NS/100 U. S. NAVAL TECHNICAL MISSION TO JAPAN
CARE OF FLEET POST OFFICE
SAN FRANCISCO, CALIFORNIA

18 January 1946

RESTRICTED

From: Chief, Naval Technical Mission to Japan.
To : Chief of Naval Operations.

Subject: Target Report - Japanese Infra-Red Devices, Article 3 - Research, Development, and Manufacture of Infra-Red Equipment.

Reference: (a)"Intelligence Targets Japan" (DNI) of 4 Sept. 1945.

1. Subject report, dealing with Target X-02 of Fascicle X-1, of reference (a), is submitted herewith.

2. The investigation of the target and the target report were accomplished by Major Wilhelm Jorgensen, AUS, assisted by Major E. B. Ricker, Corps of Engineers, AUS, and Lt.(jg) E. Snow, USNR, as interpreter and translator.

C. G. Grimes

C. G. GRIMES
Captain, USN

JAPANESE INFRA-RED DEVICES - ARTICLE 3
RESEARCH, DEVELOPMENT, AND MANUFACTURE OF INFRA-RED EQUIPMENT

"INTELLIGENCE TARGETS JAPAN" (DNI) OF 4 SEPT. 1945
FASCICLE X-1, TARGET X-02

JANUARY 1946

U.S. NAVAL TECHNICAL MISSION TO JAPAN

SUMMARY

MISCELLANEOUS TARGETS

JAPANESE INFRA-RED DEVICES - ARTICLE 3
RESEARCH, DEVELOPMENT, AND MANUFACTURE OF INFRA-RED EQUIPMENT

The Japanese, in applying infra-red radiation to military uses, placed great emphasis on communications equipment. The Japanese Navy completed installation of infra-red communications equipment on over a hundred ships, and the Army had produced and issued portable photophones. Considerable research was done on image-forming telescopes and filtered searchlights, but these had not been applied to beach illumination, individual sniping, or to vehicle driving. No system of navigational aids was completed, although experiments were conducted on several types. Phosphor detectors, similar to the U.S. Army metascope, were under development. Several projects on heat detectors and one on a heat homing bomb were undertaken, but results were not considered satisfactory for tactical use.

This investigation indicates that the part of the spectrum to which caesium-silver-oxide photocathode image tubes are sensitive cannot be counted on for secrecy and surprise, and that other sensitive materials and other parts of the spectrum must be explored in order to provide night fighting equipment.

Japan had the potential ability to produce infra-red equipment, either as countermeasures or as offensive measures, but although many projects were undertaken and several agencies pursued quite extensive development programs, the equipment developed, with the single exception of the Navy communication devices, never attained practical value for field use, and was distinctly inferior to that of the Allies or the Germans. Technical assistance from the Germans was negligible.

TABLE OF CONTENTS

The Report

LIST OF ENCLOSURES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS, Cont.

REFERENCES

Location of Targets:

The Military Establishments, Manufacturers and Research Laboratories working on Infra-Red Devices are listed in Enclosure (A).

Japanese Personnel Who Assisted in Gathering Documents and Equipment:

Lt. Col. T. TAKESHITA, Seventh Military Technical Laboratory.
Capt. K. AOKI, IJN, Second Naval Technical Institute, ZUSHI Field Laboratory.

Japanese Personnel Interviewed:

Lt. Col. T. TAKESHITA, Seventh Military Technical Institute.
Maj. Y. OGINO, Seventh Military Technical Institute.
Lt. Gen. R. SHINODA, Ninth Military Technical Institute.
Maj. Gen. S. KUSABA, Ninth Military Technical Institute.
Col. S. YAMADA, Ninth Military Technical Institute.
Maj. OTSUKI, Ninth Military Technical Institute.
Maj. M. KAGI, Yocho-Machi Branch of Army Ordnance Board.
Maj. HIZUTA, Yocho-Machi Branch of Army Ordnance Board.
Maj. SHIRAKURA, Yocho-Machi Branch of Army Ordnance Board.
Capt. K. AOKI (Navy), Second Naval Technical Institute.
Dr. S. HAMADA, Chief of the Technical Division, Tokyo Shibaura Denki K.K. TOKYO.
Mr. M. NAGASHIMA, Assistant Supervisor, Tokyo Shibaura K.K. TOKYO.
Mr. K. HAYASHI, Tube Research, Kawanishi Kikai, KOBE.
Mr. K. OWAKI, Tube Research, Kawanishi Kikai, KOBE.
Mr. M. HORI, Laboratory Director, Mitsubishi Denki K.K., AMAGASAKI.
Mr. T. ONAKA, Engineering Manager, Itami Plant, Mitsubishi Denki K.K.
Prof. T. HORII, Television Tubes, Hamamatsu Higher Technical School.
Ass't. Prof. R. NISHIDA, Television Tubes, Hamamatsu Higher Technical School.
Ass't. Prof. K. KAKAGI, Oxide Cathodes and Fluorescent Screens, Hamamatsu Higher Technical School.
Prof. N. KATO, Infra-Red Research, Kyoto Imperial University.
Assoc. Prof. Y. ATAMI, Infra-Red Research, Kyoto Imperial University.
Prof. N. KAMEYAMA, Fluorescent Screens, Tokyo Imperial University.
Ass't. Prof. S. MAKISHIMA, Fluorescent Screens, Tokyo Imperial University.
Dr. T. TAKAMINE, Limits of Vision, Tokyo Institute of Physics and Chemistry.
Prof. Y. HOSHINO, Infra-Red Filters, Tokyo College of Engineering.

INTRODUCTION

The Field of Investigation. This report is concerned with utilization of infra-red radiation for military purposes by the Japanese. It covers research, development, and manufacture of Japanese infra-red equipment, including image-forming telescopes, light-beam communications equipment, filters, phosphor receivers, heat detectors, and heat-seeking bombs.

Purpose. The purpose of the investigation covered by this report was to determine the types and quality of infra-red equipment developed by the Japanese; new methods or materials used in producing infra-red-sensitive electron tubes or heat detectors; the amount of information exchanged with German agencies; and the extent of Japanese knowledge of Allied used of infra-red equipment.

Procedure. The investigation was divided into four phases:

1. Study of reports prepared by Japanese military agencies, interrogation of military personnel, and visits to military laboratories.
2. Interrogation of research personnel in universities and other non-military laboratories, which, according to the Japanese had contributed to this development.
3. Visits to manufacturers stated by the military to be producers of component equipment.
4. Investigation of additional sources of information obtained through War Department Target Lists, or by coordinate action with other Allied intelligence agencies.

Coordination. In all phases of this investigation, liaison was established and maintained with the Air Technical Intelligence Group, Far Eastern Air Forces; the Technical Liaison and Investigation Division, Signal Office, AFPAC; and the U.S. Engineer Technical Intelligence Group. In particular, the investigations were conducted jointly with a representative of the Engineer Technical Intelligence Group, Major E. B. Ricker, Corp of Engineers. A similar report on the Japanese use of infra-red radiation will be published by the Engineer Technical Intelligence Group. NavTechJap Reports, "Japanese Infra-Red Devices, Article 1 - Control for Guided Missiles", Index No. X-02-1, and "Japanese Infra-Red Devices, Article 2 - Heat Locator Equipment", Index No. X-02-2, have been prepared on the subject of far infra-red radiation. Translations of Japanese documents and other data jointly obtained are contained in the reports of each agency.

Japanese Infra-Red Equipment and Documents. Equipment and documents being shipped to the Engineer Board and to the Naval Research Laboratory are listed in Enclosures (B) and (C).

THE REPORT

Part I
LIGHT-BEAM COMMUNICATIONS EQUIPMENT

Two types of Navy infra-red communications equipment and an Army photophone were developed and produced in Japan.

A. Navy Type II.

This equipment was developed by the Second Naval Institute in 1942, for use aboard large warships. About 100 sets were made and installed, and it was stated by operational personnel that this equipment was used as the basic means of communication under conditions of darkness and radio silence. The speed of communication was 30 Japanese code letters per minute, as compared to 50-75 letters by conventional Japanese blinker systems. The useful range was 15 km under ordinary weather conditions.

The equipment consists of three parts: A call-up receiver designed for all-round view, a filtered light source, and a narrow angle receiver mounted coaxially. One set is mounted on each side of the ship. Each call-up receiver has six caesium photocells mounted in pairs and so connected that a signal can be located within ±30° (see Figure 1). A separate amplifier is connected to each pair, and a neon glow tube on the control panel indicates the direction of the received signal (see Figure 1). The light source employs a 1000 watt tungsten lamp, mechanically modulated at 20 cycles, at the focus of a glass lens system (F number = -0.75), and is covered with a glass IR-D1 filter. It is coded by an electrically-controlled shutter and a CW key. The beam-spread is six degrees. The narrow-angle receiver consists of a caesium photocell, an F = 1.67 lens system, an amplifier, and a set of earphones. The amount of radiation received by the photocell is regulated by mechanically interposing an appropriately-sized iris in the optical system. The angle of view is 10° (see Figures 1 and 3).

In operation, the first ship to signal searches the horizon with a steady beam until a reply is received. When a signal is picked up by the call-up receiver, each operator points his own light source in the direction of the received signal and searches until the two sets are on axis. A pair of 20 power binoculars is mounted coaxially with the light source and receiver to aid in this initial search procedure, and to maintain contact. Since the equipment is not stabilized, the operator must rotate the entire equipment and tilt the receiver and light source on their trunnions to compensate for the movements of the ship.

An overland infra-red communications net was under construction between TOKYO and YOKOHAMA using Type II and Type III equipment. Units were installed on the Army and the Navy Ministry buildings, the Diet building and the TOKYO Technical College when the war ended.

All features of this equipment are standard. The equipment appears to be well-engineered, and, according to operational personnel, has proven quite satisfactory in operation. A complete set has been forwarded to the Naval Research Laboratory, Anacostia, D.C., for further study. (NavTechJap Equipment Nos. JE22-6135A to F, inclusive, and JE22-6136A to F, inclusive).

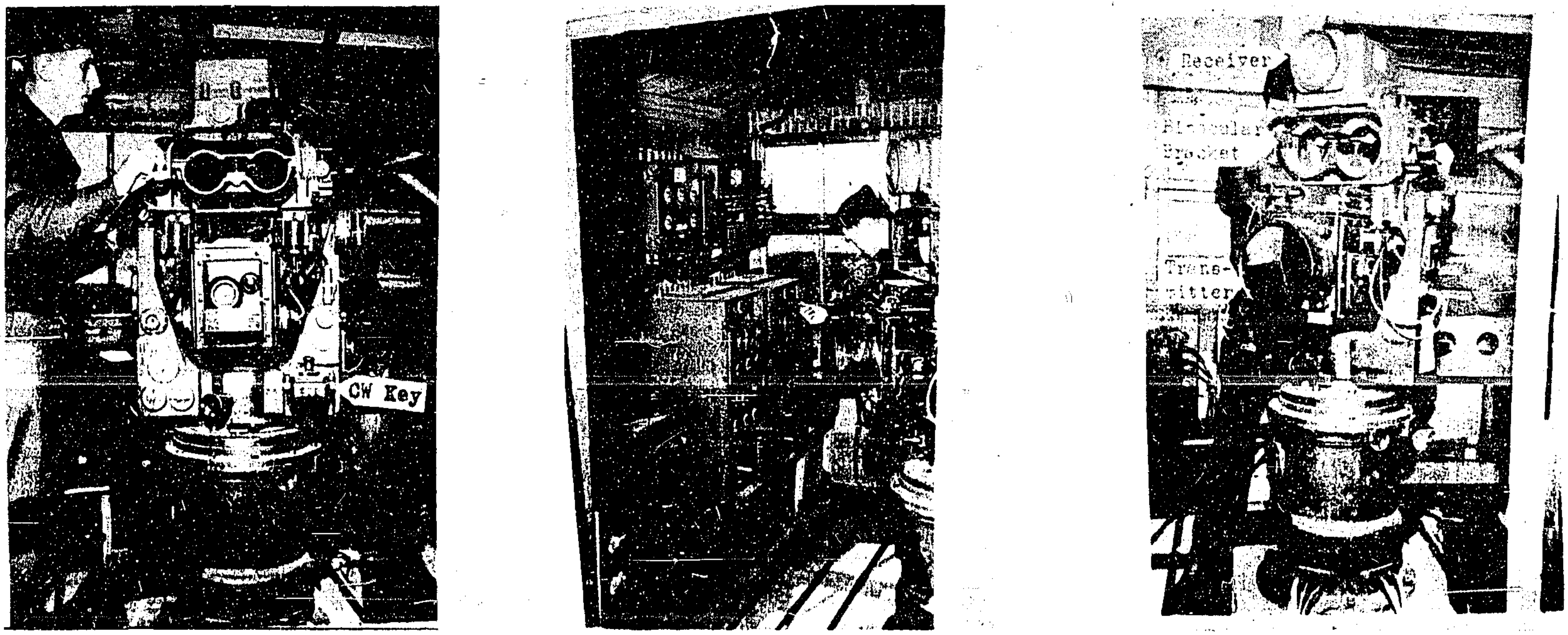
B. Navy Type III.

This type of communications equipment was developed in 1943 by the Second Naval Technical Institute, for use on small warships. About 100 sets were

a. Call Up Receiver Installed

b. Call Up Receiver Out Of Case

c. Call Up Receiver Photocells



d. Transmitter-Receiver, Rear View

e. Amplifiers and Controls

f. Transmitter-Receiver, Front View

Figure 1

NAVY TYPE II COMMUNICATIONS EQUIPMENT

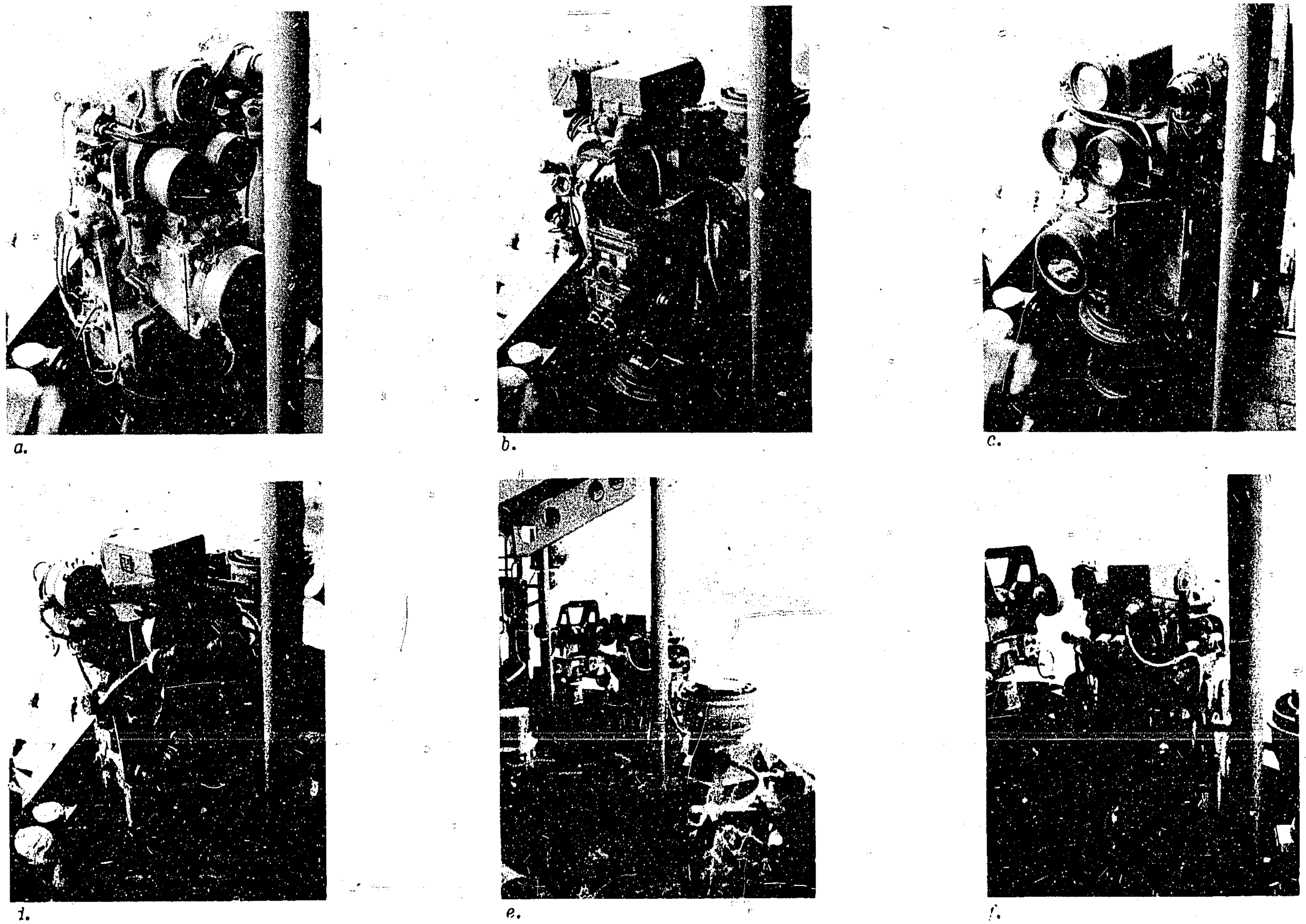
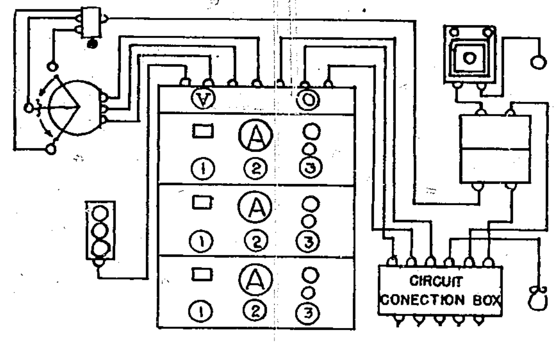


