cap and inserting several filters comparing values obtained with table of densities.
3. Remove baffle caps from  $\alpha$ -meter projector and receiver housings and clean windows with soft tissue (these are Plexiglass and will scratch easily). Replace the baffle caps.
4. Set  $\alpha$ -meter "Zero Set" potentiometer to obtain an  $\alpha$  reading of 0.0437 or a density reading of 0.0311 on the recorder with the instrument in air. Use calibration curves to determine the number of scale divisions on the chart for this  $\alpha$  or density value. The  $\alpha$  receiver should be protected from direct sunlight when attempting this calibration. Set  $\alpha$ -Range Selector Switch to "0.5" log range unless water is known to be particularly turbid. (Range may be changed during operation without affecting calibration.)
5. Check Deck Illuminometer reading to determine if operation and location are satisfactory.
6. Depth indication should be zero.
7. Check h reading to determine if it is on scale. If not throw h filter switch to "in" position.
8. Try sequencing operation.

### 3.4 Data Taking Procedure

1. With instrument in position to be lowered take final air readings by either manual or automatic sequencing. Note locations, times, date, sensitivity settings, functions, cloud cover, sea condition, etc., directly on recorder chart paper.

2. Lower to first depth station. Make similar notations on chart as necessary. Make certain sufficient motion of instrument in water occurs to break loose any air bubbles which may cling to  $\alpha$ -meter windows. Take a number of cycles of data to allow meaningful averaging of the data in the reduction procedure. A minimum of three complete cycles should be obtained at each depth if the data shows little variability, or if little time is available. If the record shows considerable variability, a larger number of cycles or a few long manually sequenced complete cycles should be obtained to allow for an adequately large statistical sample of each function record.
3. Repeat data taking procedure of step 2 at each depth station as the instrument is lowered and, if time permits, again as it is raised.
4. When instrument is raised to the deck, remove baffle caps from receiver and projector housings and clean windows of water, etc. Dry caps and replace on housings. Take check reading on  $\alpha$ -meter air setting with instrument in same orientation (i.e., vertically or horizontally suspended) as used in data run.

### 3.5 Post Operational Routine.

1. Place underwater instrument in its case after water has drained from it. Occasionally hose instrument down with fresh water.
2. Disconnect cable at junction box. Place protective covers over junction box and cover plate. Cover RNK-L15-1" B & AN plug with a waterproof cover or tape with electrical tape in order to protect the plug pins from contamination and salt spray.
3. Protect cable from foot traffic and damage from heavy objects.
4. Remove Deck Illuminometer and replace in its case if instrument is not to be used for an appreciable period. Clean off white plastic diffuser cap with clean fresh water and occasionally with alcohol to prevent loss in sensitivity.

#### 4.0 THEORY OF OPERATION

##### 4.1 h-Meter and k Determination

The k-value that is required for use in the swimmer nomograph calculations is, actually, that defined by the equation

$$E_z = E_0 \exp(-KZ)$$

where E is the downwelling illumination on a horizontal plane. The difficulty with measuring E in the field is that it is not readily possible to determine or control the orientation of a flat plate collector, when it is located at the end of a long cable. Effects of wire angle and motion of the vessel, etc., may cause considerable variation from a horizontal orientation of the collection surface. By using a diffuse spherical collector the instrument is equally sensitive to flux from all directions and it is, therefore, not necessary to determine or control the orientation of the instrument. The small solid angle occluded by the main body of the instrument does not introduce appreciable error, as it is normally below or, at worst, at the same level as the sphere. In most situations which will be encountered in natural ocean waters, the great preponderance of flux collected by the sphere will be contributed by the downwelling flux; therefore, the effect upon the total reading of the occluded angle will be small and variations in the measurement caused by motion of the instrument will, likewise, be small.

A truly spherical collector would measure the parameter known as scalar irradiance (or more accurately, scalar illuminance), for which the symbol h is used. The attenuation of h with depth is expressed by a similar equation to that used to describe the attenuation of illuminance. Thus

$$h_z = h_0 \exp(-kZ).$$

Here the attenuation coefficient is denoted by the symbol k to differentiate it from the K used for the attenuation coefficient for downwelling illuminance.

As the depth increases,  $k-K \rightarrow 0$  and the validity of using the former in place of the latter in the computation of sighting ranges for underwater swimmers needs no justification. Near the surface a difference of 6% or less between the k and K will exist, but it is felt that the errors introduced by using k in place of K will not be appreciable especially in view of the greater possibility of error in the measurement of K.\*

\*For a detailed discussion of these factors see the following: Preisendorfer, R. W., Directly Observable Quantities for Light Fields in Natural Hydrosols, Visibility Laboratory Report, SIO Reference 58-46, Bureau of Ships Contract NObs-72092, Scripps Institution of Oceanography (June 1958); et seq.

An appreciation of the accuracy which can be expected in the determination of  $k$  can be obtained from the following expression:

$$\% \text{ error in } k = (\% \text{ error in } h) \frac{1}{k \Delta Z} .$$

Thus we can see that as  $k$  becomes small, greater errors in its determination will ensue unless larger depth intervals,  $\Delta Z$ , are used. The percentage error in the determination of  $h$  will be constant regardless of the absolute scale value as a result of the logarithmic type of response which the  $h$ -meter has. This error will be of the order of  $\pm 5\%$  or less, if the instrument is carefully calibrated and read. To obtain a like accuracy in  $k$  we must use a  $\Delta Z$  which is the reciprocal of  $k$ , i.e.,

$$\Delta Z = \frac{1}{k} \text{ (feet).}$$

If we encounter values of  $k$  in the range of 0.1 to 0.03, the  $\Delta Z$ 's should be 10 to 30 feet, respectively, to obtain a  $\pm 5\%$  accuracy in  $k$ . The above is purely for illustrative purposes and the actual value of  $\Delta Z$  used will depend upon the requirement for detail in the vertical profile.

#### 4.2 $\alpha$ -Meter

The  $\alpha$ -meter portion of the Water Clarity Meter is similar to instruments variously known as "transmissometers" or "hydrophotometers". The difference between the  $\alpha$ -meter and these other instruments is the fundamentally greater accuracy obtained in the measurement of the true volume attenuation function (or, equivalently, beam transmittance) of natural waters by the use of a more advanced optical design in the  $\alpha$ -meter. The  $\alpha$ -meter measures this coefficient absolutely (i.e., with respect to air, or essentially 100% transmission with no forward scattering) by noting the ratio between the air and water readings. The receiver of the  $\alpha$ -meter thus measures only the flux in the beam which is not attenuated (absorbed or scattered out of the beam) in traveling through the water from the projector to the receiver. To do this one must be certain that any change in the apparent positions or images of the aperture stops, due to the difference in index of refraction of water and air, does not alter the flux available at the receiver in any way. The beam must therefore be cylindrically limited and the glass to water interfaces parallel. For example, let us assume that the glass windows are not parallel but are inclined to one another at an angle  $\theta$ . When the projector beam is lined up with the receiver acceptance beam in an air medium and the instrument is then placed in a water

medium the water thus placed between the non-parallel windows acts as a weak prism on the beam. The resulting deviation or lateral displacement "d" of the beam can be calculated by the equation

$$d = (n-1) r$$

where n is the index of refraction of water and r the distance between windows. If  $r$  approaches a significant value then the beam could become displaced far enough to cause its blocking by one of the stops in the receiver tube and thus give false values of  $\alpha$ . Likewise, if the windows were parallel but the beam inclined at an angle  $\phi$  other than  $90^\circ$  to the glass, a lateral displacement will occur given by

$$d = \phi r \left( \frac{n-1}{n} \right)$$

where r and n have the same meaning as above. Thus two conditions must be fulfilled: 1) perpendicularity of the beam to the windows, and 2) parallelism of the windows. The receiver acceptance beam is about 3 millimeters in diameter larger than the projector beam to allow a tolerance for slight misalignment.

One more correction term must be included in the readings of air and water transmission. This is due to the decrease in reflection loss of light flux at the exterior window interfaces when the instrument environment is changed from air for calibration to water for measurement. This can be calculated from Fresnel's law

$$\Delta \rho = 100 \left\{ 1 - \left[ \frac{1 - \left( \frac{n_G - 1}{n_G + 1} \right)^2}{1 - \left( \frac{n_G - n_W}{n_G + n_W} \right)^2} \right]^2 \right\} = 100 \left\{ 1 - \left( \frac{1 - R_A}{1 - R_W} \right)^2 \right\}$$

where  $\Delta \rho$  is the amount of diminished reflection loss of light flux in percent,  $n_G$  and  $n_W$  are the indices of refraction of the glass (or Plexiglass) windows and water, respectively, and  $R_A$  and  $R_W$  are the reflection losses at glass-air and glass-water surfaces, respectively. Using Plexiglass windows  $\Delta \rho$  amounts to 6.923% or 0.0311 density units.