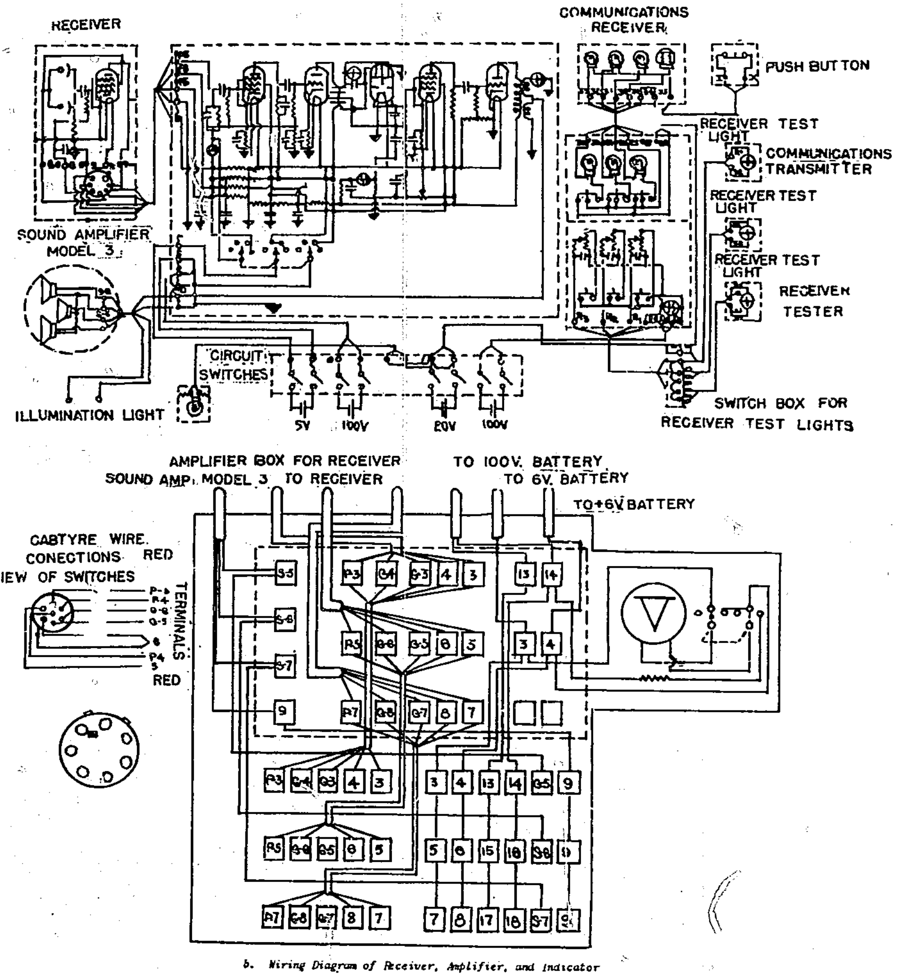
Figure 2

TYPICAL INSTALLATION OF TYPE II NAVY COMMUNICATIONS SENDER-RECEIVER ON A KATSURAGI CLASS DESTROYER

(All Around Call Receivers Located Above The Deck House)



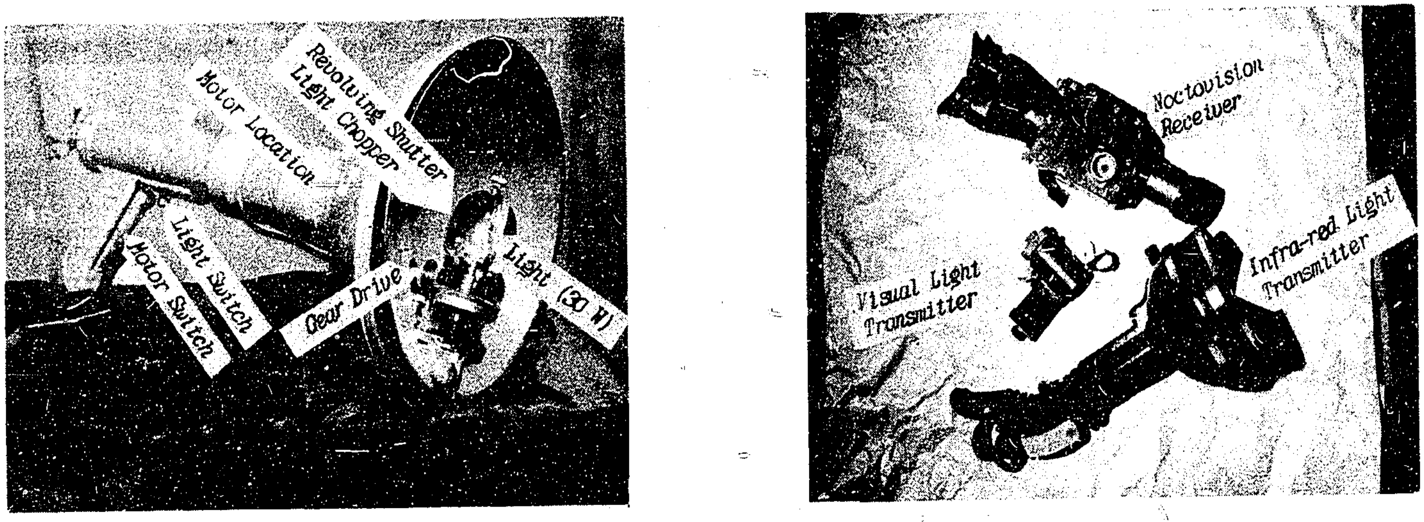
a. Operational Schematic Diagram



b. Wiring Diagram of Receiver, Amplifier, and Indicator

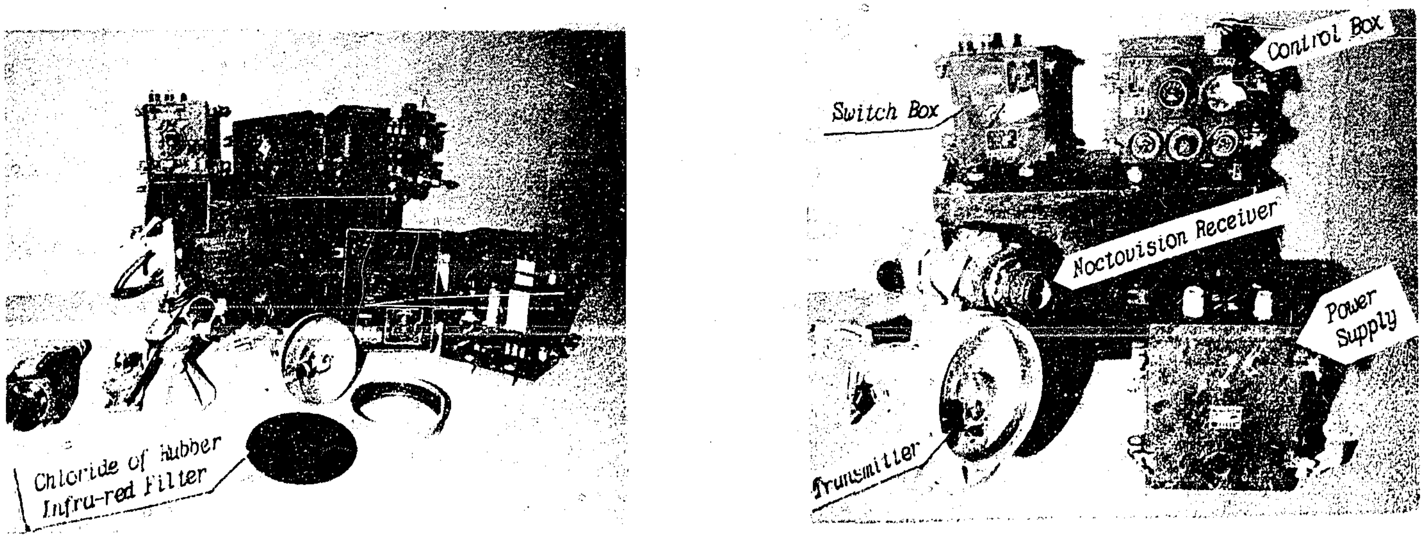
Figure 3

TYPE LL NAVY COMMUNICATIONS EQUIPMENT



a. *Transmitter Components*

b. *Transmitters and Noctovision Receiver*



c. *Equipment Disassembled*

d. *Equipment Assembled*

Figure 4

NAVY TYPE III COMMUNICATIONS EQUIPMENT

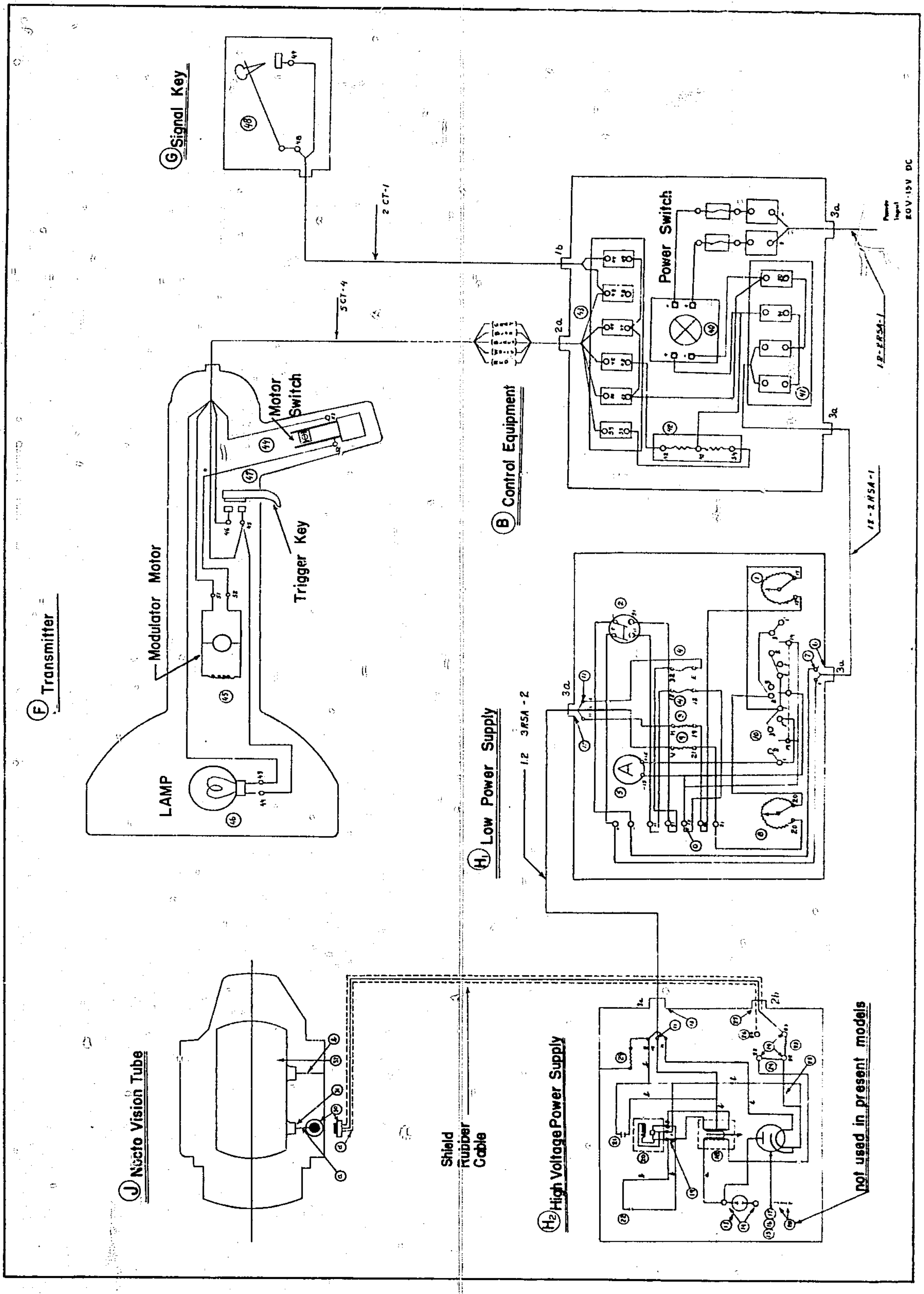


Figure 5

NAVY TYPE III COMMUNICATIONS EQUIPMENT (WIRING DIAGRAM)

Cable Type		Drug #	Circuit	Size	Exterior Diameter	Conducters	Use
Type	Model No.						
Gen. Ignition	Fujiura Cable	KA-451	a	12/0.32	7	1	High Vol.
Shielded High Voltage Cable	Fujiura Cable	KA-452	b	19/0.26	27	1	Low Vol.
Rubber Covered Cable	Showa Cable	Navy Specs.	c	1/1.2	14.1	2	Control
Shielded Rubber Cable		KA-416	d	19/0.18	10.2	1	
Rubber Covered Cable	Fujiura Cable	Navy Specs.	e	1/1.2	14.6	3	Control
Single High Voltage Cable		KA-452-1	f				

	Print No.	No.	Unit	Specs.	Remarks
F		1	Transmitter		
B		1	Switch		
G		1	Signal Key		
H_1	KA-800-K	1	L.V. Power Supply		
H_2	KA-950-K	1	H.V. Power Supply		
J	KA-100-K	1	Noctovision Unit		
O	KA-837-K	1	Term Strip.		
①	KA-838-K	1	Fil. Cur. Rheo	100Ω at 20°C.	
②	KA-818-K	1	Switch	5H Rotary type	Navy Mfgr.
③	KA-671	1	Fixed Rheo.	46Ω at 20°C.	
④	KA-549	2	Fuse	1A: 304 type 1	Navy Mfgr.
⑤	KA-520	1	D.C. Ammeter	½A.-S.A.M.-7 Model A	
⑥	KA-894-K	1	Sealing Screw	Input Side	
⑦	KA	1	Term.	Input Side	
⑧	KA-838-K	1	Variable Rheo.	42Ω at 20°C.	
⑨	KA-675-K	1	Fixed Rheo.	3.15Ω at 20°C.	
⑩	KA-815-K	1	Sel. Switch	3 pole - 4 way	
⑪	KA-979	2	Term. Strip		
⑫	KA-956	2	Sealing Screw	14.69mm Cable Dia.	
⑬	KA-523	1	Neon Tube	1.5-3.5 A.C.-D.C. #3	
⑭	KA-530-531	5 sets	Bushings	9 K.V.	
⑮	KA-527	1	Rectifier	Fel. 6.3V. Plate 5KV-Exp. 2205	
⑯		1	Rectifier Socket	UX Model-Type SU 100	
17	NE-216	1	Cap Grid		

	Print No.	No.	Unit	Specs.	Remarks
⑱	KA-990	1	H.V. Transformer	According to Specs.	Mikami Mfg. Co.
⑲		1	Vibrator Socket	Model UZ & SO 100.	
⑳	KA-525	2	Vibrator	12.5V. imput-Air 11 Model	Hikari Electronic Co.
㉑	KA-669	1	Condensor	1000 Mf. 25V. DC HK-2	Navy MFG.
22	KA-534	1	Paper Condensor	4 Mf. 1000V. DC PC-560	
㉓	KA-995	1	Mica Condensor	0.1 MF. 5KV MC 137	
㉔	KA-995	1	Fixed Res.	3MΩC-5	Nihon Comm Co.
㉕	KA-996	1	Fixed Res.	10MΩC-5	
㉖	KA-979	1	Ground Term.		
㉗	KA-961-K	1	Sealing Screw		
㉘	KA-999	2	Mica Condenser	50mmf. 7KV. Mark 2 Model B	
29	KA-997	1	Fixed Res	1 K Ω C-2	Nihon Comm Co.
30	KA-400ᴬ-K	1	Plug	5KV	
31		1	Clip		
32	KA-120ᴬ	1	Noct Vision Tube	#201	
40			Power Supply	5A Rotary type	Navy Mfg.
41			Term Strip		
42			Res.	3Ω for light source 6W for motor.	6W is varied for motor
43			Term Strip		
44			Motor Switch		
45			Modulator Motor		
46			Lamp	12V. 30W.	
47			Signal Trigger		
48			Signal Key		