To measure true volume attenuation function, there must be no forward scattering within the light beam. From the simple geometrical considerations of this situation, it is apparent that the beam would have to have zero diameter (i.e., no beam would exist in the physical sense). If we

utilize Preisendorfer's nomenclature\*, where  $\alpha$  and  $\alpha'$  are the true and measured attenuation coefficients, respectively, and  $\sigma_0$  is the value of the scattering function in the forward direction, one obtains\*\*

$$\alpha' = \alpha - 2\pi\sigma_0 \left(\frac{a}{r}\right)^2$$

where  $a$  is the radius of the beam and  $r$  is distance between windows.  $\alpha'$ , therefore, approaches true  $\alpha$  when the ratio  $a/r$  approaches zero (e.g., when  $a$  goes to zero). Clearly, this condition is physically impossible. The next step therefore is to choose a ratio  $a/r$  such that under given conditions (i.e.,  $\sigma_0/\alpha$  ratios) the deviation of measured  $\alpha'$  from true  $\alpha$  is within a certain allowable tolerance. Many other instruments of this type have in the past ignored this relationship and allowed large diameter beams with respect to length, (large  $a/r$  ratios), with consequent errors in true  $\alpha$  as great as 20%. Some have ignored a cylindrically limited beam and a receiver tube with small forward scattering acceptance angle and have thus experienced large and variable error due to the changes in the amount of forward scattering accepted along the length of the beam. On the other hand, there is likewise a lower limit of  $a/r$  ratios beyond which little is gained by decreasing it. This limit is approximately 1 to 150 in most natural water situations. It should also be remembered that the forward scattering coefficient,  $\sigma_0$ , may change non-proportionately with  $\alpha$  so that in some extreme cases  $\sigma_0/\alpha$  ratios may increase an order of magnitude over those given in Preisendorfer's report.\*\* Thus one may have conditions where practically no absorption of the beam occurs but the particles contributing to scattering may be such as to cause large values of  $\sigma_0$ . The ratio  $\sigma_0/\alpha$  and the percentage error between  $\alpha'$  and  $\alpha$  would, therefore, likewise increase.

The Water Clarity Meter has as its  $a/r$  ratio a value of 1/124 and thus has less than 2% error in measurement of true  $\alpha$  under extreme water conditions where  $\sigma_0/\alpha$  are 10 times that given in the above mentioned report. This error drops to under 0.2% in regions of moderately clear near-shore water. The above values of error for measurement of  $\alpha$  were determined with the previous mentioned receiver acceptance tolerance taken into account and do not include electrical and electronic instrumental errors.

\*Preisendorfer, R. W., A General Theory of Perturbed Light Fields With Application to Forward Scattering Effects in Beam Transmittance Measurements, Visibility Laboratory Report, SIO Reference 58-37, Bureau of Ships Contract NObs-72092, Scripps Institution of Oceanography (May 1958).

\*\*Ibid. p. 16

## 5.0 REDUCTION OF DATA

There are five functions computed directly from the readings given by the water clarity meter. These are:

- a. Depth,  $Z$
- b. Deck illuminance,  $E$
- c. Relative underwater scalar irradiance,  $h$
- d. Attenuation for collimated light,  $\alpha$
- e. Attenuation coefficient for diffuse (or ambient) light,  $k$

The first four of these are each based on a reading on the recorder chart, and the fifth,  $k$ , is based on the first three functions,  $Z$ ,  $E$ ,  $h$ . The order of sequenced readings is:  $E$ ,  $\alpha$ ,  $Z$ ,  $h$ .

### 5.1 Depth: $Z$

The depth is read directly from the chart by use of the triple-scale overlay, using the scale marked: "Depth,  $Z$  (feet)". If the linear scale develops an error a calibration factor or constant may be applied to the scaled value. With the meter in proper adjustment this last should not be necessary.

### 5.2 Deck Illuminance: $E$ .

This is the total ambient light falling on the surface of the water. It is read directly from the chart with the triple-scale overlay, using the scale marked, "Deck illuminance,  $E$  (foot-candles)". Here again a correction may be applied if the scale should develop error. The function,  $E$ , is used later to normalize  $h$  in computing  $k$ .  $E$  may also be read on the left hand meter on the control panel. For approximate calculations of the underwater illuminance it may be considered that about 0.04  $E$  is lost at the surface by reflection, or that about 0.96  $E$  passes the water surface.

### 5.3 Relative Underwater Scalar Irradiance: $h$

This may be considered the total radiance falling on a point underwater. It is read on the chart with the triple-scale overlay, using the scale marked "Relative underwater scalar irradiance,  $h$ ". This scale is calibrated for multiplier phototube Number 5, which is in the instrument at the time this instruction is written. With replacement of the phototube it will be necessary to make a new scale.

If it is wished to relate several  $h$  readings they should be normalized with reference to the  $E$  taken at the time of each  $h$  reading.

An approximate value of the illuminance  $E(Z)$  at any depth  $Z$  for most natural water and lighting conditions may be obtained by taking the illuminance above the water surface,  $E(O-)$ , from the deck illuminometer, multiplying this by 0.96 to obtain  $E(O+)$ , the illuminance just below the water surface and normalizing the  $h(Z)$  curve to this value. Thus:

$$E(Z) = 0.96 E(O-) \frac{h(Z)}{h(O+)}$$

### 5.4 Attenuation Coefficient for Collimated Light: $\alpha$

This is the measure of the attenuation of a beam of light in the water. It is read from the chart with one of the " $\alpha$ /ft scales" appropriate to the position on the " $\alpha$  range selector switch" being used.

To determine the  $\alpha$  from the chart reading, select the " $\alpha$ /ft scale" overlay determined by the " $\alpha$  range selector switch". Set off the reading of the zero set knob on the "Zero Set" scale on the overlay. Draw a line from this point parallel to the  $\alpha$  scale, perpendicular to the Zero set scale. This line and its intersections with the  $\alpha$  graduation curves forms the scale for reading  $\alpha$  directly from the chart. Of course it is not necessary to actually draw this line on the overlay, it may be constructed mentally.

If it is not convenient to use the scales, the following expression may be used to compute  $\alpha$ . This expression takes into account the difference in reflectance loss at the Plexiglass windows between the air and water immersion conditions and neglects the correction for  $\sigma_0$ , which for most circumstances may be neglected. Thus

$$\alpha \text{ (ft}^{-1}\text{)} = 1.404 (D_w - D_a) + 0.0437$$

where  $D_w$  = Density reading in water  
 and  $D_a$  = Density reading in air.

If the density correction of 0.0311 for the air condition is used, the instrument reads the optical density of the water path directly and the above expression becomes

$$\alpha (ft^{-1}) = 1.404 D_w .$$

### 5.5 Computation of Attenuation Coefficient for Diffuse (Ambient) Light: $k$

This is the attenuation with depth of  $h$ . It is computed from the data developed with the aid of the following relation:

$$k = \frac{\ln \frac{h E_{12}}{h E_{21}}}{Z_2 - Z_1}$$

where:  $h_i$  = scalar irradiance at depth  $Z_i$  when deck illuminance is  $E_i$ .

The above mathematics may be avoided by plotting  $\frac{h_i}{E_i}$  on K & E 359.91, 5 cycle semi-log paper with  $Z$  along linear axis and  $\frac{h_i}{E_i}$  along the log axis; then placing the overlay, "k/ft scale-Diffuse Attenuation", on the graph properly oriented and moving the overlay about in this orientation to determine which  $k$ -line is tangent to the  $\frac{h_i}{E_i}$  curve at each point desired.