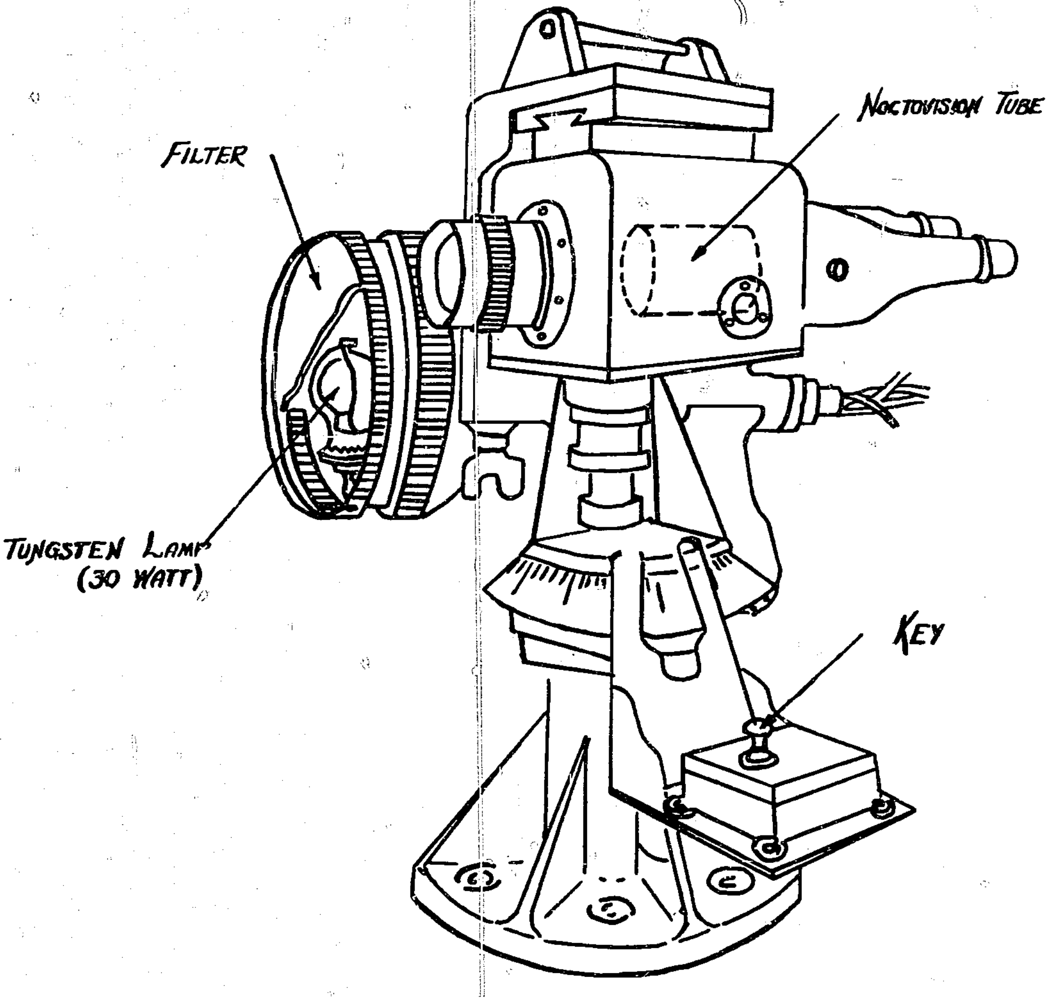


Figure 6
NAVY COMMUNICATION EQUIPMENT TYPE V

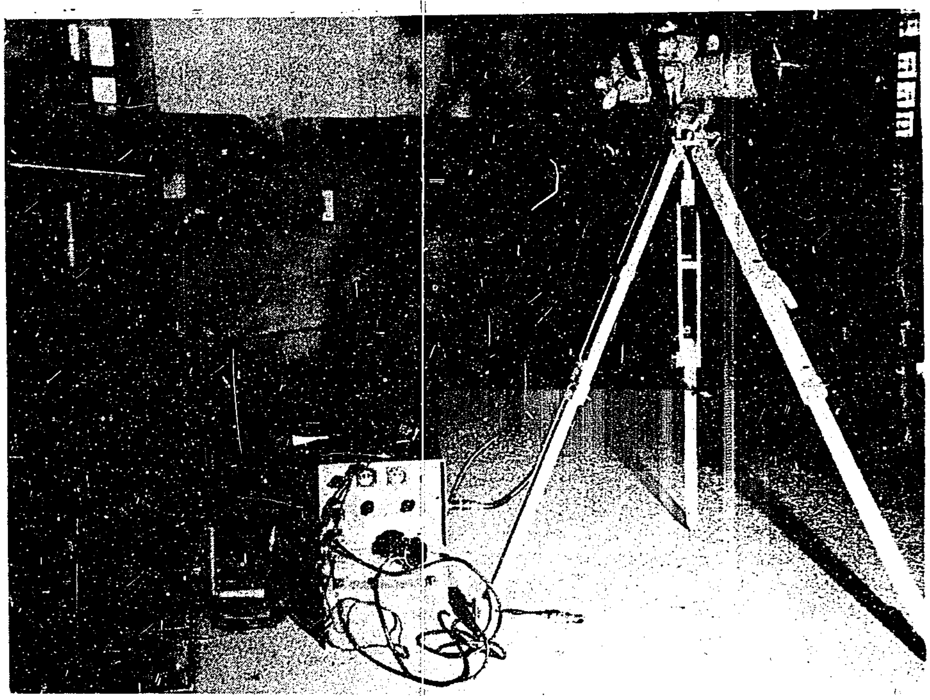


Figure 7
ARMY TYPE II PHOTOPHONE, ASSEMBLED

made, but only 60 were installed on ships. The effective range was stated to by 5 km, which was considered unsatisfactory. Operational personnel were also dissatisfied by the need of a constant watch, since no call-up system was provided.

This equipment is simpler than the Type II, both in construction and operation (see Figure 4). The transmitter consists of a 30 watt tungsten lamp, filtered by a polyvinyl alcohol sheet, and in appearance resembles the pistol-type signal lamp used by the U.S. Army, except that it is operated on alternating current. A revolving shutter, interposed between the lamp and the reflector, is rotated by a small electric motor so as to modulate the light at 20 cycles, and the signal is coded by a CW key on the base of the mount. For communication between Type III units, an unmodulated signal is used.

The receiver consists of a noctovision image tube together with a simple refractive lens system and inverter-transformer power supply (see Figure 5). The transmitter and receiver can be mounted coaxially on a mount allowing movement in a horizontal plane only, or can be hand-held.

The only part of this equipment which is of intelligence interest is the image tube. Complete sets have been sent to NRL and the Engineer Board (NavTechJap Equipment Nos. JE50-5834, JE50-5835, JE50-5840, JE22-6136 and JE21-6333).

C. Navy Type V.

This equipment was a modification of the Type II, the only difference being a larger optical system. It was intended for use in communication between land bases, and was said to have a range of 30 km. Two experimental sets were produced, neither of which was available at the time of this investigation (see Figure 6). A large noctovision image tube and infra-red filters were shipped to the Naval Research Laboratory (NavTechJap Equipment No. JE21-6333).

D. Army Photophone.

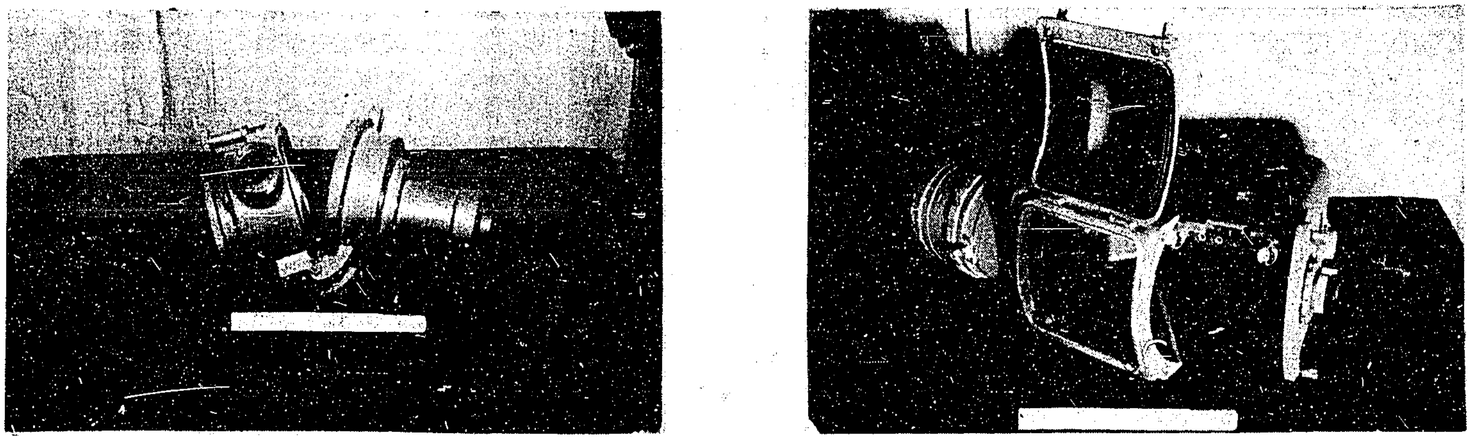
A portable photophone was developed before the war by the Seventh Military Laboratory. One model (No. 2) was put into production in 1937 with an order for 2000 units, but only a few hundred were delivered, since those issued to troops in Manchuria were not satisfactory and were rejected by the field commanders (see Figure 7). An edited report on this development, prepared by an officer of the Seventh Laboratory, is included as Enclosure (D). Photophones have been shipped to NRL and to the Signal Corps Laboratories, Ft. Monmouth, N.J. (NavTechJap Equipment Nos. JE50-5801 to JE50-5812 inclusive). Direct modulation of H_2-filled and neon-filled tubes was also studied. No equipment remained but some neon-filled and other odd tubes were obtained and shipped to the Naval Research Laboratories (NavTechJap Equipment No. JE50-5838).

Part II
INFRA-RED ILLUMINATING AND VIEWING EQUIPMENT

Projects for near infra-red illuminating and viewing equipment were carried on by the Japanese Naval, Air Force, and Army Laboratories.

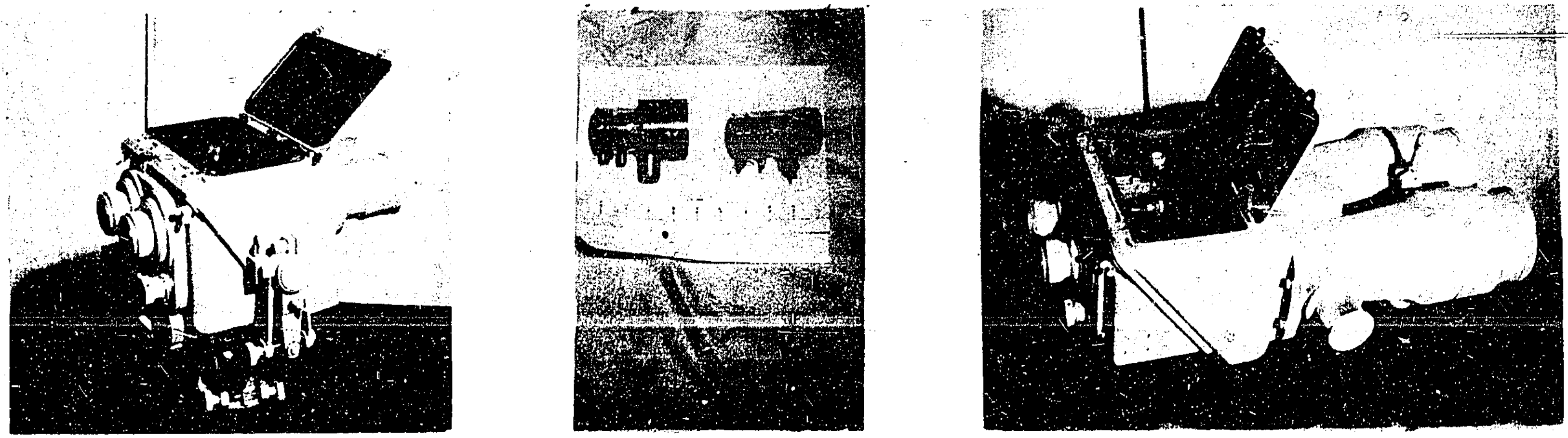
A. Army Light Sources.

The Seventh Military Laboratory investigated both tungsten lamps and carbon arcs for use as sources of infra-red radiation. A study of the spectral distribution of the radiation from various searchlight carbons showed that the standard carbon with a selenium fluoride core was the most satisfactory. Both glass and sheet filters were used (see Part VIII). Figure 9-a shows a typical light source, from the Seventh Military Laboratory. Sample light and tubes were shipped to NRL (NavTechJap Equipment No. JE50-5833 and JE50-5838).



a. Monocular (5cm)

b. Monocular (10cm Detachable Lens)



c. Binocular (5cm)

d. Image Tubes

e. Binocular (15cm)

Figure 8
ARMY NOCTOVISION TELESCOPES AND TUBES

B. Army Infra-Red Image Tube Telescopes.

Both refractive and reflecting optical systems were used with the noctivision tubes.

Several types of refracting telescopes were built by the Seventh Military Laboratory. All are of simple optical design, with a two-element objective and exterior focusing arrangement which is not hermetically sealed. The image tubes were inserted through a removable panel and held in an adjustable cradle, allowing transverse and longitudinal adjustment and orientation (see Part VIII for a description of image tubes). Although the metal parts of the telescope are of aluminum, the design is bulky and the weight excessive. The power supplies used are of a standard inverter-transformer type.

The quantities, types, and dates of manufacture of the different telescopes, samples of each of which were shipped to NRL and the Engineer Board, (NavTech-Jap Equipment Nos. JE50-5827 to JE50-5830 inclusive) are given below: (See Figure 8).

Type	Focal Length	No. Made	Date of Development
Binocular	15cm	3	1941 - 1944
Binocular	5cm	2	1942 - 1944
Binocular	10cm	2	1942 - 1945
Monocular	Interchangeable Lens	2	1940 - 1943
Monocular	10cm	2	1942 - 1944

The ranges obtained with a typical set of equipment (150 on searchlight, 15cm focal length binocular) were said to be:

800 meters	Recognize existence of single man.
1000 meters	Recognize existence of ship at sea.
1500 meters	Distinguish features of landscape.

The range estimates as given are considered to be optimistic. For instance, upon close questioning, it was stated that distinction of Japanese from American soldiers could probably not be made at more than 300 meters; this and all other ranges were hedged by qualifying statements.

C. Navy Infra-Red Image Tube Telescopes.

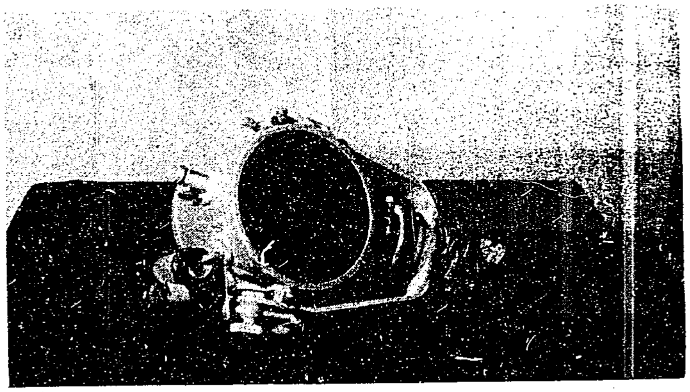
The Second Naval Technical Institute had developed some oversize image tubes and Schmidt lens systems for viewing targets, but none of these were successful. The equipment was laboratory bench equipment only and never reached a complete unit design.

D. Airplane Mounted Equipment.

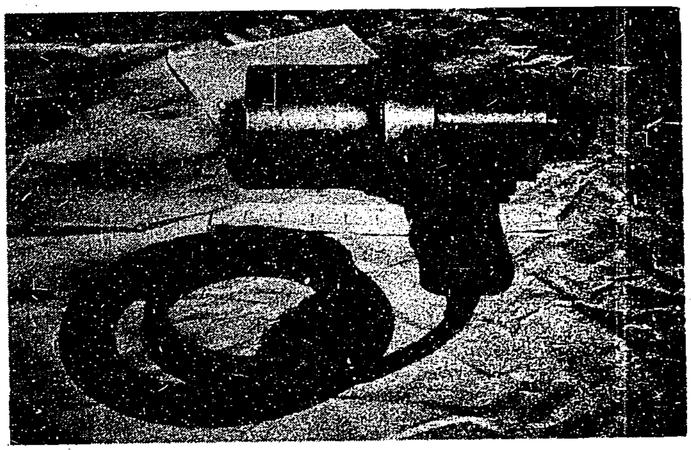
The Fourth Air Research Laboratory experimented with an image tube telescope and filtered light source to be mounted in an airplane for night attacks on enemy bombers. It was never test flown, although ground tests showed ranges of 2 km on large ships and 0.5 km on airplanes. Various experimental image tubes (see Part VIII) and relatively large light sources (300mm diameter, 1500 watts, 2,800,000 beam cp) were used. Several power supplies were tested, and the selenium-cell type rectifier was preferred. None of this equipment was available for inspection, as the laboratory was destroyed by bombing.

Part III
INFRA-RED IFF

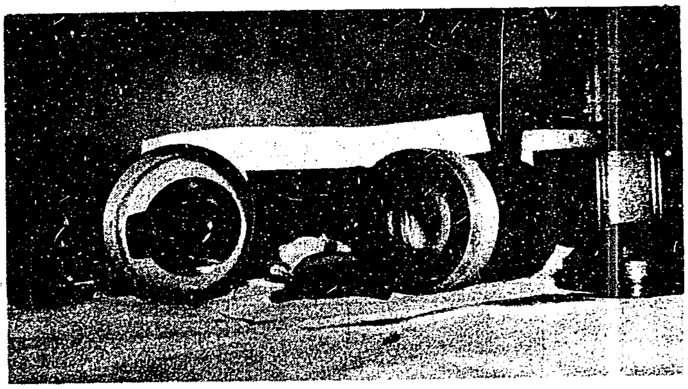
As an alternative to radio frequency IFF (Information Friend or Foe), the Second Naval Technical Institute developed a hand-held image tube telescope



a. Typical Army Light Source (Mirror and Filter)



b. Navy Infra-red IFF Receiver



c. Navy Infra-red IFF Receiver, Disassembled

Figure 9
NAVY INFRA-RED IFF RECEIVER AND TYPICAL ARMY LIGHT SOURCE

for use in conjunction with an all-round beacon for identification of friendly ships and planes (see Figure 9-b). A Schmidt optical system was employed in the receiver, with a sharply curved concave-convex first element (see Figure 9-c). The useful range was 5 km for plane beacons and 10 km for ship beacons. Several samples of the receiver and power supply have been shipped to NRL and to the Engineer Board, (NavTechJap Equipment No. JE21-6333).

Part IV
NAVIGATIONAL AIDS

A. Photophone.

A modification of the Army photophone was designed for use in voice control of small boats in river crossings (see Enclosure (D)).

B. Telescope and Beacon.

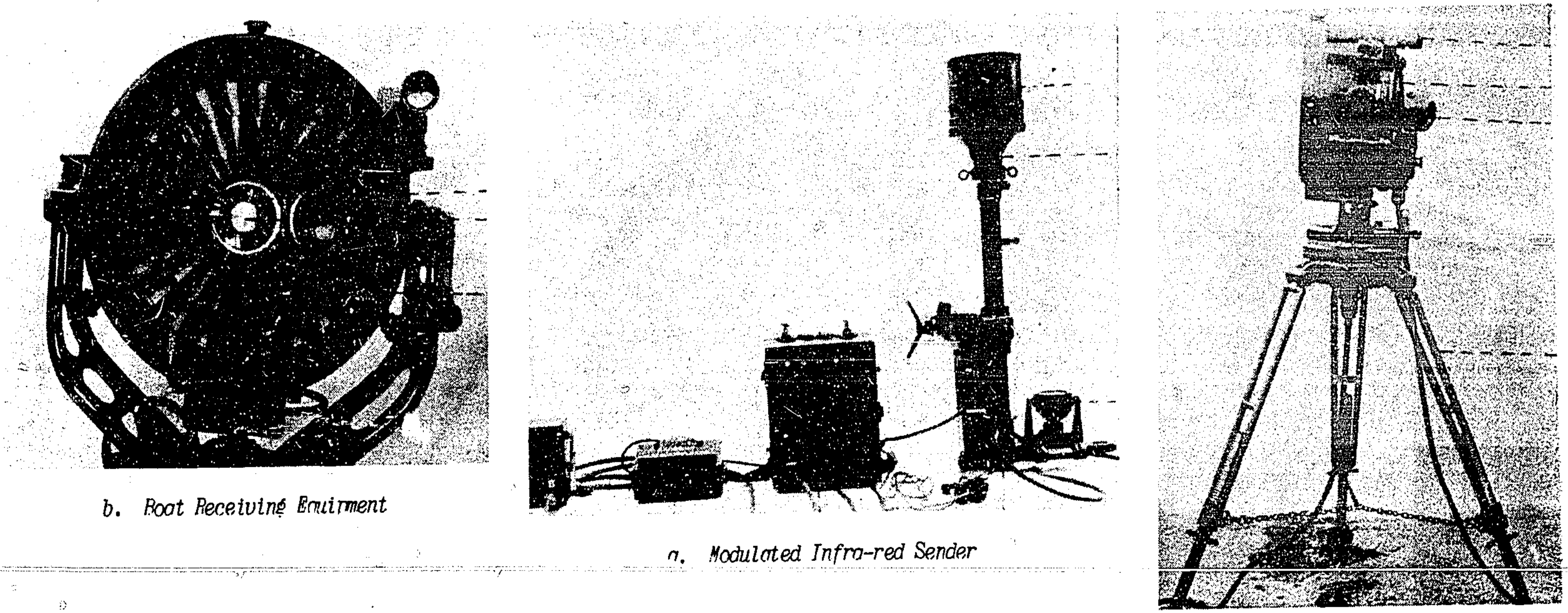
A small sized receiver was under development by the Navy as a means of guiding small boats. Only two units were built; these were the most compact models encountered in Japan, but did not represent any new ideas and were not waterproof.

C. Direction Finder.

The Fifth Military Laboratory developed a unique means of keeping small boats on course during river crossings. This equipment consisted of a modulated light source for use at the shore station and a caesium photocell receiver on the boat (see Figure 10). A small, visible red tail-light on the receiver was followed through a telescope attached to the light source, to enable the transmitter operator to keep pointed toward the boat. As the light source was swung off course to the left or right, the beam was interrupted in an appropriately coded signal. The operator in the boat detected this signal through earphones and by indicator lamps, and corrected his course accordingly. The range of this equipment was 3 km, with a guiding accuracy of ±1.30. Only one unit was built. Since it was found satisfactory, no further work was done. A translation of the final Japanese report on this development is included as Enclosure (E). This report is interesting in that it outlines a four year development program which involves only minor improvement in the original idea, and the successful completion of a device for which there was no military requirement.

Part V
PHOSPHOR DETECTORS

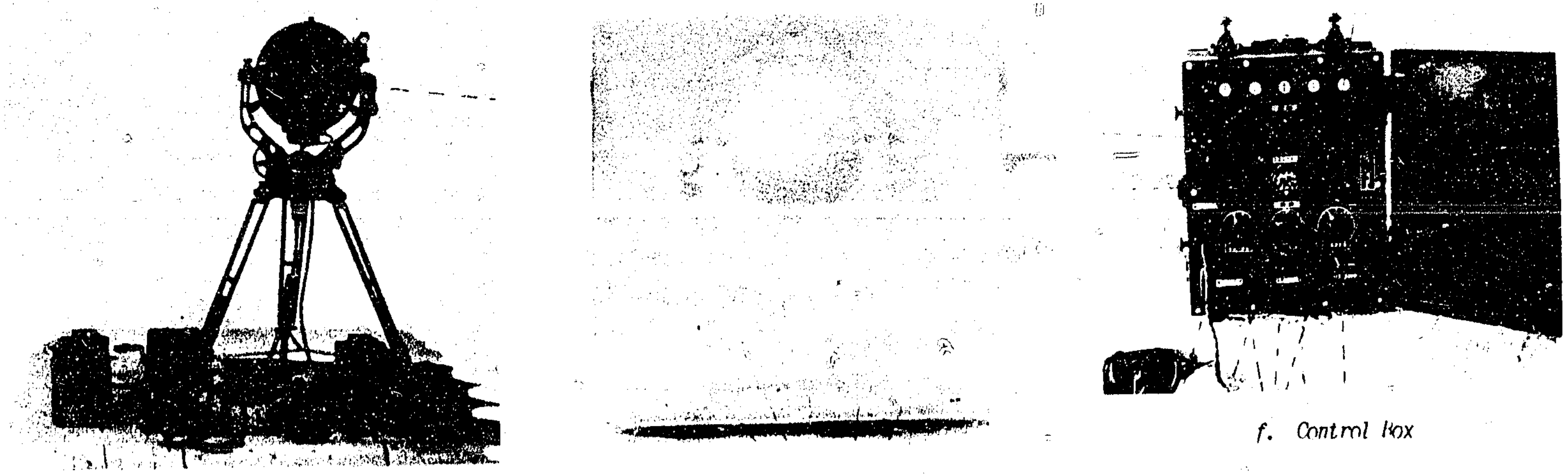
Infra-red-sensitive phosphors were independently investigated by Prof. N. KAMEYAMA, of Tokyo Imperial University, beginning about 16 years ago. This development was classified "secret" by the Army, and there was no evidence that KAMEYAMA exchanged information with German or American scientists. He developed both "Ausleuchtung" phosphors in which the phosphorescence was accelerated by infra-red radiation, and "Teilgung" phosphors, in which the phosphorescence was extinguished by infra-red radiation. For Army uses it was planned to place a phosphor screen at the focus of an objective lens system similar to the American Metascope. Some instruments of this type were sent to Rabaul, New Britain, in 1943 to investigate possible American use of infra-red searchlights. The ship carrying these was sunk, and the investigation was not carried further. At a demonstration in Prof. KAMEYAMA's Laboratory during the present investigation, it was found that the available phosphors had deteriorated and the infra-red sensitivity was poor. A paper prepared by Dr. KAMEYAMA describing their preparation and characteristics is included as Enclosure (F). Samples of the phosphors listed therein are being shipped to the Engineer Board.



b. Boat Receiving Equipment

a. Modulated Infra-red Sender

c. Sender, Side View



d. Sending Equipment, Assembled

e. Indicator Box

f. Control Box

Figure 10
INFRA-RED DIRECTION FINDER

Part VI
HEAT DETECTORS

Four types of heat detectors were developed by the Japanese. A complete report on heat detectors is given in NavTechJap Report "Japanese Infra-Red Devices, Article 2 - Heat Locator Equipment," Index No. X-02-2, but a brief summary will be repeated here.

A. Navy Airborne Type.

The Second Naval Laboratory was working on an airborne heat detector for use against enemy ships and planes.

The sensitive element was a tellurium-constantan thermopile, (see Part VIII), placed at the focus of a 28cm mirror which was spirally rotated for scanning. The speed of scan was 10^o/sec through an angle of 200^o. The vertical angle of elevation and depression was 40^o. A rock salt window covered the thermopile, and a chloride of rubber sheet 0.03mm thick was held over the opening of the optical system by a light steel grid (see Part VIII). The amplifier used was a modification of that used in the magnetic submarine detector, with an output of 675 cycles/sec and a sensitivity of 5×10^{-7}v. Signal presentation was by meter indication. The range of the first experimental models was 7 to 10 km on a clear night; the improved models described above had not been completed. A set of parts has been shipped both to NRL and the Engineer Board.

B. Army Airborne Type.

The Fourth Military Laboratory had been working since 1940 on an airborne heat detector to be used in fighter-bombers. The sensitive element used was a constantan-iron thermopile at the focus of a 300mm diameter, 400mm focal length paraboloidal mirror. The angle of view was one degree horizontal and 13^o to 20^o vertical. The rate of scan was about 10^o/sec, with an amplification of 120 decibels.

The range of this equipment, in ground tests, was 5 km (10 km max) on ships of 3000-6000 tons. No detailed heat surveys were conducted, but it was generally agreed that ship signals were given off by the stack. The maximum sensitivity (measured in the laboratory on a precision galvanometer) was 2.5×10^{-4}°C.

All the equipment and records were destroyed in air raids.

C. Army Ship Detector.

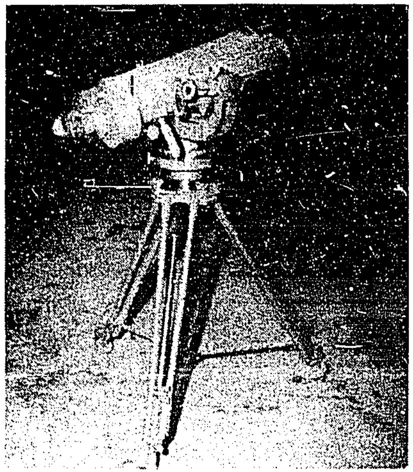
The Seventh Military Laboratory had done some work on a heat detector for use against ships, using constantan-iron or constantan-manganin thermopiles, or nickel bolometers. It was tested against ships and found to have a range of 4 km under good conditions.

D. Army Personnel Detector.

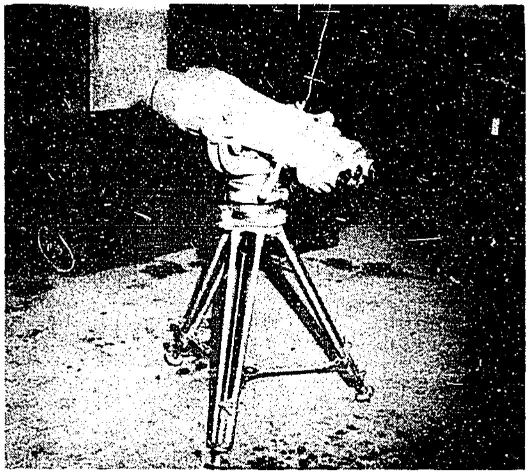
The Second Military Laboratory experimented with the same type of heat detector as the Seventh Laboratory for use in detecting personnel. Ranges up to a hundred meters were obtained on a single man. No equipment was available, but a similar unit was obtained at the Yocho-Machi Laboratory and has been shipped to NRL.

E. Special Optical Equipment.

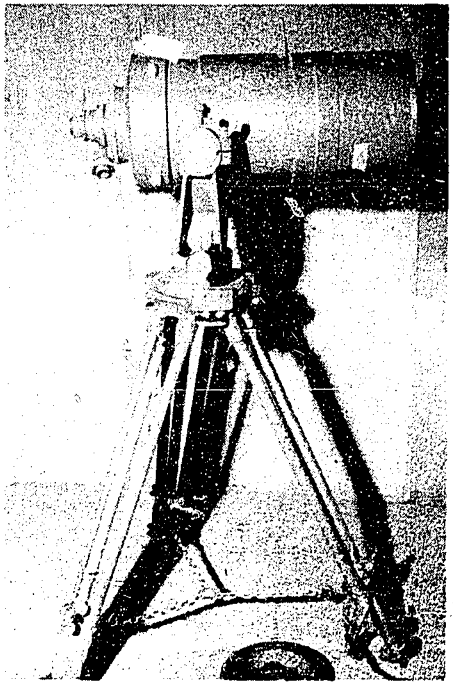
The Seventh Military Laboratory ran some comparison experiments between transmission and reflecting type telescopes. They were performed rather qualitatively with very little difference obtained between instruments of equal aperture. The scopes, Figure 11-c, d and e, were shipped to NRL, (NavTechJap



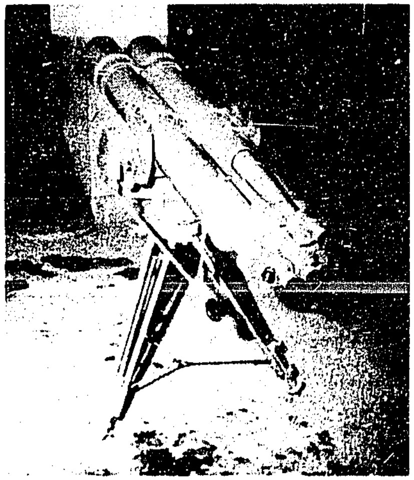
a. Binocular, 25 Power



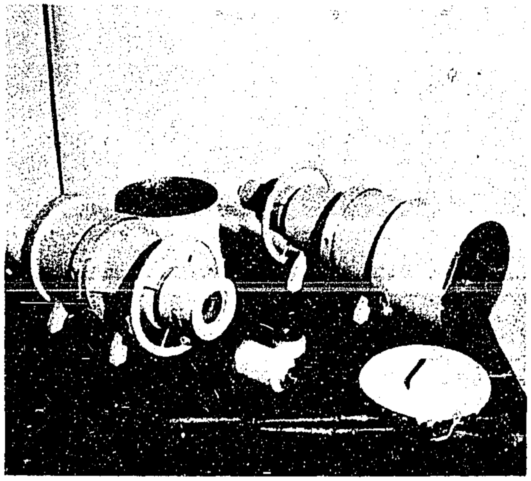
b. Binocular, 25-50 Power



e. Schmidt Type Reflecting Telescope. (To Be Used for Infra-red Noctovision Experiments)



c. Binocular, 50-100 Power



d. Objective Lenses, F 2.3

Figure 11
ARMY INFRA-RED TELESCOPES AND BINOCULARS

Equipment Nos. JE50-5826, 5813, 5814, 5815, and 5832).