## 6.0 ALIGNMENT AND CALIBRATION PROCEDURES

### 6.1 Optical Alignment of $\alpha$ -meter

To facilitate the alignment of the  $\alpha$ -meter in the field a number of special tools have been provided. A brief description of these follows:

1. Alignment Telescope: (See Fig. 14) This is a small optical tool whose function it is to allow one to determine how well the image of the projector aperture stop is centered in the receiver field stop. This tool can be mounted in a specially provided seat just ahead of the field stop and when the telescope itself is properly aligned its circular reticle will have the same apparent optical position as the true receiver field stop. By using a ground glass reticle the virtual position of the stop and the imaged flux can both be seen even if the image completely misses the "stop". This facilitates the initial adjustment. Conversely, the fact that one can see the "stop", or more precisely reticle, even when the image is entirely inside it makes it possible to center the image in the stop, a procedure which is difficult at best when working without the telescope.

2. Alignment Tube: (See Fig. 15) The Alignment tube has as its main element a brass cylinder whose ends are carefully machined to be parallel and normal to the axis of the tube. Glass windows of similar material and thickness as the plexiglass ones used on the  $\alpha$ -meter housings are held in place by knurled brass caps. This tube is mounted on a frame which can be adjusted to hold the tube in such a position that the windows have the same position with respect to the light beam as the windows of the housings. The base of the frame has metal dowel pins that fit into the mounting holes for the baffle assembly and thus locate the tube. Seals are provided between the glass and the brass tube to retain the water. The tube should be filled with clean water when required for the alignment procedure.

3. Auxiliary Lamp and Power Supply (Dwg. 3-545-4). The Auxiliary Lamp consists of a GE No. 1493 double contact bayonet base lamp mounted in a socket secured to a brass cylinder designed to sit over the rear of the receiver telescope assembly in place of the  $\alpha$  phototube. A small plastic diffuser is interposed between the lamp and the telescope to assure that the receiver field stop is filled with light.

The power supply allows both the Auxiliary Lamp and the  $\alpha$ -meter projector lamp to be operated independently of the deck control unit for alignment purposes. The power supplied to each lamp is independently adjustable to allow for matching the brightnesses in certain steps in the alignment procedure. The voltage supplied to the  $\alpha$ -meter lamp is limited to about 5.6 volts to prevent damage to the lamp by overvolutaging it.

4. Alignment Caps. Two special brass caps have been provided to be used as aids in the various alignment procedures. Both of these are made to slip over the ends of either the projector or receiver telescopes. One of these has its flat surface painted white and has a hole in its center large enough to pass the light beam. This cap is used to determine the degree of autocollimation by noting the concentricity of the reflected image on the white surface with the central hole. The other cap has a large hole in its flat surface which contains a red filter and a matte plastic diffuser. This cap is useful for determining the axial alignment of the two optical systems by noting the concentricity of the red and white light images on the plastic diffuser. It is for tests involving this filter cap that it is necessary to balance the light in the two beams to obtain the best contrast between the two fields.

Step I(a).

This step is used to align or check the alignment of the  $\alpha$ -meter portion of the WCM using the tools provided in the "Aligning Tools" box. The projector is assumed to be in alignment for this step. Periodic checks on the alignment of the optical system are needed. This procedure (Step I(a)) should also be undertaken after major transportation of the equipment to ascertain that it is still in alignment.

1. Remove baffles and projector and receiver housings.
2. Unscrew knurled cap on side of receiver tube and insert alignment telescope, engaging the pin in the guide ring in the upper hole.
3. Screw down cap over guide ring until finger tight.
4. Turn  $\alpha$  lamp on and observe position of blurred image with respect to the circular hole in the reticle of the alignment telescope. Either the regular lamp supply or the auxiliary power supply may be used to power the lamp.
5. Fill alignment tube with distilled water and place in baffle mounting; holes with indicated end toward projector without moving alignment telescope. Again note position of image with respect to the reticle.
6. If the image is not within the circle in the reticle, in 4 or 5, loosen the lock nuts on the adjusting screws of both rings of the receiver tube mounting.
7. Adjust the screws in one ring at a time until image is centered within reticle circle and check to see if the entire light beam is entering the receiver aperture stop.

8. If the beam hits the aperture stop keep adjusting all 6 screws until alignment is achieved.
9. Remove the alignment tube completely from the baffle position and examine the air image through the alignment telescope. If the image does not alter its position so that the beam is hitting the aperture stop or is outside the reticle circle then the instrument is optically aligned.
10. Tighten up the lock nuts being careful to recheck the alignment after tightening.
11. Replace housings and baffles. Now the instrument's projector and receiver are in line and perpendicular to the housing windows providing the alignment tools are in adjustment. The  $\alpha$ -meter is now ready for use.

Step I(b): Adjustment of Aligning Telescope.

This step is used to adjust the alignment telescope so that the reticle circle corresponds in optical path length with the position of the rear stop of the receiver tube. This procedure should be undertaken when Step I(a) fails to give conclusive proof of alignment during actual operation or after transit of the "Aligning Tools" box where rough handling is suspected; or at any other instance where the alignment or adjustment of the telescope is doubted.

Housings should be removed to expose optical parts. The small auxiliary test lamp using the same type of bulb as used in the  $\alpha$  projector will be needed for the alignment, together with the auxiliary power supply. Both the auxiliary test lamp and the  $\alpha$  lamp should be connected to this power supply.

1. Mount the small lamp in its cell behind the rear stop of the receiver (first removing the phototube). The receiver now acts like a projector and the image of its field stop is formed on the aperture stop of the projector end. To examine this image place the brass filter cap with red filter over the projector tube and adjust intensities of both lamps until the white and red spots are clearly seen. The receiver image will be out of focus and larger than the projector aperture but should be concentric with it. With the filter cap in place this should appear as a small red spot concentric with a larger white one when properly aligned.
2. If it does not, then the receiver should be adjusted by means of the six adjustment screws on the receiver tube as in Step I(a) above until the spots are concentric.

3. Place alignment telescope in position in the receiver tube, first loosening the three small Allen set screws in the guide ring on the barrel of the telescope. Then turn and slide (in and out) the telescope until the image formed by the projector becomes concentric with the reticle circle. This should be done with the cap screwed down as the guide ring does not seat properly unless this is done.
4. After the image is centered, carefully unscrew the cap and tighten the set screws. Caution should be then exercised in removing the telescope and when inserting it again. Do not leave the tool lying around when not in use. Always replace it in its box when finished or not in use.

#### Step II.

This step is to be used if Step I(a) above does not produce optical alignment. Its purpose is to align the optical system by methods slightly different than those used in Step I(a). If Step I(a) does not result operationally in alignment even after utilizing Step I(b) then Step II should be used. This step assumes that both the projector and the receiver are not perpendicular to the alignment tube windows which results in a lateral shift of the image at the receiver tube aperture and field stops from air to water. If the projector is jarred or doubts as to its alignment are raised this step should be used.

1. The projector tube must be altered in position so that the light beam is perpendicular to the alignment tool windows. After ascertaining that the alignment telescope is in adjustment, alternately insert and remove the alignment tube (filled with water) checking to see that the image from the projector falls within the receiver tube aperture stop and the alignment telescope reticle circle. If not, alter position of the projector tube by means of its six adjustment screws.
2. For an aid in arriving at this adjustment Step I(b)-1 in the procedure may be used by alternately moving the brass filter cap from projector tube to receiver tube.
3. Likewise the reflected projector light from the front glass window of the alignment tube should give a concentric light blur with respect to the projector aperture stop. By placing the white painted cap over the projector end this light blur can be seen easily.
4. A field check can now be made by replacing the housings and removing the h-meter unit so that viewing access to receiver field stop can be had.

5. Insert the instrument vertically in water until both housings' windows are submerged and note the position of the image with respect to the receiver stop.
6. If the respective images in air and water are not occulted (blocked as to be non-circular) by the receiver stop, then the instrument is optically aligned and the procedures of Step I for any later adjustment should be sufficient.
7. The auxiliary power source for the lamp, a long focal length lens (8 - 10") to be used as a magnifier and a matte plastic screen will be needed for viewing of these images.

### Step III.

This step is to be used if the above condition of the field test does not yield alignment. Its purpose is to fundamentally align the optical system and the aligning tools. In Step II when the field check does not yield alignment, Step III or the final adjustment should be used. This failure indicates the actual housing windows are inclined to the beam at an angle that is not  $90^\circ$  and consequently the alignment tube windows do not correspond to the windows in the housings. This step is a fundamental one used in aligning the instrument initially and then respectively the alignment of the tools. It should only be used when all of the above steps fail to gain alignment as indicated under operating conditions, or if serious handling of the instrument has resulted in housing support displacement.