The Ninth Military Technical Laboratory also experimented with land infra-red photography using some very large aperture Schmidt and glass lens type cameras. Samples of the equipment were shipped to NRL (NavTechJap Equipment Nos. JE50-5821 to JE50-5826 inclusive). The tests appeared to be purely terrain photography without reference to selective camouflage properties.

Part VII
HEAT HOMING BOMB

This equipment is described in full in NavTechJap Report "Japanese Infra-Red Devices, Article 1 - Control for Guided Missiles", Index No. X-02-1. Data concerning the heat sensing unit are contained in Enclosure (G) of this report. Two heat sensing heads have been shipped to NRL.

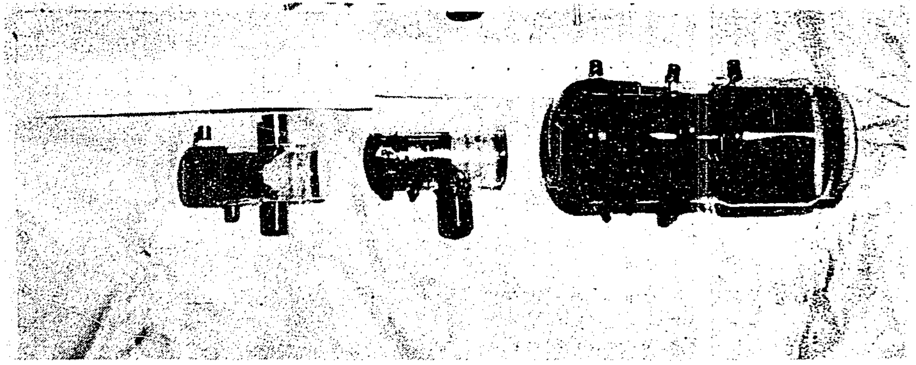
Part VIII
COMPONENTS OF JAPANESE INFRA-RED EQUIPMENT

A. Electron Image Tubes.

The Japanese have done considerable research on the improvement of image tubes, or noctovision tubes, as they were called. Starting with copies of the original Zworykin tubes, they studied the physical-chemical properties of the caesium-silver-oxide photocathode, methods of sensitization, electron optics, and other features in attempts to reduce the physical size and increase the spectral sensitivity. They succeeded to a large extent, developing tubes comparable to American, British, and German tubes in size and sensitivity. However, they were not able to produce them except in laboratories, under rigid procedures, and by highly skilled personnel. The greatest number produced in one month was 30 tubes, at Hamamatsu Higher Technical School.

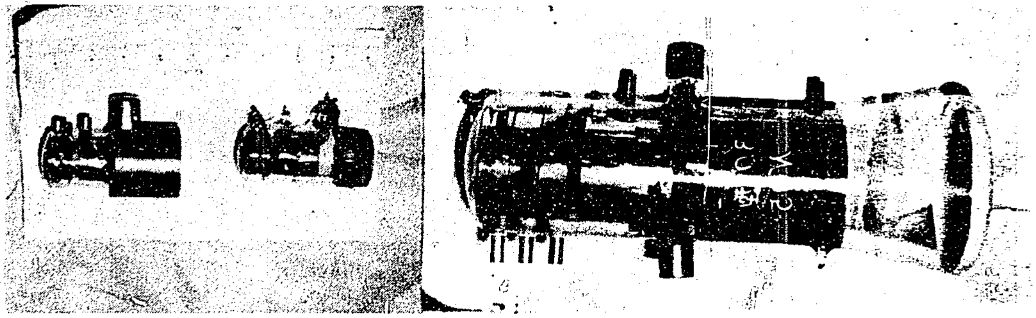
Many experimental types and sizes of tubes were produced which are not of technical interest. Two organizations produced most of the tubes: Tokyo Shibaura Electric Company for the Navy and Air Forces (see Figure 12-a); and Hamamatsu Higher Technical School for the Army (see Figure 12-b). These tubes are similar in size and design, and show signs of collaboration in their development. Characteristics of the two types are given in the following tabulation:

Characteristic	Navy	Army
Length	107mm	105mm
Diameter	42mm	42mm
Cathode Diameter	30mm	30mm
Anode Material	Glass, coated with liquid platinum	Glass, coated with liquid gold
Number of Anodes	1	3
Anode Voltage	4,000 v	4,000, 200, 100 v
Focus	None	100 v anode
Screen	Willamite	Zn_2SiO_4 Mn
Magnification	1:1	1:1.2
Luminous Output		
White light, 2700°K	20 microamps/L	45 microamps/L
w/3mm IR-D1 filter		
minimum		3 microamps/L
average	4 microamps/L	
maximum		6.6 microamps/L
Resolution		
minimum		17 lines/mm
average	17 lines/mm	
maximum		25 lines/mm
Breakdown Voltage	7,000 v	6,000 v



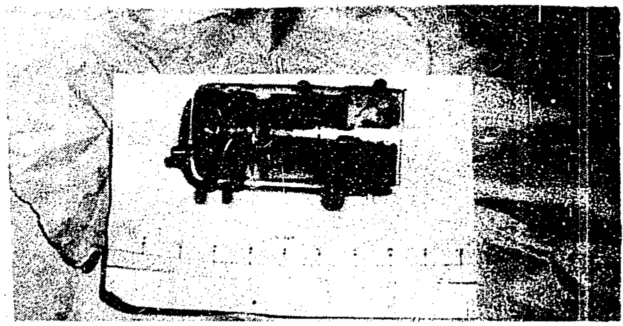
a. Navy Type Image Tubes

(1) Production Model
(2) Experimental Model with 3 Anodes
(3) Schmidt System Model with 3 Anodes



b. Army Type Image Tubes

(1) Early Experimental Model
(2) Production Model
(3) Brass and Ceramic Ring Mounting



c. Anode and Sensitive Cathode of an Army Image Tube Showing Detail of the Glass Ring Anodes

Figure 12
INFRA-RED NOCTOVISION IMAGE TUBES

There are two features of interest, the glass anodes (see Figure 12-c) and the method of using a mica ring to prevent the deposition of caesium on the anodes.

The anodes are made by cutting cylindrical rings out of glass tubes and grinding the edges smooth. Colloidal gold or platinum is painted on the inside surface and baked, providing a smooth metallic conducting surface. The anodes are then fastened in place by small glass columns, thus avoiding the difficulties encountered in the German tubes in accurately fitting glass and metal surfaces.

In the multi-anode Army tubes, a mica sleeve is inserted so as to cover the inside of the anodes and the openings between. During caesiation, this sleeve prevents the deposition of caesium on the anodes or through the openings onto the walls of the tube. Upon completion of the "after treatment", the mica sleeve is slid out of the anodes by tapping the tube longitudinally; a tab on the mica prevents it from sliding back inside again.

Both of the above steps have possibilities of reducing arcing-over and cold cathode discharge, and hence in permitting the use of higher operating voltages.

Detailed descriptions of the method of making these tubes are included in Enclosures (H) and (I).

B. <u>Non-Transparent Photocathode Image Tubes</u>.

Prof S. KATO, of Kyoto Imperial University, headed one branch of an organization called the Wartime Research Council. His group developed infra-red image tubes, filters, window materials, and thermocouples. Previous to the war, KATO had done considerable research on photocells, so he was engaged to improve the image tubes. Several papers covering various phases of his research are included as Enclosures (J) to (N) inclusive. His principal development was a non-transparent photocathode image tube, in which the optical image was introduced through an annular lens at the screen end of the tube. By theory and experiment he showed results greatly superior to the semi-transparent photocathode image tube, both in peak sensitivity and in sensitivity at longer wavelengths. However, military personnel stated that the few tubes of this type which were tested by them were inferior to the standard semi-transparent cathode types. The reports of Prof. KATO should be studied further, and the non-transparent cathode investigated to determine whether it has practical value. All the experimental tubes were destroyed, either in air raids or for security purposes.

C. <u>Optics</u>.

A brief study by optical personnel attached to the Mission indicated that none of the optical designs employed by the Japanese are new or novel. The matter of fitting the curvature of the optical image to that of the cathode was given considerable attention, but no fully-corrected multi-element lens systems, such as employed by the Germans, were designed. In fact, the design moved in the opposite direction. Since the electron optics produced large aberrations, a simple two-element objective was used, on the theory that the aberrations thus introduced were of a lesser order, and would not materially affect the final image. Various Schmidt systems were studied in an effort to gain greater light-gathering power and to fit the optical image to the cathode surface, but none were built in quantity. Some of the optical design studies of Prof. KATO are included in Enclosure (N). The equipment shipped to the United States was selected to include representative optical systems.

D. <u>Near Infra-Red Filters</u>.

All the filters commercially produced in Japan were made by <u>Tokyo Shibaura</u> Electric Company. This company manufactured both glass and <u>polyvinyl alcohol</u>

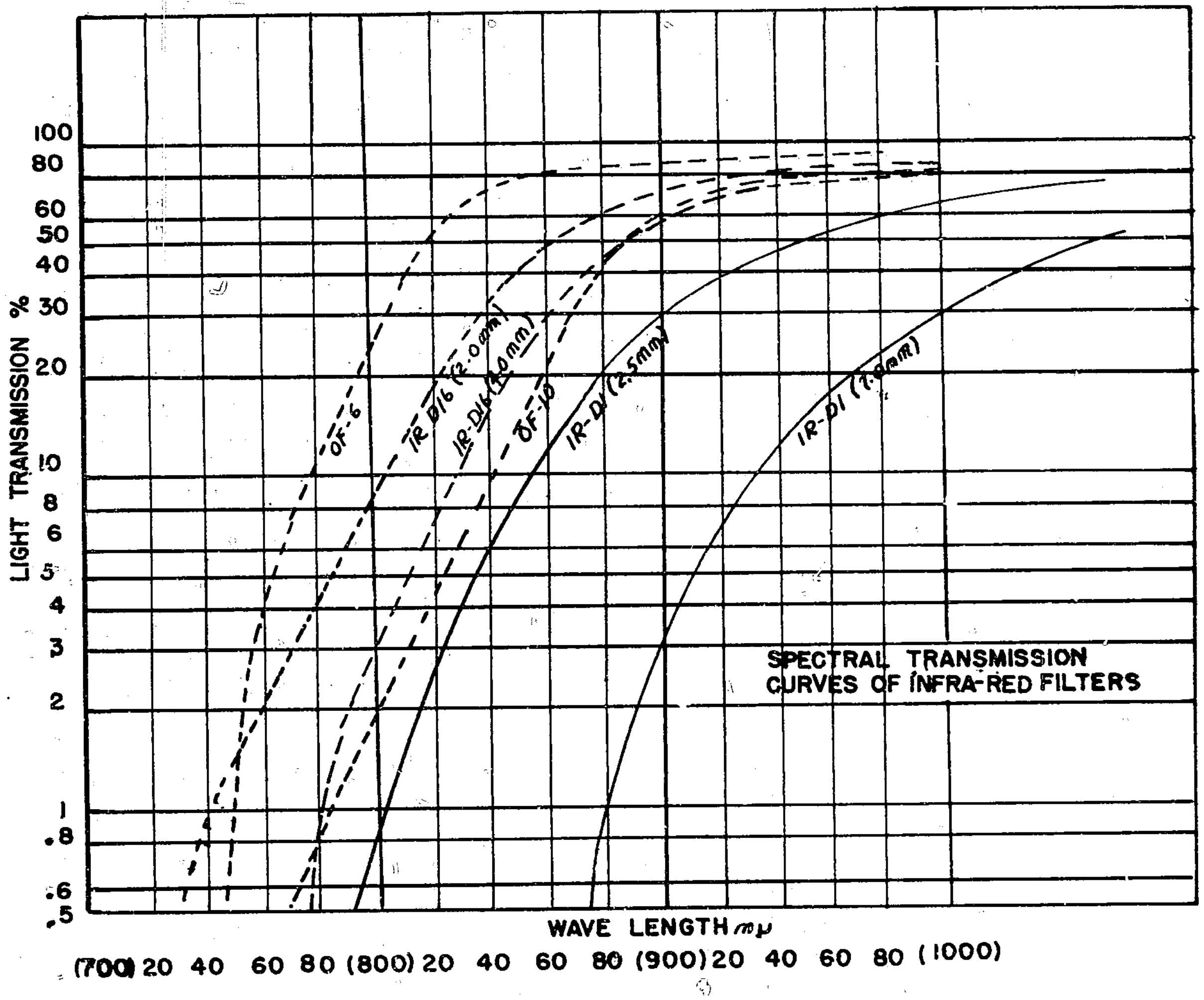


Figure 13

SPECTRAL TRANSMISSION CURVES OF INFRA-RED FILTERS sheet filters, the transmission curves of which are shown in Figure 13. The standard filter for laboratory measurements was 3mm of IR-D1. Glass filters were generally used for military equipment, since the PVA filters were neither heat nor moisture resistant.

The following tabulation shows the materials used in the various filters:

Type	Base	Dye
IR-D1	Lead Glass	Mn, Cr
IR-D16	Borosilicate glass*	Sb, S, Se
OF-6	Polyvinyl Alcohol	Organic Dye Hat Black 3 GX
OF-10	Polyvinyl Alcohol	Organic Dye Congo Red (treated in H_2SO_4)

*Contains no heavy metal.

Experimental filters were made at the Tokyo School of Engineering, by Dr. Y. HOSHINO, who had tested over 200 different dyes in working for his doctorate. He stated that his best filter, dyed with napthaline fast black, was superior to any of the Tokyo Shibaura filters; that it had 1.7 times the transmission of the glass filters; and it was much more water-resistant than the PVA filters. Enclosure (O) contains an edited report by Dr. HOSHINO.

The visibility threshold limits required by the various laboratories varied considerably, but the maximum distance at which the light source could be detected by a dark-adapted observer was in some cases as great as 300 meters. This requirement is very lax in comparison to American standards, and is pointed up by the fact that the viewing equipment to be used with this light source (air-to-air) had a range of only 500 meters.

A series of experiments was carried on by Dr. TAKAMINE, of the Institute for Physical and Chemical Research, to determine the limit of visibility in the near infra-red. The results, giving a limit of 8520 Angstrom units, are described in a report by Dr. TAKAMINE, which is contained in Enclosure (P).

Sample glass and sheet filters have been shipped to NRL and the Engineer Board (NavTechJap Equipment Nos. JE21-6333 and JE50-5834).

E. Thermopiles.

The sensitive element common to all the heat detecting devices is the constantan-manganin or constantan-iron thermopile. These were produced by Kawanishi Machine Mfg. Company to a total of about 50-60 thermopiles, of which 10 were considered of high quality.

The thermopiles were produced by the Moll (Dutch, 1919) method, as follows: A bar 3mm wide, 20mm long, and 2mm thick was made by silver-soldering the two metals together. The bar was then rolled to a thickness of 0.005mm and cut into strips 0.5mm by 12mm. The surface was blackened by camphor black. Banks of 15 to 36 strips were used in the thermopiles. The time constant was stated to be 0.5 sec (time to reach 63% saturation); the time to reach peak response 2 sec; and the recovery time "about the same", although not measured. The sensitivity was stated to be 0.1 micro-volts/erg/sec/cm^2.

The constantan-iron thermopiles were said to be more sensitive than those of constantan-manganin, but suffered from rusting of the iron.

The three-element, or self-compensating, thermopiles were similar in construction. The center element, which limits the angular discrimination, was 0.5mm long. Attempts were made to reduce this to 0.3mm, but were unsuccessful.

F. Nickel Bolometers.

Nickel strip bolometers were used in the heat homing bomb and were tested with some of the heat detectors. They were prepared (at Tokyo Shibaura) by evaporation of nickel onto glass. Strips were then cut, 10mm by 1mm the thickness being about 1 micron. The resistance was stated to be about 1 ohm. The sensitivity, as measured in a laboratory test set-up described in Enclosure (G), was 1/30°C at a distance of 1 meter.

G. Heat Transparent Window Materials.

Fluorite and rock salt were used as cover plates for the thermopiles. The rock salt was preferred because of its higher transmission, but was impractical, since no adequate moisture-proof coating was found. A chloride-of-rubber sheet, about 10 microns thick, was used as a heat transparent window of the front of the bomb and detector heads, and was supported by a steel or piano wire grid. Transmission curves and other data are included in Enclosure (Q).

Part IX
RESULTS OF INVESTIGATION

A. Uses of Infra-Red Equipment.

The Japanese considered infra-red radiation to be of primary value as a means of secret communications, and all equipment which reached the field was of this category. The Japanese Navy used the Types II and III equipment as a basic means of communication under conditions of darkness and radio silence. Army development personnel stated that their photophones were never widely accepted or used. Army and Air Force personnel attempted to develop equipment for viewing targets illuminated with infra-red radiation, but were unsuccessful due to excessive weight and lack of sensitivity. The phosphor type receivers were planned for detection of enemy use of infra-red searchlights and for initial contact between communications sets, but only experimental units were produced. The heat detectors and seekers were primarily intended for use against ships; none of these were developed further than the test stage. There was no evidence of the use of infra-red photography for the detection of camouflage, or of applying the image tube telescopes as sniperscopes, or in airborne operations, other than the land photography tests conducted by the Ninth Military Laboratory (see Part VI).

B. Logistic Aspects of the Investigation.

1. Research and Development.

Branches of five Army agencies and one Navy laboratory were engaged in the development of infra-red equipment. Although the Army agencies all reported to the same headquarters, there was surprisingly little coordination of effort among them. The technical personnel had a general knowledge of the projects of other laboratories, but there was no coordination from above, and each organization tended to pursue its own line of development with a common belief that the equipment of the others was inferior to its own. In the last year or so of the war informal meetings were held about once a month to exchange technical information, but this committee had no power to coordinate parallel projects or eliminate unpromising projects.

Generally speaking, development of new items of equipment originated with technical personnel, rather than through military requirements stated by field commanders. The technicians "saw the need" for their own equipment, and, after a period of development, held demonstrations for high-ranking field personnel. The criticisms followed a familiar theme: Too heavy, not waterproof, not enough range. Interest in most of the items decreased towards the end of the war. Inability to produce even standard military equipment discouraged the research personnel, and many projects were dropped. No new projects were undertaken after 1944.

In most cases the military laboratories conducted only a small share of the actual development, depending heavily on university laboratories and manufacturers for basic research and construction of experimental models. The heat homing bomb was an exception, in that technical personnel were assembled in a special organization for the prosecution of this one project.

2. Manufacture.

The only infra-red devices which got past the development stages were the Navy Communications Equipment and the Army Photophone. Each of these was engineered and manufactured by private companies, under the direction of the respective military agencies, and with subcontractors providing subassemblies. Only a small number of each model was produced, so that standard procurement and supply procedures were not followed.

C. Development and Progress.

1. Image Tube Telescope.

The infra-red-sensitive caesium-silver photocathode electron image tube was first developed in the United States, by Dr. Zworykin of R.C.A. The results of his experiments were published in scientific journals about 1936 and were widely known.

Soon after the publication of Zworykin's paper, the Japanese started experimenting with image tubes, and published their own results before the war. The earliest Japanese scientist in this field, Dr. NAGASHIMA, of Tokyo Shibaura, has been interviewed, and gives full credit to Dr. Zworykin as the originator of this type of tube.

The Japanese attempted to produce smaller and more sensitive tubes, and succeeded in doing so, to an extent comparable to that achieved by the American, British, and German experimenters. Two features are perhaps of significance, (a) the use of metal-coated glass electrodes, and (b) the use of mica strips during caesiation. The small size image tubes were first made in 1943, and were improved substantially in sensitivity in 1944 and 1945.

The associated optical and electrical components are inferior to the American counterparts, and the equipment is generally bulky and insufficiently waterproofed for field use.

2. Filters and Window Materials.

The Japanese applied the standard glass, pliofilm, and dye techniques to the production of filter and window materials, without achieving unusual results. In general, these materials are less dense, have poorer transmission qualities, and are more susceptible to heat and moisture deterioration than similar American materials.

3. Far Infra-Red or Heat Detectors.

In all heat detecting or heat seeking equipment, the Japanese depended on the the thermopile, which inherently has a large time-constant, or on the bolometer, which they had not fully developed, for a sensitive element. The associated amplifiers and presentation means followed standard techniques, without notable improvements. Several projects were carried on at different times during the war; the only one actively prosecuted being the heat homing bomb, and the drop tests on it were not successful.

Part X
DISCUSSION

A. Value of Findings.

The information obtained in this investigation confirms the previous belief that the Japanese had no infra-red equipment to counter American use of the sniperscope or other infra-red equipment. None of the Japanese equipment had been produced in quantity, and it was bulky and depended on nonportable power supplies. The technical value of this investigation will be small, with the possible exception of an application of the new Japanese techniques in the production of image tubes.

B. Japanese Originality.

The Japanese did not develop any new components or technical equipment in the infra-red field. In certain instances, the image tube and the infra-red-sensitive phosphor, ingenuity was shown in laboratory procedures and the improvement of well-known devices. Some of the most obvious applications (sniperscope, night driving telescope) and weaknesses (high-voltage breakdown under tropical conditions, inability of ship detector to range or to distinguish between targets) were entirely overlooked.

C. German Technical Assistance.

Only one instance of direct interchange of information with the Germans was discovered. Early in 1945 a paper was received covering the preparation of phosphors for image tube screens. This was not exploited, due to bombing effects and general lethargy. It was confirmed that German technicians and further technical information were expected by submarine, but their fate (capture by U.S.) was not known. Intelligence on the German image tube phosphors was obtained by the CIOS Engineer Team in Europe.

ENCLOSURE (A)

LIST OF TARGETS

A. MILITARY ESTABLISHMENTS

1. Second Military Technical Laboratory.
   Location: Miyata-MURA, Kamiina-Gun.
   General Function: Development of optical equipment.
   Infra-red Interest: Development of personnel heat detector.

2. Fifth Military Technical Laboratory.
   Location: Koganei-MACHI, Kitatama-Gun.
   General Function: Development of communication equipment.
   Infra-red Interest: Development of direction finder.

3. Seventh Military Technical Laboratory.
   Location: Yodobashi-KU, Tokyo. Evacuation laboratories at Matsumoto, Nagano-Ken.
   General Function: Physical Research.
   Infra-red Interest: Development of photophones, telescopes, image tubes, filters, and ship detectors.

4. Ninth Military Technical Laboratory.

5. Yocho-Machi Branch of Army Ordnance Board.
   Location: Fujimi-MURA, Nagano-Ken.
   General Function: Development of heat homing bomb.

6. Fourth Air Technical Laboratory.
   Location: TACHIKAWA.
   General Function: Development of air force communication equipment.
   Infra-red Interest: Development of telescopes, image tubes, and ship detectors.

7. Second Naval Technical Institute.
   Location: Zushi-MURA, Kanagawa-Ken.
   General Function: Development of infra-red communication equipment.

B. MANUFACTURERS

1. Tokyo Shibaura Electric Co.
   Location: KAWASAKI, Kanagawa-Ken.
   General Function: Manufacture of all types of electrical and electronic equipment.
   Infra-red Interest: Manufacture of, and research on, Navy communication equipment, image tubes and filters.

2. Kawanishi Machine Mfg. Co.
   Location: KOBE.
   General Function: Manufacture of airplane instruments.
   Infra-red Interest: Manufacture of thermopiles.

3. Mitsubishi Electric Co.
   Location: AMAGASAKI, Osaka.
   General Function: Manufacture of all types of electrical and electronic equipment.
   Infra-red Interest: Research on photophones.

ENCLOSURE (A), continued

C. RESEARCH LABORATORIES

1. Hamamatsu Higher Technical School.
   Location: HAMAMATSU.
   Key Personnel: Prof. T. HORII.
   Infra-red Interest: Research on, and manufacture of, image tubes.

2. Kyoto Imperial University.
   Location: KYOTO.
   Key Personnel: Prof. N. KATO.
   Infra-red Interest: Research on image tubes, optics, and heat detectors.

3. Tokyo Imperial University.
   Location: TOKYO.
   Key Personnel: Prof. N. KAMEYAMA.
   Infra-red Interest: Research on infra-red sensitive phosphors.

4. Institute for Physical and Chemical Research.
   Location: TOKYO.
   Key Personnel: Dr. T. TAKAMINE.
   Infra-red Interest: Research on limit of human vision.

5. Tokyo College of Engineering.
   Location: TOKYO
   Key Personnel: Prof. Y. HOSHINO.
   Infra-red Interest: Development of filters and window materials.

* * * * *

ENCLOSURE (B)

LIST OF JAPANESE DOCUMENTS FORWARDED TO WASHINGTON DOCUMENT CENTER AND NAVAL RESEARCH LABORATORY

NavTechJap No.	ATIS No.	Title
ND50-5838.1 to .4	4097	Blueprints: Type II Army Photophone.
ND50-5838.5	4097	Type II Army Photophone Manual.
ND50-5838.6	4097	Type II Army Photophone and Beam Direction Indicator.
ND50-5839	4096	Blueprints: Type III Navy Infra-Red Communication Equipment and Other Infra-Red Equipment.
ND50-5841	4273	Infra-red ray navigational aid equipment.
ND50-5842.1	4274	Experimental infra-red photography.
ND50-5842.2	4274	Investigation of infra-red photography.

ENCLOSURE (C)

EQUIPMENT SHIPPED TO ENGINEER BOARD AND TO THE NAVAL RESEARCH LABORATORY

Sources

9 - Ninth Military Technical Laboratory
7 - Seventh Military Technical Laboratory
N - Naval Technical Laboratory, ZUSHI
S - Tokyo Shibaura Electric Co.
K - Kure Naval Base
D - Diet Building, TOKYO

Identification tags are attached to each piece of equipment, giving identification number, name of equipment, name of component, and source.

I. INFRA-RED EQUIPMENT SHIPPED TO ENGINEER BOARD FOR FURTHER STUDY.

No.	Item	Source
IR-1	Image Tube, 100mm	7
IR-2	Image Tube, 100mm	7
IR-3	Image Tube, 100mm	S
IR-4	Image Tube, 100mm	N
IR-5	Image Tube, 100mm	N
IR-6	Image Tube, 200mm	N
IR-7	Image Tube, 350mm	7
IR-8	Image Tube, 250mm	7
IR-9	Image Tube, 250mm (electrodes only)	7
IR-10	Thermopile	N
IR-11	Thermopile	N
IR-12	Thermopile	N
IR-13	Thermopile	N
IR-14	Thermopile	N
IR-15	Thermopile	N
IR-16	Filter, glass, 1 RD-1, sector	S
IR-17	Filter, glass, 1 RD-1, 3 in	7
IR-18	Filter, glass, 9½ in	7
IR-19	Filter, glass, 9½ in	7
IR-20	Filter, glass, 9½ in	7
IR-21	Filter, glass, 9½ in	7
IR-22	Filter, dyed sheet	N
IR-23	Chloride of rubber, sheet	N

Airborne Heat Detector

No.	Item	Source
IR-24	Mounting Frame and Scanning Head	N
IR-25	Amplifier	N
IR-26	Dynamotor	N
IR-27	Mirror, parabolic, 7 in (2)	N
IR-28	Panel Board	N
IR-29	Switch Board	N
IR-30	Window Holder	N

IR Communications, Type 3

No.	Item	Source
IR-31	Mounting Stand	N
IR-32	Mounting Stand	N
IR-33	Telescope	N
IR-34	Telescope	N

ENCLOSURE (C), continued

	Item	Source
IR-35	Signal Lamp, damage	N
IR-36	Power Supply	N
IR-37	Power Supply	N
IR-38	Switch Box	N
IR-39	Switch Box	N
IR-40	Control Panel	N
IR-41	Control Panel	N
IR-42	Receiver, w/tube	N
IR-43	Receiver, w/tube	
IR-44	Receiver, w/tube	
IR-45	Power, Supply	N
IR-46	Power, Supply	N
IR-48	IR Telescope, binocular, 15cm focal length, w/o tube	7
IR-50	IR Telescope, binocular, 10cm focal length, w/o tube	7
IR-52	IR Telescope, binocular, 5cm focal length, w/o tube	7
IR-54	IR Telescope, monocular, demountable objective, w/o tube	7
IR-55	IR Telescope, monocular, position detector, w/o tube	7
IR-59	Lens, Petsval, f:2.3	7
IR-60	Lens, Petsval, f:2.3	7

II. EQUIPMENT SHIPPED TO THE NAVAL RESEARCH LABORATORY FOR FURTHER STUDY.

NavTechJap No.	Name	Source
JE22-6116 A to J incl.	Type II Navy Infra-Red Communications Equipment	K
JE22-6135 A to J incl.	Type II Navy Infra-Red Communications Equipment	K
JE22-6136 A to F incl.	Type III Navy Infra-Red Communications Equipment	K
JE50-5834	Infra-Red Light Sending Gun for Type III Navy Communications Equipment	D
JE50-5835	White Sending Gun for Type III Navy Communications Equipment	D
JE50-5840	Infra-Red Light Sending Gun for Type III Navy Communications Equipment	D
JE21-6333	Noctovision tube and receiver for Type III Navy Communications Equipment and IFF receiver, a large noctovision tube for Type V Navy Communications Equipment and several sheets of chloride of rubber filter material	N
JE50-5801 to JE50-5812 incl.	Four sets of Type II Army Photophones.	7
JE50-5838	Miscellaneous Tubes: 3ca Neon Glow Discharge (Photophone) 1ca Photocell (Caesium) 1ca Mercury Vapor Lamp (Light Source) 1ca Carbon Arc Lamp (Light Source) 1ca FR Tube (Picked up from Ninth Lab.) 1ca RF Resistance (Picked up from Ninth Lab)	7
JE50-5833	Infra-Red Searchlight Sending Lamp	7
JE50-5827	Noctovision Binocular (15cm)	7
JE50-5828	Noctovision Binocular (10cm)	7
JE50-5829	Noctovision Binocular (5cm)	7
JE50-5830	Noctovision Monocular (10cm)	7
JE50-5813 to JE50-5816 incl.	Glass Binoculars (50-100 power)	7
JE50-5826	Mangin Lens for IR Telescope	7

ENCLOSURE (C), continued

NavTechJap No.	Name	Source
JE50-5831 to JE50-5832 incl.	Two IR Objective Lenses (f 2.3)	7
JE50-5821 to JE50-5822 incl.	Two Schmidt Infra-Red Cameras	9
JE50-5823 to JE50-5826 incl.	Periscopic Infra-Red (glass lens that may be corrected for infra-red) Camera	9

ENCLOSURE (D)

PHOTOPHONE RESEARCH BY THE SEVENTH MILITARY LABORATORY

PART I

A report Covering Research on Photophones, Nomenclature, and Description of Critical Features.

By: Lt. Col. T. TAKESHITA

1. Research on photophones at the Seventh Military Technical Laboratory was started in 1929 and ended in 1941. During the period that followed, the personnel in charge of the research changed many times and none of the original men remained. Since the papers and documents were burned by our own judgment at the end of the war, it will be difficult to write the exact history of photophones. However, I (Lt. Col. TAKESHITA) have been in the same laboratory since 1927, and though not in charge of the research on photophones, I remember something about them and will write the history as best as I can.

2. Prior to 1932 fundamental research was conducted in which various systems for modulating the intensity of the light source by the voice current were studied.

a. Pair of slits with Vibrating Mirror. This system, later improved by the use of a pair of gratings and a vibrating mirror, was very simple and easy to handle and was adopted as the formalized No. 2 (Army) Photophone for field use.

b. Direct Modulation of the Light Sources. Attempts were made to modulate Tungsten AG lamps and Carbon Arc lamps directly. However, the degree of modulation obtained was very small and the noise level was very high and successful results were not obtained. In about 1932, however, a white incandescent lamp with hydrogen vapor in it was perfected by Dr. S. SUZUKI, Engineer of the Electrical Research Laboratory (Communications Department). This lamp was found to have good modulation quality and was accepted for photophone use. However, the associated amplifiers were necessarily large and the system was not accepted for Army field use, though it was recommended for use with ships.