1. Remove housings.
2. Center the projector and receiver units in their mounting rings at approximately the same height above the I-beam.
3. Next bolt on the projector housing and place the auxiliary test lamp behind rear stop in the receiver tube as in Step I(b)-1.
4. Use the receiver as a projector and note the image reflected from the projector housing window surface onto the white-painted cap with center hole placed over the receiver end. (A front surface mirror that is truly parallel may be placed against the projector window as an aid.) Autocollimate (center image around hole in white cap) the beam by adjusting the receiver tube alignment.
5. Next remove the projector housing and align the projector using the alignment telescope or methods in Step I(b)1 (do not adjust the receiver at this juncture).
6. Lock the adjusting nuts on the projector.

7. Bolt the receiver housing on and check autocollimation from the projector as was previously done for the receiver, but now use the window on the receiver housing as a reflector and place the white cap on the projector end.
8. If autocollimation does not occur then a loosening of the housing support bolts to the I-beam and a tapping or shimming will be necessary to autocollimate.
9. Remove the receiver housing and line the receiver tube up with the projector using the alignment telescope or use the methods in Step I(b)-1 and Step II-2.
10. For checking use the water immersion test of Step II - 4, 5, 6.
11. The alignment tube must now be altered to conform to this change.
12. Remove both housings and place alignment tube in baffle mounting holes.
13. With the tube filled with water, loosen the adjusting screws for the alignment tube and also the screws on the tube clamps.
14. Position the tube so no change of the image position with and without the tube (water and air) occurs in the alignment telescope.
15. Secure the screws on the alignment tube.
16. Alignment can now be easily checked in the future by using Step I.

This is an optical instrument and should be handled with care.

## 6.2 Calibration of Depth Transducer

The calibration of the Bourne potentiometer depth transducer is effected by adjusting the 250 ohm "Depth Calibrate" potentiometer on the Deck Control Unit. Its range of adjustment is such that the depth transducer may be set for a full scale 10 millivolt recorder indication for any depth between 177 feet to 220 feet.

It is preferable to calibrate the WCM depth transducer against another known-accurate depth measuring instrument. The two instruments should be attached together and lowered to almost 200 foot depth and the "Depth Calibrate" potentiometer adjusted until the desired reading is obtained. If the water is calm the operator can determine the non-responsive or "dead band" region due to potentiometer hysteresis and wiper arm friction. This may be done by lowering the instrument to depth, marking the cable with respect to the sheave, and then raising the instrument slowly and noting how far the mark moves up

before the recorder pen moves. It is necessary, of course, that the underwater cable hangs plum, (i.e., no cable angle due to underwater current), if this technique is to be valid. Knowing the magnitude of this "dead band" will enable the operator to more accurately calibrate. He should set the WCM calibration at 1/2 the dead band less depth than the known depth, realizing that the underwater unit has been lowered to its calibrating depth.

If no other accurate depth measuring instrument is available, one may calibrate on a calm sea, (no cable angle) by measuring the cable paid out, for example, over a metering sheave. The above discussion for "dead band" will also apply to this procedure as a calibration correction.

### 6.3 Calibration of Logarithmic Photometer Chassis

This operation is accomplished by making full use of the versatility of the WCM and its special components.

First, remove the baffle system and attach the adaptor for  $\times$  and h calibration over the end of the baffle cup on the  $\times$  receiver housing. The Deck Control Unit and  $\times$  -lamp must be turned on and warmed up for at least 15 minutes; for the  $\times$  -lamp in its normal circuit configuration is used as the calibration light source in both  $\times$  and h calibration procedures. Set the "Function Selector" switch at  $\times$  and the " $\times$  Range Selector" switch at "short" in order to check the recorder electrical zero. This must check as zero before proceeding further.

Set " $\times$  Range Selector" switch at "1.0" and standardize recorder as outlined in Section 2.38.

Next set the "Zero Set" control to 500 and attempt to zero the recorder by adjusting the adaptor iris diaphragm. If this should not be possible, set the "Zero Set" control to 600 and again try to zero with the iris diaphragm. The "Zero Set" control should be set at even multiple of 100 if one is to avoid interpolation when using the density calibration curves.

In the following calibration procedures it is assumed that the neutral density filters provided with the WCM are used. These filters are marked with the nominal neutral density value of the gelatin alone. In all cases in the calibrations the actual values of the gelatins as mounted in glass should be used. These values are given in the body of the procedures and tabulated in the  $\times$ -Meter Calibration Table and the h-meter Calibration Table located at the end of this section.

The neutral density filters should always be placed in the adaptor with the yellow label in the upper right-hand corner and facing toward the lamp projector housing.

Insert the neutral density filter marked N.D. 0.70 and record the indication on the chart paper. This record should indicate 0.877 N.D. units when read with the density calibration curves. If the indication is within 0.01 density units of the correct value the calibration is close enough to justify a complete calibration check in 0.10 density steps. If so, insert the neutral density filters in the following order of combinations: N.D. 0.1, N.D. 0.2, N.D. 0.3, N.D. 0.5, N.D. 0.7, and N.D. 0.2 + N.D. 0.5. Other combinations can be used if further check points are desired. (See  $\alpha$  Meter Calibration Table). Now compare the complete calibration record to the density calibration curves. If all check points are within 0.01 density units the calibration is correct.

If the calibration is not correct, remove all filters from the adaptor and replace them with the N.D. 0.7 filter. Open the Deck Control Unit and adjust the " $\alpha$  Cut In" control until the recorder indicates the correct reading as determined from the "Zero Set" reading and the density calibration curves. Another complete calibration check should now confirm that correct calibration has been attained. It should be possible to repeat the original calibration, if the same phototube is used. However, if it is not or if a new phototube is calibrated, a new set of  $\alpha$ -scales will have to be made.

Calibration of the h measuring circuitry is effected by mounting the spare receiver telescope clamping ring (See Figure 12) to the h multiplier phototube assembly and then placing this assembly in the normal  $\alpha$  multiplier phototube assembly position. The transfer jumper cable for the h multiplier phototube unit is utilized to connect the h-meter high voltage and low voltage connectors to their normal mates; a small notch has been filed into the edge of the aluminum disk of the underwater electrical chassis to permit passage of the transfer jumper cable. Set the "Function Selector" switch to the h position and allow the normal 15 minute warm up. The  $\alpha$  multiplier phototube assembly is necessarily not connected for this h calibration.

Attempt to zero the recorder by adjusting the adapter iris diaphragm. This will probably not be possible and it will be necessary to insert a neutral density 1 filter and then zero.

It is advisable to check the existing h calibration before attempting recalibration. Do this by inserting into the adapter the following filters and filter combinations and record the "rule" on the chart paper. The "rule", when read with the h calibrated scale, should agree with the values listed below under "h-Meter Density Reading".

Filter Combinations	h-Meter Density Reading
N.D.	
1.0	0
1.0+0.3+0.1	0.52
1.0+0.7+0.1	1.01
2.0+0.3+0.1	1.49
3.0+0.1	2.03
3.0+0.5	2.49
3.0+0.7+0.2	2.99
4.0+0.5	3.54
4.0+0.7+0.2	4.02
5.0+0.2	4.36

If the h-meter is out of calibration, it will be necessary to re-calibrate. Open the Deck Control Unit and connect a vacuum tube voltmeter from chassis terminal board (terminal 37) to chassis ground. (Danger, high voltage.) This voltage should be -400 V DC when the recorder indicates zero (maximum measurable light flux for h-meter). Adjust the adapter iris diaphragm so as to get the -400 V DC reading; if this combination of conditions is not attainable, insert the neutral density 1.0 filter into the adapter holder and then adjust for -400 V DC. Now loosen the lock nut on the "h Bucking" control and adjust it until the recorder indicates zero; tighten lock nut.

Next turn all h "Cut-In" controls to their extreme clockwise position; this removes all cut-ins from the metering circuit.

Place the N.D. (neutral density) 0.5 and N.D. 1.0 filters in the adapter; adjust the "h Sensitivity" control until the recorder indicates a density of 0.635. Remove the N.D. 0.5 and the N.D. 1.0 filters and insert the N.D. 2.0 and the N.D. 0.10 filters in the adapter; adjust "h-Meter Cut-In 1" until the recorder indicates a density of 1.126 on the chart paper. Now remove the N.D. 2.0 and the N.D. 0.10 filters, insert the N.D. 0.5 and the N.D. 1.0 filters and check to see if the first calibration point of density 0.635 has been affected by the setting of "Cut-In 1". There is some interaction between these two controls, so it may be necessary to repeat the above several times before both points check as correct.