3. The Caesium photocell had been perfected and was adopted as the standard photophone receiver for Army use. The principal manufacturer of these photocells was the Tokyo Electric Co. (now Tokyo Shibaura Co.). At first concave mirrors were used in receivers to collect the light, but were unsuccessful in the daytime because too much noise from stray light was picked up. An optical system, therefore, was adopted which used a diaphragm, with a circular hole in front of the photocell, to reject the disturbing light. This optical system operated very well in the daytime.

4. Photophone communication requires that the light beam from the sender be projected toward the receiver and for this purpose a finding telescope was attached to the photophone. A special prism was incorporated in the photophone to reflect some light from the sender back into the finder telescope as a means of checking the collimation alignment between the sender and the finder optical axes. The image of the light source should fall on the crosshairs in the finder when the two are collimated.

5. To increase the range of the photophone, Fresnel lenses of 30 to 60cm. apertures were manufactured in 1931 but their aberration was so bad that they offered very little success.

ENCLOSURE (D), continued

6. In about 1937 a high pressure mercury lamp was developed and used as a light source. The lamp could be modulated directly and offered good possibilities for long distance photophone use. However the lamp was very short-lived and often became untransparent in two to three hours. Using mercury lamps, in temporary test set-ups, a range of 30 km was obtained with 60cm mirrors or 60cm Fresnel lenses, and a range of 100 kilometers with a 150cm mirror.

7. Several experimental photophones of less significance were set up but were not manufactured and the parts were used for later experimentations. Some of the equipment was burned by the bombardment at OKUBO, Tokyo. The research on photophones was stopped in 1941 and attempts were made to summarize the results as a basis for future research, but the work was never completed. The priority of the research was not very high since the Ordnance Bureau accepted only one (No 2 Photophone) and even that was not used successfully in the field.

8. No. 2 Photophone. The No. 2 photophone was manufactured by the Nippon Kogaku, TOKYO, in about 1937-1939. Some of this equipment was sent to Manchuria and was intended to be used to control river boat crossings and to furnish front-line communications across rivers. The average range of the equipment was about four kilometers.

9. Photophone Receiver to be used with the No. 2 Photophone. A small photophone receiver was designed to be used on river boats so that they could receive messages from a No. 2 photophone located on the shore. These receivers were manufactured in about 1936 by the Mizojiri Kogaku (now Fuji Kori) at EBARA, Tokyo, and were intended to be used in the frontiers of Manchuria. In this manner the soldiers on the boat could receive orders from the ground without being detected.

10. No. 3 Photophone. The No. 3 photophone, also manufactured by the Nippon Kogaku, TOKYO, was the same as the No. 2 photophone except that it was made much smaller and was intended to be used by the infantry. Its range was about two kilometers, but the equipment was never adopted by the Ordnance Bureau.

11 Photophone for Ships. (Modulated light source) Photophone for ships was desired by the captains of transports but were never accepted by the Ordnance Bureau, and were not used.

a. The basic equipment consisted of a 30cm glass mirror in both the receiver and the sender, with an infra-red filter over the sender. The sender used the incandescent white lamp containing hydrogen vapor (see above) since the high pressure mercury lamp had not yet been perfected. The mirrors and modulating light source system were used for the following reasons:

(1) The grating system could not be used with mirrors.

(2) Optical systems with large apertures are easier to make with mirrors than with glass lenses, especially when short focal lengths are desired in order to keep the equipment small.

(3) Large mirror systems are not as heavy as large lens systems.

b. An auxiliary system consisting of a 20cm glass mirror, white incandescent lamp and infra-red filter was used to show the position of the sender. To locate this auxiliary sender a monoscope receiver having a special infra-red sensitive fluorescent screen at the focal plane of the objective lens was used. The fluorescent screen was invented by Dr.

ENCLOSURE (D), continued

KAMEYAMA, professor at the Tokyo Imperial University, Technical Faculty. This fluorescent screen required illumination by white light to sensitize the screen before used. Its range was about four kilometers with white light and two kilometers with infra-red light.

12. Combined Amplifier for Photophone and Radio. An attempt was made to utilize communications radio amplifiers for photophone use. Radio was to be considered the primary means of communication with photophone the secondary means and the common amplifier was intended to minimize the total equipment. A few were manufactured in about 1935 at Tamura Seisakujo.

13. Periscope for No. 2 Photophone. A sample periscope was manufactured at Nippon Kogaku in 1940, and was intended to adapt the No. 2 photophone to trench use. Only one was made.

PART II

Operating Procedure for the No. 2 Army Photophone.

By: Major Y. OGINO

1. Setting up the Equipment (See Figure 1(D).)

   a. Mount the photophone telescope on the tripod.

   b. Mount the finding telescope.

   c. Mount the correcting prism.

   d. Mount the photo-cell.

   e. Connect the leads (lamp and vibrating mirror).

2. Setting of the Amplifier

   a. Pull out the hand generator from the amplifier box.

   b. Connect leads to the amplifier as indicated in Figure 1(D) and Figure 3(D).

   c. Connect the microphone and receiver as indicated in Figure 3(D).

3. Setting of the Optical System

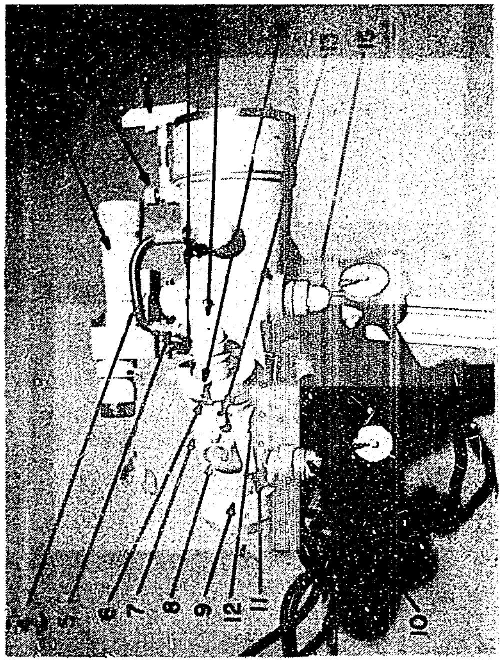
   a. Put the lever (7) to transmitting and receiving side.

   b. Rotate the hand generator, keeping the voltage at about 6.5 V (Excess voltage will burn out the lamp).

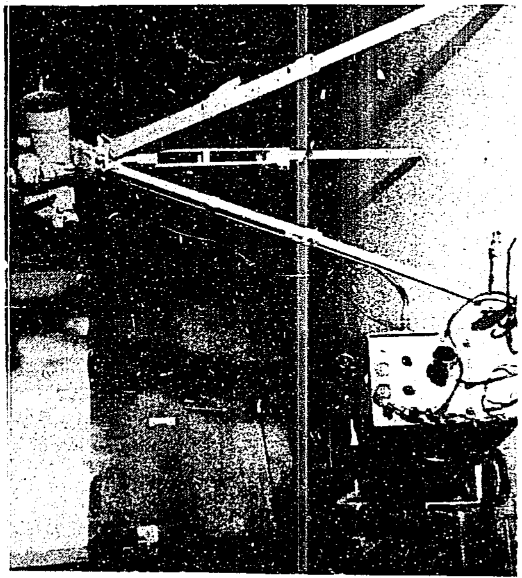
   c. Keep the current of the lamp at about one ampere by regulating the lamp current resistance.

   d. Loosen the fastener of the lamp socket (14) and by moving the lamp in a plane vertical to the optical axis, coincide the lamp filament with the cross lines of the finding telescope.

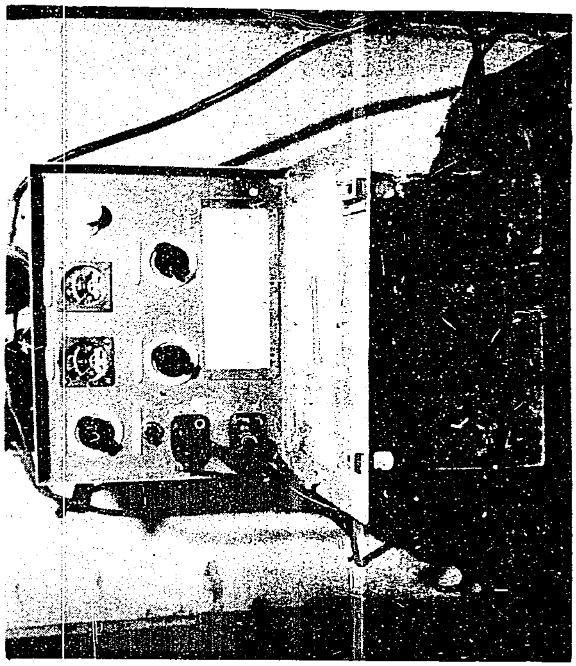
   e. Open the window (11) and put the frosted glass in front of the No. 2 grating, and then while peeping through the front lens, adjust the No. 1 grating "Adjusting Screw" until the image lines of No. 1 grating are half overlapping the lines of No. 2 grating. Then test the light modulation



a. Top View



c. Photophone Assembled



b. Amplifier

Figure 1(b)
ARMY PHOTOPHONE

ENCLOSURE (D), continued

Key to Figure 1(D)

Top View of Photophone No. 2

1. Correcting prism
2. Mounting screw of the correcting prism
3. Finding telescope
4. Fastener of the finding telescope
5. Screw of the iris for the receiving photocell
6. Prism to illuminate the micro of the finding telescope
7. Lever to choose type of operation:
    a. Usual sending and receiving at one time
    b. Receiving only
8. Adjusting screw of the No. 1 grating
9. Vibrating mirror casing
10. Connector of the sending lamp and the vibrating mirror
11. Knob of the window to examine the grating
12. Hole to insert the filter
13. Fastener of the lamp house
14. Fastener of the lamp socket
15. Connector of the photocell
16. Fsatener of the lamp socket
17. Sending lamp socket

ENCLOSURE (D), continued

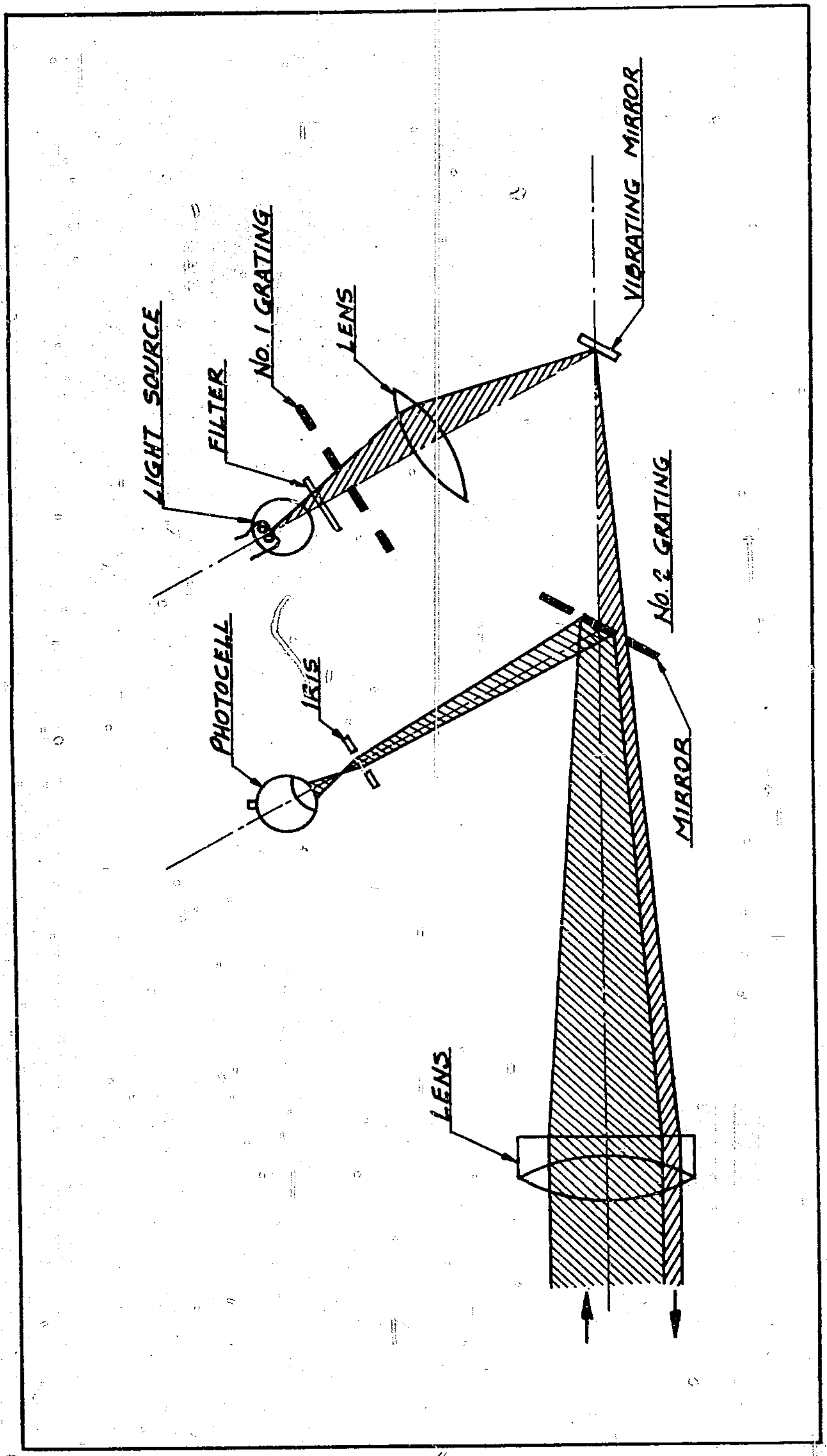


Figure 2(D)
OPTICAL SYSTEM (ARMY PHOTOPHONE)

ENCLOSURE (D), continued

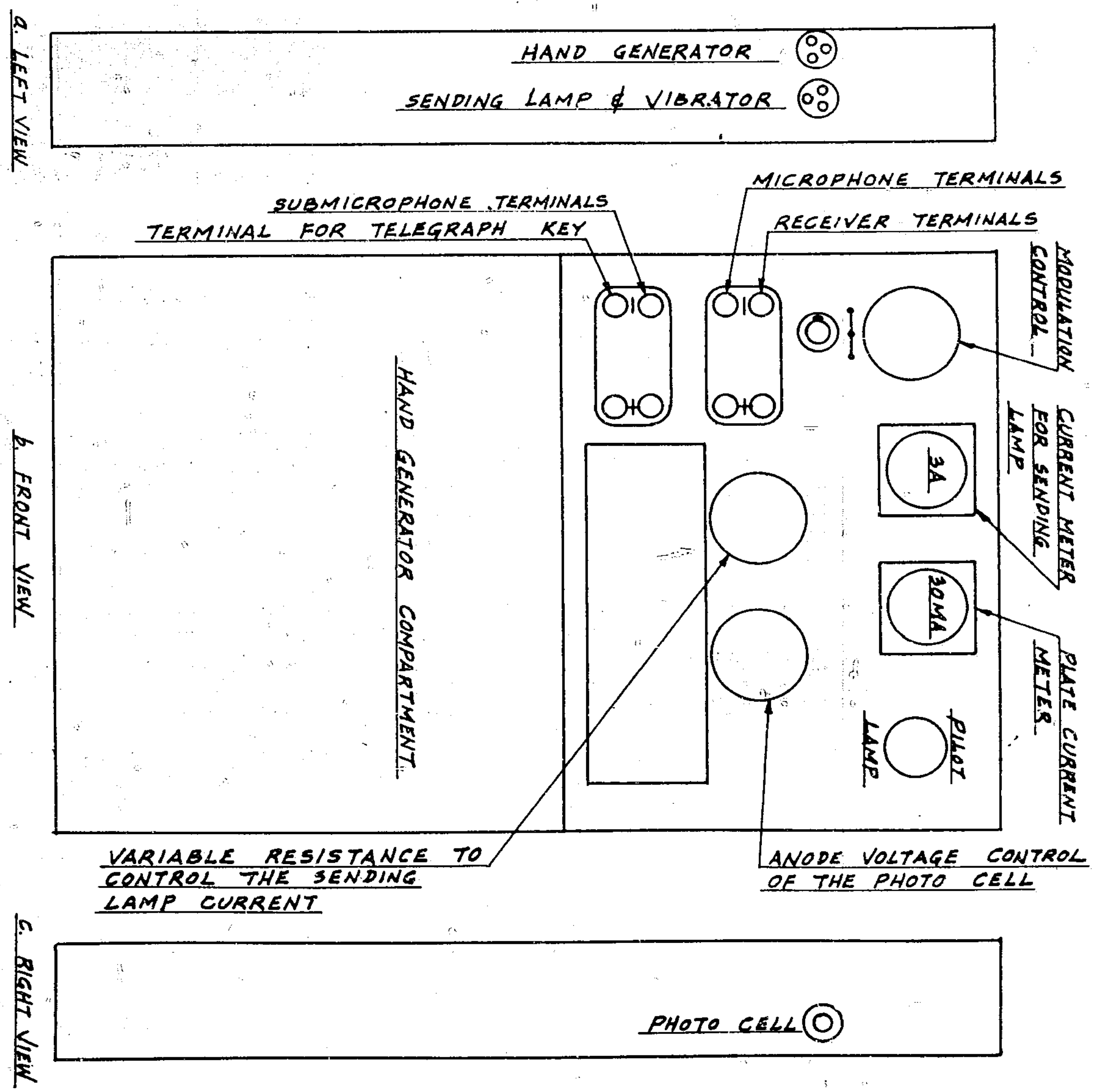


Figure 3(D)
AMPLIFIER (ARMY PHOTOPHONE)

ENCLOSURE (D), continued

or flickering for optimum conditions by observing the effect while talking into the microphone. Then remove the frosted glass.

f. In the daytime put the iris of the photocell at about eight and at night about 20. Avoid sunlight since it will increase the background noise if it scatters into the photocell.