Next insert the N.D. 2.0, the N.D. 0.3 and the N.D. 0.10 filters in the adapter and adjust "h-Meter Effect 1" until a chart density reading of 1.496 is obtained. Now check the density 1.126 point with the proper filters, and then re-check the 1.496 point making fine adjustments until the interaction is compensated and both readings are correct.

Insert the N.D. 1.0 and the N.D. 2.0 filters and adjust "Cut-In 2" for a density reading of 2.08. Insert the filter combination N.D. 2.0 + 0.7 + 0.5. Adjust the "Effect 2" control until a recorder density reading of 2.469 is attained. Remove filters and replace with the combination N.D. 2.0 + 1.0 and check "Cut-In 2" to see if it is still 2.08. Make fine adjustments as outlined in the preceding paragraph until the correct 2.08 and 2.469 readings are attained.

Insert the combination N.D. 3.0 + 1.0 and adjust "Cut-In 3" to attain a recorder density reading of 2.97. Replace these filters with the combination N.D. 4.0 + 0.5 and adjust "Effect 3" to attain a recorder density reading of 3.545. Re-check the 2.97 density point and then again the 3.545 density point. Remove all filters and insert the combination N.D. 4.0 + 1.0 and adjust "Cut-In 4" for a recorder density reading of 4.04. Remove these filters and insert N.D. 5.0 + 0.3 and adjust "Effect 4" for a reading of 4.44. Aid in setting to this value may be had by replacing the N.D. 0.30 with the N.D. 0.70; the chart density reading should indicate 4.92. If it

does not, the 4th Effect may be adjusted slightly to the setting which gives approximately the correct 4.44 and 4.92 density readings with the appropriate filters.

If it is not possible to calibrate to the 4.92 density reading or even to the 4.44 density reading, due to the "dark noise" characteristic of the tube as evidenced by the erratic operation of the recorder pen, it may be necessary to start all over again at a lower zero, e.g., at a voltage of -390V at terminal 37. If -390 volts is not low enough, a zero of -380 should suffice. One should first determine, however, that the temperature of the h multiplier phototube assembly is not above normal, since a high temperature can cause above-normal "dark noise" and prevent calibration in the fourth log. Allowing the h multiplier phototube assembly to cool to normal temperature is the only remedy in this case.

Once the correct calibration has been attained, all of the lock nuts loosened prior to calibration must be securely tightened. It is now advisable to "run a rule" in 0.1 density unit steps in order to check the complete 5 log calibration; see "h-Meter Rule Check Table" for the required filter combinations and their correct recorder indications in density units.

A summary table, "h-Meter Calibration Table", has been included at the end of this section in order to facilitate faster calibration once the procedure is understood.

$\alpha$ -METER CALIBRATION TABLE

Filter Combinations, Nominal Neutral Density	Recorder Density Readings
0.1	0.179
0.2	0.290
0.3	0.375
0.1+0.2	0.468
0.1+0.3	0.549
0.5	0.642
0.2+0.3	0.663
0.1+0.5	0.818
0.7	0.877
0.2+0.5	0.930

## h-METER CALIBRATION TABLE

Filter Combinations, Nominal Neutral Density	Approximate Density Points	Actual Density Readings	Adjustment
1.0	0	0	h bucking
1.0+0.5	0.5 log	0.635	h sensitivity
2.0+0.1	1.0 log	1.126	cut-in 1
2.0+0.3+0.1	1.5 log	1.496	effect 1
1.0+2.0	2.0 log	2.08	cut-in 2
2.0+0.7+0.5	2.5 log	2.469	effect 2
3.0+1.0	3.0 log	2.97	cut-in 3
4.0+0.5	3.5 log	3.545	effect 3
4.0+1.0	4.0 log	4.04	cut-in 4
5.0+0.3	4.5 log	4.44	effect 4
5.0+0.7	5.0 log	4.92	effect 4

## h-METER RULE CHECK TABLE

Filter Combinations, Nominal Neutral Density	Approximate Density Points	Recorder Density Readings
1.0	0	0
0.7+0.3	0.1	0.09
1.0+0.1	0.2	0.179
1.0+0.2	0.3	0.290
1.0+0.3	0.4	0.370
1.0+0.2+0.1	0.5	0.469
1.0+0.5	0.6	0.642
1.0+0.3+0.2	0.7	0.663
1.0+0.7	0.8	0.877
1.0+0.5+0.2	0.9	0.930
2.0	1.0	0.95
2.0+0.1	1.1	1.126
2.0+0.2	1.2	1.24
2.0+0.3	1.3	1.325
1.0+0.7+0.3+0.1	1.4	1.431
2.0+0.3+0.1	1.5	1.496
2.0+0.5	1.6	1.585
2.0+0.3+0.2	1.7	1.615
2.0+0.7	1.8	1.827
2.0+0.5+0.3	1.9	1.967
2.0+1.0	2.0	2.08
2.0+0.7+0.2	2.1	2.102
2.0+0.7+0.3	2.2	2.202
2.0+1.0+0.3	2.4	2.45
2.0+0.7+0.5	2.5	2.469
2.0+1.0+0.2+0.1	2.6	2.546
2.0+1.0+0.5	2.7	2.722
3.0+0.5+0.3	2.8	2.857
2.0+1.0+0.7	2.9	2.957
3.0+1.0	3.0	2.97
3.0+1.0+0.1	3.1	3.149
3.0+1.0+0.2	3.2	3.260
3.0+1.0+0.3	3.3	3.345
4.0+0.3+0.1	3.4	3.459
4.0+0.5	3.5	3.545
3.0+1.0+0.5	3.6	3.612
4.0+0.5+0.1	3.7	3.731
4.0+0.7	3.8	3.787
4.0+0.7+0.1	3.9	3.966
4.0+1.0	4.0	4.04
5.0	4.1	4.070
5.0+0.1	4.2	4.249
5.0+0.2	4.3	4.360
4.0+0.7+0.5	4.4	4.429
5.0+0.3	4.5	4.440
5.0+0.3+0.1	4.6	4.624
5.0+0.5	4.7	4.712
4.0+1.0+0.5+0.1	4.8	4.861
4.0+1.0+0.7	4.9	4.917
5.0+0.7	5.0	4.920

## 7.0 MAINTENANCE

### 7.1 Mechanical Precautions and General Maintenance

Although this instrument has been built in a sturdy manner and is intended for field use, it is an optical instrument and should be handled with care. Because of the nature of the phenomena being investigated with this instrument rather stringent requirements are imposed upon the optical system, and the instrument should be handled with the respect due any type of precise equipment. With normal handling and care it is expected that little maintenance or adjustment will be required. If the instrument experiences extremely rough handling or receives a heavy blow, it is not unlikely that the optical assemblies may be jarred out of alignment. Whenever the instrument has been shipped, or it is suspected that it has been mistreated, it should be inspected for damage and the optical alignment should be checked. The optical alignment should also be checked periodically to ensure the proper functioning of the instrument. The procedure for checking the optical alignment and making any necessary adjustments is detailed in section 6.1 Optical Alignment of the  $\alpha$  Meter.

### 7.11 Water Seals

To ensure the water tightness of the instrument two types of seals are used. One is a packing gland type and is used where an electrical cable must pass through the wall of a watertight enclosure. The other type is a standard "O" ring seal used where provision has been made for opening a watertight enclosure such as at the windows and at the pressure transducer.

The packing glands consist of a packing gland housing silver soldered in place, a molded rubber packing, a back-up ring, and a tightening nut. The gland is assembled by sliding the nut, the back-up ring, and rubber packing over the cable. The rubber packing is square on one end and has a  $45^\circ$  taper on the other end. It should be slid onto the cable so that the tapered end will be inward toward the instrument. The cable is inserted through the close fitting hole in the bottom of the packing gland housing. The rubber packing is slid down the cable into the space around the cable inside the housing; the back-up ring is slid down to lie against the rubber packing; the nut is screwed into the internal threads of the top of the housing and tightened. Tightening the nut causes the back-up ring to drive the rubber packing against a  $45^\circ$  conical surface at the bottom of the packing housing. This wedges the packing against the cable and seals between the cable and the housing. Lubricant may be applied to the parts before they are assembled. Lubricant allows the parts to slide more freely when the nut is tightened and helps effect a seal. No lubricant should be used which may be detrimental to the rubber parts. It is recommended that Dow-Corning silicone grease DC-4 be used for this purpose.

When parts are assembled which are sealed with an "O" ring the following procedure is recommended: Remove the rubber "O" ring and wipe the mating surfaces, the "O" ring groove, and the "O" ring clean. Apply a liberal amount of Dow-Corning DC-4 grease to the "O" ring and place the "O" ring in its groove. Assemble the parts and tighten all screws securely.

Note: One exception which must be taken to the above procedure is the installation of the safety "O" ring seal which lies around the 1 inch diameter plastic "light pipe" which is located at the base of the h-sphere. No grease should be used at this point since grease on the surface of the plastic rod would affect its light retaining properties.

All "O" rings used are standard size and are commercially available.

#### "O" Rings Used in the Water Clarity Meter

<u>Nominal Size</u>	<u>Where Used</u>	<u>Total No. Req'd.</u>
6 x 5 3/4 x 1/8	h-sphere mounting plate	1
5 5/8 x 5 1/8 x 1/4	Housing seals	3
4 x 3 3/4 x 1/8	Junction box	1
2 1/4 x 2 x 1/8	h-sphere base seal	1
1 3/8 x 1 1/8 x 1/8	Housing window seal	2
1 1/4 x 1 x 1/8	Safety seal on 1 inch plastic light pipe and transducer mount seal	2
11/16 x 1/2 x 3/32	Transducer finger cot binder	1

### 7.12 Use of Desiccant and Nitrogen

Moisture present in the air sealed within the watertight enclosures of this instrument may cause the instrument to function improperly. This moisture may condense on the walls of the enclosures as they are cooled when the instrument is lowered into cold waters. Any water formed on the inside surface of the windows will interfere with the transmission of the light flux and may cause a large error in the  $\alpha$  reading. A dry environment is also desirable for the electronic components housed within the receiver base mount.

One way to prevent the formation of water condensation is to enclose some dry unused moisture absorbing desiccant within the enclosures when the instrument is sealed. An easy way to do this is to strap a small bag of desiccant to both of the tubes of the receiver and the projector assemblies between their mounting rings using black plastic electronic tape. Care should be taken to not disturb the optical alignment when this is done. Also some desiccants will produce a fine dust when handled, and this dust settling on the optics could affect the transmission of light flux.

A second way to avoid moisture within the instrument is to flush the enclosures with dry nitrogen or dry air until the moisture has been expelled and then seal the enclosure while it still contains the dry nitrogen or dry air. Flushing should continue at a slow rate for a time sufficient to purge the enclosure of all moisture laden air and also until any moisture on the surfaces evaporates and is removed by the dry gas. Four small pipe plugs are provided to allow the instrument to be flushed in this manner in the event that this procedure becomes necessary or is preferred. One plug is located in the 6 inch diameter plate at the foot of the h-sphere. There is a plug in the end of each housing near the plastic windows, and the fourth plug is located in the plate against which the projector housing mounts. Whenever these plugs are removed, they should be sealed with some waterproof compound (such as "Permatex") and securely tightened when replaced.

### 7.13 Pressure Transducer

This assembly is pictured removed from the instrument in Figure 7. Its guard can be seen protruding from the wall of the receiver mount in Figure 1. A description of this unit is presented in section 2.315.

Periodically the guard, which is the chrome-plated cap with a small hole in its end, should be removed and the unit inspected. The guard is removed by rotating it counter-clockwise with a wrench and unthreading it from the assembly. After the threads are disengaged pull the guard gently outward. The internal threads may drag on the "O" ring which holds the finger cot in position as the guard is moved outward. If this occurs, do not

forcibly pull the guard, but rotate it counter-clockwise while gently pulling it outward and unscrew it off over the "O" ring. If the guard is forcibly removed over the "O" ring, it may drag the "O" ring and finger cot off the assembly and unnecessarily require the reassembly and filling with oil of the finger cot. There may be another "O" ring between this guard and the large nut immediately below it. This is not a seal but acts only as a lock ring to prevent the guard from backing off on the threads. After the guard has been removed, inspect the unit being careful not to damage the exposed rubber cot. Make sure the hole in the guard is open and clear. Clean away any accumulation of debris and inspect the condition of the finger cot. It should be securely held by the "O" ring which binds it to the end of the brass adapter and should be full of oil. If it is in satisfactory condition, carefully replace the guard and lock tight with a wrench. If the finger cot is deflated, is full of air (a small amount of air within the finger cot is not detrimental), or has become disengaged from the end of the adapter, it will be necessary to refill the unit with oil.

Refilling the unit with oil is best accomplished by removing it from the instrument. This requires that the h-meter assembly be separated from the instrument to give access to the inside of the receiver mount enclosure. (See section 7.14 h-meter.) After the h-meter has been removed, the pressure transducer can be reached. On the face of the transducer are three terminal connections consisting of spade lugs held by small screws. The three wires leading to the transducer are color coded and the terminals are numbered. They are connected as follows: yellow lead to #2 terminal, orange lead to #3 terminal, remaining lead to #1 terminal. After these leads are disconnected, hold the body of the transducer with one hand and with a wrench loosen and remove the large nut threaded onto the adapter from the outside. This frees the transducer and it may be removed from the instrument. Unscrew the transducer from the adapter using a small wrench on the square section on the transducer nipple where it threads into the adapter. Remove the finger cot and its "O" ring and wipe all parts clean. If the finger cot is damaged, it should be replaced. Pull the finger cot over the small end of the adapter so that it lies well over the external "V" groove near this end. Place the small "O" ring over the finger cot so that it locates in the "V" groove and firmly binds the finger cot in place. The finger cot should extend approximately 1/2 to 3/4 inch beyond the end of the adapter. Position the adapter with the finger cot downward and the flanged end with the threaded hole upward. Completely fill the assembly, through the threaded hole in the center, with lightweight Dow-Corning silicone oil type DC-200. Inspect and clean the small "O" ring on the threaded nipple of the pressure transducer. Screw the transducer into the adapter and tighten, using a small wrench on the square section of the nipple. Inspect the finger cot. It should now be filled with oil and stand straight out from the end of the adapter. Inspect, clean, and grease with Dow-Corning silicone DC-4 the large "O" ring and place it on the flange of the adapter on the side away from the transducer and toward the finger cot. Wipe clean the underneath

side of the lip around the hole in the boss in which the assembly mounts. Carefully insert the assembly, from the inside, finger cot first, through the hole. Make sure the assembly is centered in the hole and that the flange on the adapter presses the "O" ring against the lip around the hole in the boss so as to make a seal. Thread the large nut onto the adapter from the outside and tighten with a wrench, holding the transducer so that the black face with the three terminals faces the h-meter end of the instrument to enable the leads to be reconnected. Inspect the finger cot and carefully screw the guard over the finger cot "O" ring and onto the adapter. Tighten in place. Secure the three lead wires to the proper terminals on the transducer.

The reasons for using silicone oil as a pressure transmitting medium are two-fold. First it is not injurious to the material used for the pressure sensing cavity in the transducer, and second, it does not apparently affect the finger cot. Any other low viscosity oil which will not cause swelling and deterioration of the finger cot will be satisfactory. Hydraulic fluid, for example, may be satisfactory. In the absence of a supply of finger cots any similar device, of course, may be used. Cutting the finger from a pair of lightweight gloves would be satisfactory, particularly if they were made of neoprene rather than natural rubber. The use of neoprene would give more freedom in the selection of fluids for filling as mineral oils will not then cause excessive swelling and deterioration of the cot.

If it is desired to operate the WCM without the pressure transducer, a brass plug has been provided which will replace the transducer assembly and provide the proper pressure seal.

#### 7.14 h-Meter Removal

To remove the h-meter unit from the instrument: first, remove the wire cage which is held to the frame by four stainless steel cap head screws; and then, remove the four cap head screws which secure the mounting flange to the receiver mount and carefully slide the assembly outward. This exposes the electronic components but does not give access to the phototube or the filter mechanism. An alternate method is to remove the six cap head screws which secure the 6-inch diameter plate to the 6-inch diameter tube and carefully slide the assembly outward, leaving the mounting flange fastened to the receiver mount. This gives access to the phototube assembly and the filter mechanism as well as the electronic components. When the h-meter unit is removed in this latter manner, care must be taken when it is reassembled not to pinch or cut the "O" ring which makes the seal between the 6-inch diameter plate and the 6-inch diameter tube. Removing the h-meter in either manner separates the connector and breaks all electrical connections to the unit.

## 7.2 Electronic Maintenance

### 7.21 Vacuum Tube Replacement

In the event of tube failure it is advantageous to know which tubes may be replaced without the necessity of multiplier phototube chassis recalibration.

6AV5 Series Tube,  $\alpha$  & h circuits: These tubes may be replaced by new 6AV5's without recalibrating. Replacement may change the absolute calibration, i.e., "shift the scale", but the linearity is not affected. It is probable that a different setting will be obtained on the "Zero Set" control in order to set recorder to zero on the  $\alpha$ -meter. This is normal, and the new "Zero Set" value must be noted and used when reducing the  $\alpha$  data.

1N1238, 5Z4, 5Y3, 5V4 Rectifiers: Any of these components may be replaced by any of the above listed rectifiers without recalibration.

6005, 6AQ5W: This tube may be replaced without recalibrating the multiplier phototube chassis. It is necessary to check the +85V from chassis terminal board connection #30 to ground and reset to the proper value if it is not in the range +85.0 to +87.0 volts.

6AU6WA: The above discussion for the 6005, 6AQ5W also applies to the 6AU6WA.

OB2WA: Replacement of this tube in most cases requires complete recalibration of the multiplier phototube chassis as described in Section 6.3, Calibration of Logarithmic Photometer Chassis. It is strongly recommended that the ruggedized military version (i.e., OB2WA) be always used as the replacement since its nominal voltage is consistently about 105 volts, while the voltage drop of the commercial OB2 varies rather widely from tube to tube. The +85 volts should be checked as described above and adjusted if necessary. If a new OB2WA is installed one should check the resulting calibration to ascertain whether or not it is correct before attempting recalibration. Although unlikely, it is possible that the resulting calibration will be correct.

Consistent use of the black (MIL-S-9372C, Type B) tube shields provided with the WCM multiplier phototube chassis is strongly recommended as a means of insuring maximum tube life. These shields provide excellent heat dissipation, and consequently result in much lower operating temperatures of the tubes.

## 7.22 Replacement of Regulating Diodes

The silicon diodes used for the  $\alpha$ -lamp regulator and for the depth potentiometer-cathode follower filament circuits, like all properly used silicon diodes, have characteristically long life. Ordinarily, failure can result only from excessive current passing through them; this condition is unlikely to occur unless the underwater cable is bypassed by an improperly designed jumper cable or the Deck Control Unit is mistakenly connected to a 230 volt power source. It is unlikely that these units should ever need to be replaced, but if this does become necessary the following procedure should be observed:

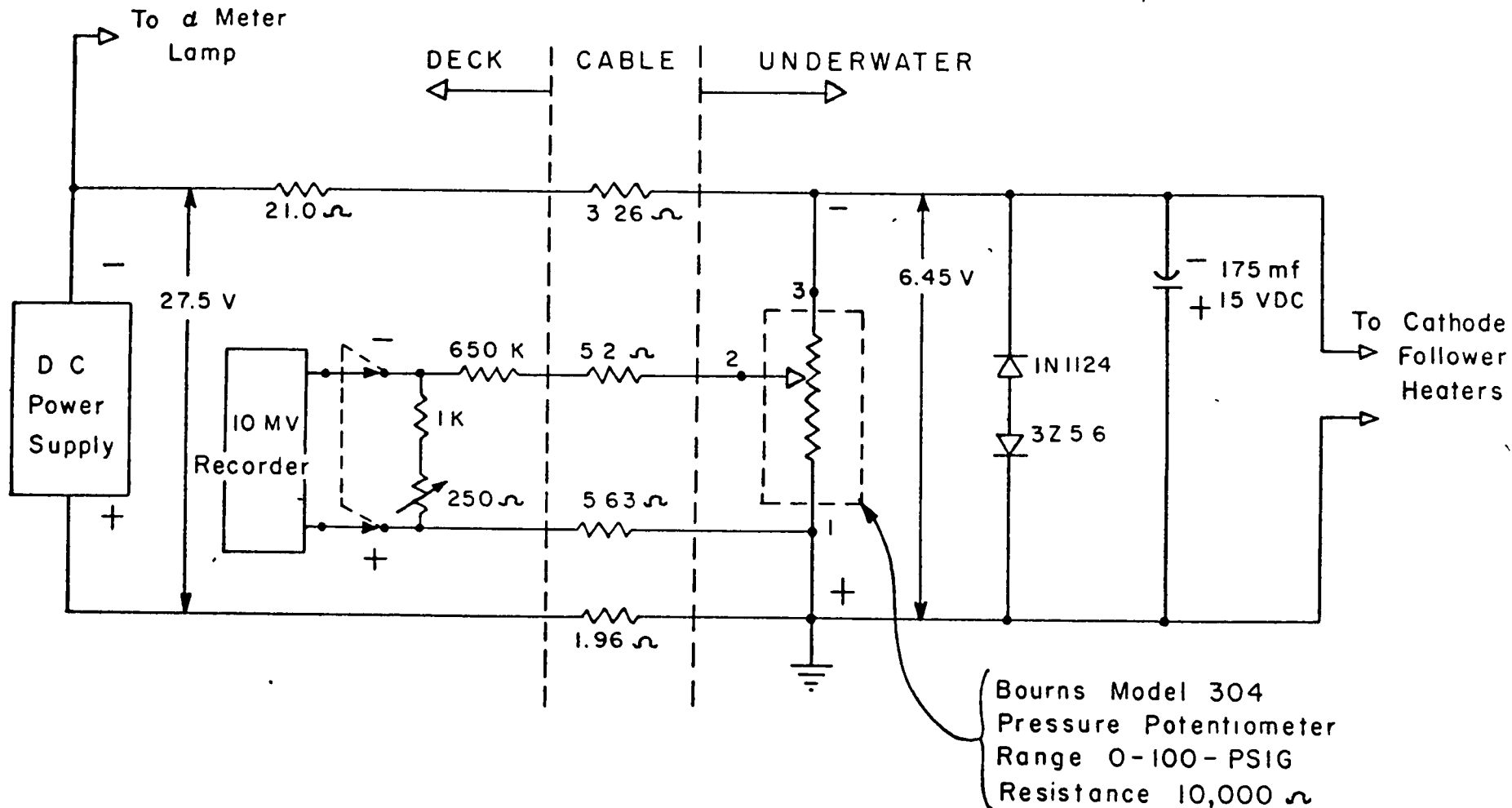
1. Disconnect the  $\alpha$  lamp and the  $\alpha$  and h phototube units until proper operation and correct voltage values are consistently obtained. These units must be protected against the possibility of filament over-voltage and consequent filament burn out.
2. Determine the source of the trouble or failure before installing the spare regulating diodes. It is preferable to replace the diodes as a pair, since the spares have been selected to operate at nearly the same voltage and current as the working diode regulators sent with the WCM.
3. Apply a film of silicone DC-200 oil (that sent for depth transducer is satisfactory) to all diode-bearing surfaces and around the mounting holes so that maximum heat transfer will be achieved.
4. Make certain that the 2 mica insulating washers and the plastic insulating sleeve are placed on the 1N1124 or the I.R.C. 3AT2 diodes; also coat these insulating parts with a thin film of silicone DC-200 oil.
5. It is advisable to solder the short bus wire between the lug terminals of the two diodes prior to their installation. Install diodes with washers provided and tighten to no more than 15 pounds.
6. Check to see if voltages are correct; if so, connect phototube units and replace the  $\alpha$  lamp.

### 7.23 Miscellaneous Maintenance

Depending on the amount of usage derived from the WCM the following miscellaneous maintenance should be performed:

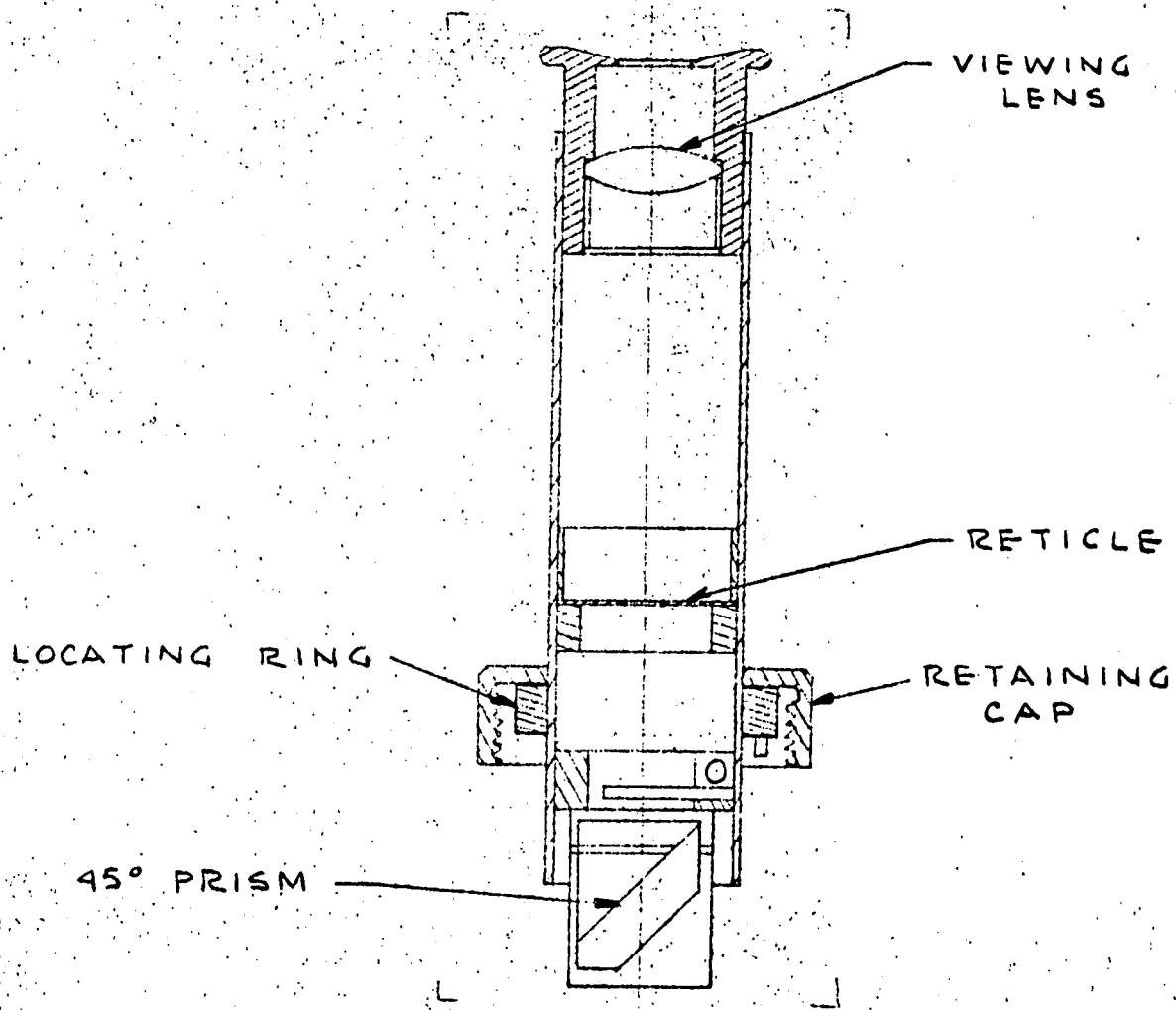
1. Oiling:
  - a. The cooling fan should be oiled approximately monthly with a light lubricating oil. A few drops in each oil hole is sufficient.
  - b. The Bodine motor which drives the function sequencing assembly should be oiled every six months with a few drops of Bodine LO-17 Oil or Standard Oil of Indiana Stanoil #35. Also oil the Microswitch actuator rollers at this time.
2. The cooling fan air filter should be inspected periodically and cleaned as needed in an evaporating type solvent.
3. The carbon brush on the Variac auto-transformer should be annually inspected and should be replaced if burned or pitted.
4. The Speedomax Type G Recorder should be occasionally serviced as outlined in its operational and maintenance manual which should be procured.
5. The main underwater cable has been heavily taped at its entrance to each packing gland in order to prevent abrasion and damage to the cable neoprene jacket. It is recommended that this taping be reinforced or renewed as needed.
6. Non-Usage: If the WCM is not to be used for an extended period it is advisable to connect and operate it for approximately an hour every three or four months. This will prevent the deterioration of the electrolytic capacitors in the  $\alpha$ -lamp and the h filter power supplies.

9 pies



PRESSURE TRANSDUCER  
SCHEMATIC DIAGRAM

Figure 13

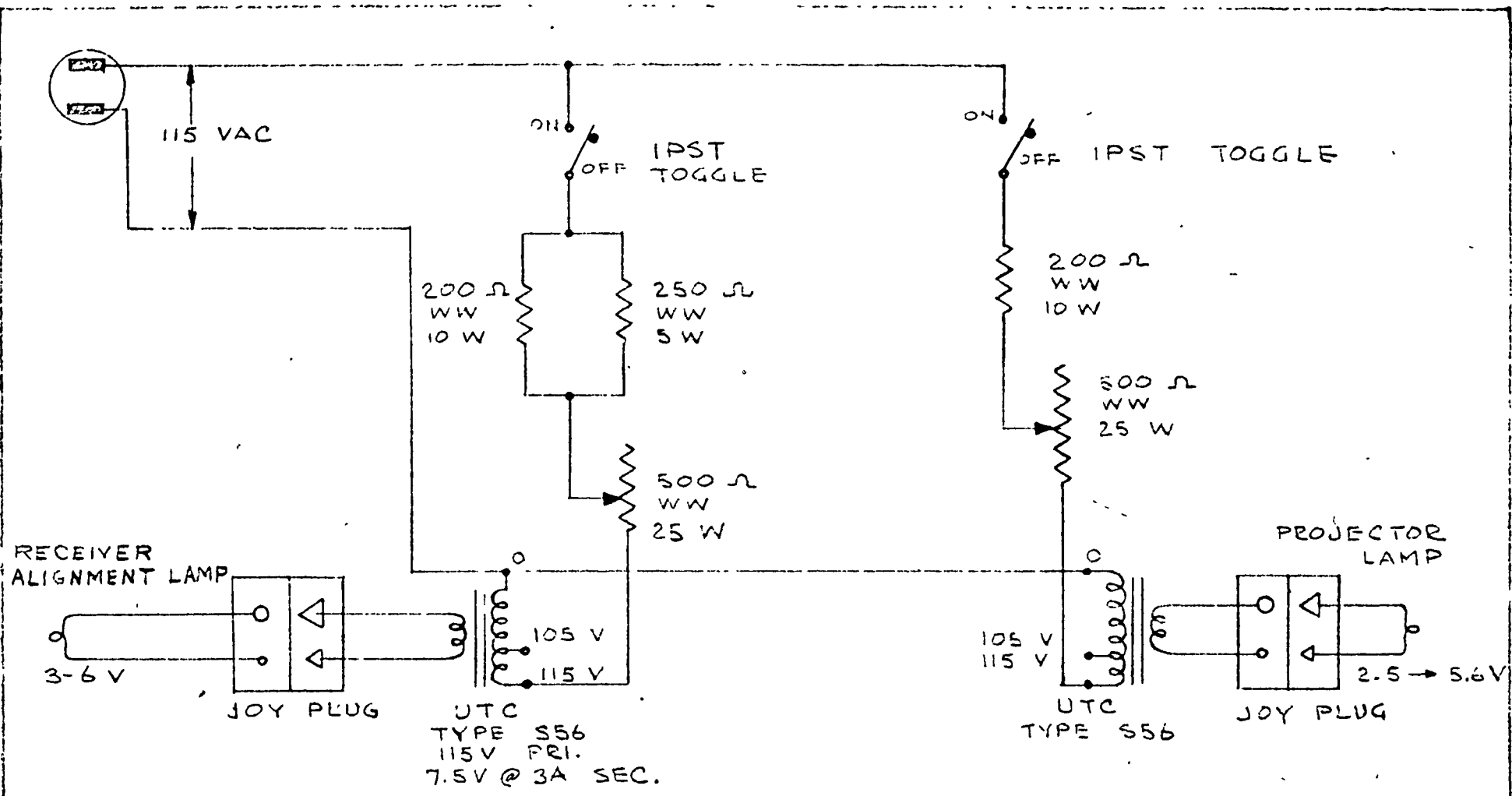


ALIGNMENT TELESCOPE

FIG. 14

topic

4 large diagrams



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MEC 1-27-59

1-27-59

WATER CLARITY METER

LAMP CONTROL CIRCUIT

FOR OPTICAL ALIGNMENT

3-545-4

5 Large  
Diagrams