4. Locating the Other Station

a. Locate the light of the opposite station by sight.

b. Locate the light of the opposite station through the finding telescope and coincide the image of the image of the opposite station sending lens upon the crosshairs of the finding telescope.

5. Adjustment of the Amplifier

a. Set the telegraph-telephone switch to the telephone position.

b. Set the control for the photocell anode voltage where hearing is the best. Increased sensitivity is offset by increased noise and an optimum choice must be made.

c. Set the control for the modulation at about six and then set for the optimum position by listening to test speech from the other operator. Increasing the modulation from one to 10 increases the sensitivity but decreases the articulation.

6. Notes

a. The equipment is normally used with white light but can be converted to red light or infra-red light by inserting the attached red or infra-red filters. The infra-red filter decreases the range to about one half.

b. Correction of the lamp position is not usually necessary.

c. The equipment can be used for telegraphy by connecting a telegraph key to the telegraph key terminals and switching the telegraph-telephone switch to the telegraph side.

d. By further setting the mirror release, the equipment can be used to send unmodulated Morse code signals by light.

ENCLOSURE (E)

RESEARCH REPORT ON INFRA-RED DIRECTION FINDER

(Translation of the Japanese final report covering development, description, and test results on the direction finder for use in river crossings.)

Fifth Army Technical Research Laboratory

24 April 1944

I. Research initiated in 1941. Authorized by Army Technical Headquarters, order numbered 296B, dated 31 March 1941.

II. Research Results and Future Plans.

1. Findings of the research. The infra-red direction finder is of excellent construction, operates with ease and is practical.

2. Future Plans. Necessary steps must be taken for standardization.

III. Research Progress Outline.

1. Research commenced in April 1941.

2. The first design was finished in June 1941 and tests were conducted at KASUMIGAURA, Kagoshima Cho, Ibaragi Ken. Although the method used to guide the boat was practical, it was recognized that further research was necessary for the improvement of performance and structure.

3. In October 1942, a revised model was completed and tested near GOTEMBA, Shizuoka Ken. The tests obtained were in general those anticipated. It was recognized that with detailed improvement it would be possible to run tests involving ship equipment.

4. In March, 1943, a model improved in detail was completed. This model was tested at MIZU Kaigan, Shizuoka Ken. The results of the tests showed that the structure and operating characteristics were excellent in general, but it would be necessary to improve the accuracy in guiding ship.

5. In September 1943, the fourth improved model was completed. The tests were run at TONEGAWA, Namiseki Cho, Ivaragi Ken. The characteristics of the equipment and also the operating convenience (handling) were, in general, as anticipated and it was of practical value.

6. October 1943 - November 1943. The Army Engineering School was commissioned to run tests and determine its practicality and suitability. The results appear in an extract of the report on test results and related measures, as per enclosure.

7. December 1943 - March 1944. Minor improvements were made on the equipment. As revealed necessary by the results of the tests, the research came to an end when the infra-red direction finder was recognized as being practical and of value.

IV. Description of Infra-Red Direction Finder.

1. Utilizes infra-red rays to guide the ship's forward progress.

ENCLOSURE (E), continued

2. The direction finder is composed of transmitter, receiver, accessories, and spare parts.

a. Transmitter is a 30cm parabolic reflector infra-red ray transmitting equipment. It mechanically changes light rays into audio frequencies and automatically selects a different signal according to the direction. The light source utilizes a small lamp and a 6 volt storage battery.

b. Receiver units are photo electric cell, amplifier and indicator. The bearing of the boat is determined by the signal received in the earphones and this is also shown on the indicator.

c. Accessories consist of three accessory boxes, five accessory bags, tools and standard aiming telescope.

d. Spare parts consist of light filter, photo electric cell, vacuum tubes, lamps and fuses.

3. Important Data.

a. Guiding characteristics of boat.

(1) Effective guiding range 3,000 meters.

(2) Guiding accuracy. The angle between the true bearing and the deviation of the boat from the true, lies within 1.3° for short distance and 0.5° for long distance.

	Component	Weight (kg)
Transmitting	Beam Transmitter	26.7*
	Transmitter Tripod	17.5**
	Hand Generator	0.7
	Storage Battery (2)	4.0
Receiving Equipment	Light Receiver	2.2
	Amplifier	13.5
	Indicator	3.5
	Hand Generator	7.3
Accessories	Light Transmitter Box	5.7
	Light Transmitter Tripod Box	4.3
	Receiver Equipment Box	5.7
	Accessory Bag (5)	9.5
Spare Parts		0.5

*Before mod. weighed 41.2 kg. **Before mod. weighed 25.6 kg.

4. Transportation Method. For long distance trips, it is packed in accessory boxes and transported by vehicles. For short distances, the equipment is packed in accessory bags and carried on the back or by hand.

V. Research Personnel.

Director - Lt. Col. SHOICHI UEDA

Supervisor - Major TOMIO ENDO

ENCLOSURE (E), continued

Enclosure to Report

Extract of Report
by
Infra-Red Direction Finder Testing Commission
Army Engineering School
November 1943

OPINIONS OF TEST COMMISSION	STEPS TAKEN AGAINST OPINIONS
I. Decision.	
To maintain the course on dark moonless nights (no fog or smoke), on large rivers, it is necessary to make detail improvements in order to make it of practical value.	
II. Essential Data for Improvement of Structural Quality.	
A. Transmitting Equipment.	
1. The weight and the size should be made smaller so that four men can carry the transmitter. The reason for this is because six men are required to carry the equipment by hand even when the hand generator is employed. Also the weight of the main unit is too heavy, 41.2 kg, for long distances and consequently the operation range is limited to 4 to 5 km. Hence it is recognized that the weight and the size must be reduced.	The weight has been reduced and transportation by hand is easy. The weight of the main unit has been reduced to 26.7 kg (recommendation was 30 kg or less) and the tripod weight has been reduced to 17.5 kg. In order to make the size smaller, it would necessitate reducing the reflector to one of 20cm, which would lower the performance and therefore there was no change made.
2. It is recommended that the transmitter be equipped with a small battery capable of giving three hours of continuous service because battery is the best source of power.	The power supply of the transmitter will be furnished by battery only; storage battery of 64 amp/hour capacity.
Reason: The hand generator used to provide power to the transmitter is light and easy to carry but power output is erratic due to difficulty in turning the handle at a constant and correct speed. When the handle is turned too fast, it causes the lamp to burn out and when turned too slow the power isn't sufficient to operate the equipment; therefore it is best that it be equipped with batteries small eneugh for easy carrying by hand.	
3. Plotting Equipment.	

ENCLOSURE (E), continued

OPINIONS OF TEST COMMISSION	STEPS TAKEN AGAINST OPINIONS
a. Install a simple compass in the main unit or in the plate of the tripod and this facilitates easy plotting.	A simple compass was installed in the main unit.
b. To make for sure, fast plotting, it is essential that the reflector unit be made to move freely on the tripod, and it be equipped with a micrometer adjustment.	The micrometer compensator made the structure complex. Ball bearings were used to make for "free" turning.
4. The part below the main unit which moves should be locked at one position or else be equipped with an illuminating device.	Was locked as recommended.
Reason: From the standpoint of operation, the moving device below the main unit makes it necessary to use an illuminating device to read the scale at night. As much as possible, it should remain locked and thus eliminate reading the scale and speed up the operation.	
B. Receiving Equipment.	
1. The main source of power for the receiver should be the hand generator. The second source of power is to use the storage battery.	
a. When storage battery is used, a D.C. transformer is necessary. The weight of the two is too great, and under damp conditions is not suitable.	
b. It is essential that the height of the receiver head be raised one meter.	It was modified in accordance with the opinion.
Reason: The height of the present receiver face when attached against the gunwhale of the boat is not sufficient to clear the engineers and other obstacles in the rear of the boat. The operation is impossible under this conditions and for this reason it is necessary to increase the height by one meter, this can be achieved by the addition of an expanding unit.	

ENCLOSURE (E), continued

OPINIONS OF TEST COMMISSION	STEPS TAKEN AGAINST OPINIONS
3. The angle of the receiver face be increased by making full 360°. Reason: In order for the equipment to be practical, the receiver face must receive without fail the infra-red rays sent out by the transmitter. If two cells are used, they must face directly into the direction of the transmetter; if not, the result is the same as before. Therefore in order to be practical and facilitate operation, the receiving head must be enlarged; the number of photocells should be increased to give a coverage of 360° or in case only two cells are used, a suitable angle which will insure proper reception should be chosen.	Two cells were placed 30° to the right and left of the center line to give 180° light coverage.
4. The window of the indicator lights should be of shutter type; be able to open and close for best plotting.	The opening and closing of the windows with respect to the deviation is of simple design.
5. It is essential to install an earphone jack in the receiving equipment.	Earphone jack was installed as recommended.
C. Handling Convenience.	
1. The transmitting equipment is simple. 2. Plotting is rather difficult.	If skill is developed in operating the transmitter, plotting becomes easy and if in the future, a simple compass is attached to the reflecting unit, operation will become easy and convenient.

ENCLOSURE (F)

MANUFACTURE OF INFRA-RED PHOSPHORS AND IMAGE TUBE SCREENS

An edited report prepared for the purposes of this investigation by Prof. T. KAMEYAMA of Tokyo Imperial University. It covers the theory of infra-red-sensitive phosphors, their physical properties, and method of preparation.

I. Effect of Infra-Red Radiation on the Brightness of Phosphors.

The effect of infra-red radiation on the Brightness of phosphors is schematically shown in Figure 1(F). "Ausleuchtung" phosphors show an accelerated phosphorescence, whereas the phosphorescence of "Tilgung" phosphors is extinguished.

II. Absolute Spectral Sensitivity. (See Figure 2(F).)

In the cases of most sensitive types of phosphors, the sensitivity is given in Figure 2(F) in the percentage of the light output by the accelerated phosphorescence (Ausleuchtung), when an equal amount (in calories) of infra-red light of various wave lengths is thrown on.

The monochromatic infra-red energy from a quartz monochromator was measured by the Hilger linear thermopile. The energy of the emitted light by the "Ausleuchtung" was measured by a sensitive light-flux counter composed of a vacuum type K-photo-cell, a powerful photoelectric amplifier, and a ballistic galvanometer.

In the most favorable case about a quarter of the incident infra-red energy is converted into visible light. In the accompanying curve, 10% means that 10% of the incident infra-red ray is obtainable as visible light.

III. Threshold Infra-Red Energy Necessary for the "Ausleuchtung" to be Detected by the Naked Eyes.

About 5×10^{-7} cal/cm^2 sec. or 21 erg/cm^2 sec.

This is the mean value for the infra-red light ranging from 800 mu to 1600 mu in the case of ZnS-Pb phosphor, one of the most sensitive types of phosphors.

IV. Various Types of Phosphors Showing High Sensitivity to Infra-Red Rays.

		Mol-Ratio
Ausleuchtung	ZnS-Pb	Zn:Pb $= 1:10^2$
	ZnS-Cu-Mn	Zn:Cu:Mn $= 1:10^4:10^5$
	CaSrS-Bi-Ce	Ca:Sr:Bi:Ce $= 0.2:0.8:10^5:10^4$
	SrSe-Tl	Sr:Tl $= 1:10^4$
	MgS-Bi-Fe	Mg:Bi:Fe $= 1:10^4:3\text{x}10^6$
Tilgung	ZnS-Cu-Co	An:Cu:Co $= 1:10^4:3\text{x}10^5$

V. Practical Data for the Detection of Various Infra-Red Light Sources.

A. Heater coil of about 400°C was clearly detected at 40 meters distance by a screen of ZnS-Pb put in a telescope of F/11 aperture.

B. With the same screen and telescope a gas-filled tungsten lamp (100 watt) at a distance of 70 meters can be detected through a Wratten Filter No. 87 until the input energy into the lamp is decreased to 15 watts,

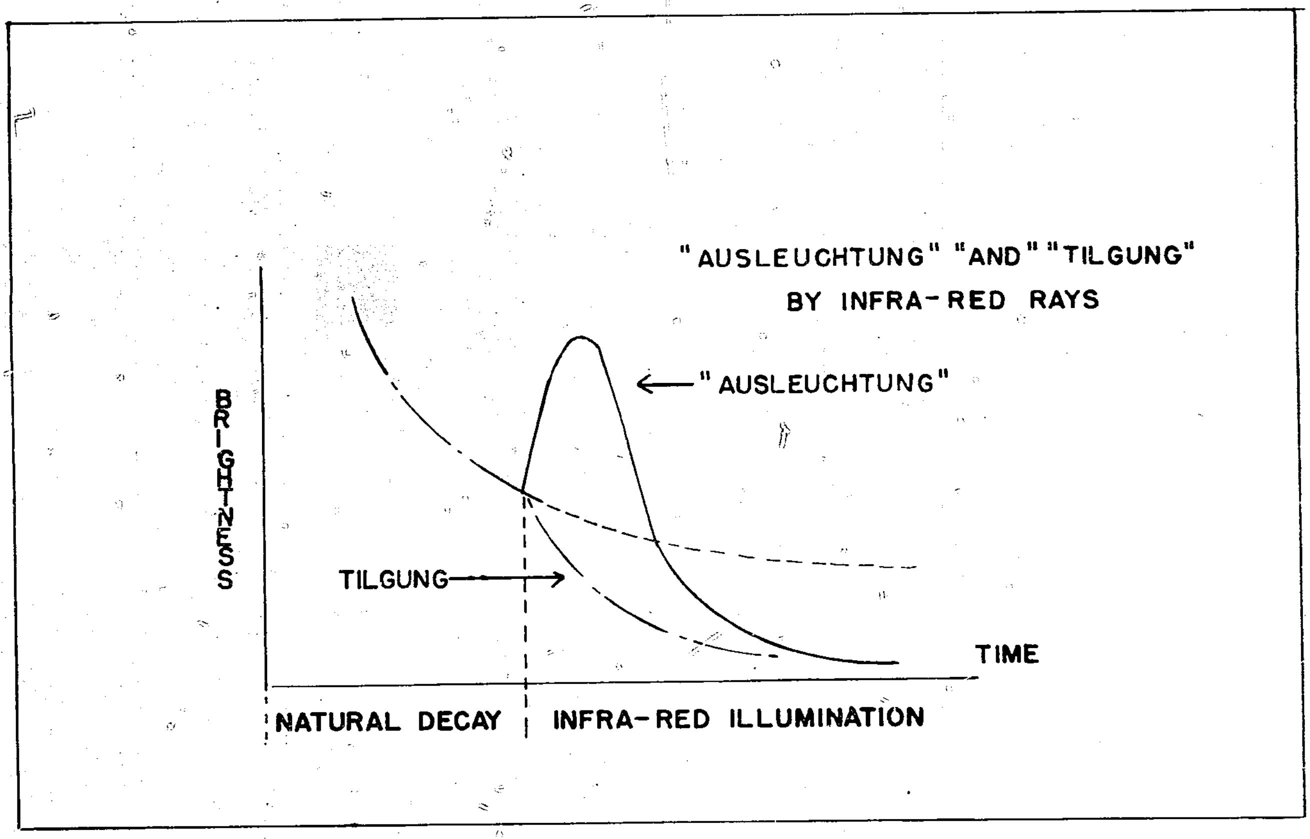


Figure 1(F)

"AUSLEUCHTUNG" AND "TILGUNG" BY INFRA-RED RAYS

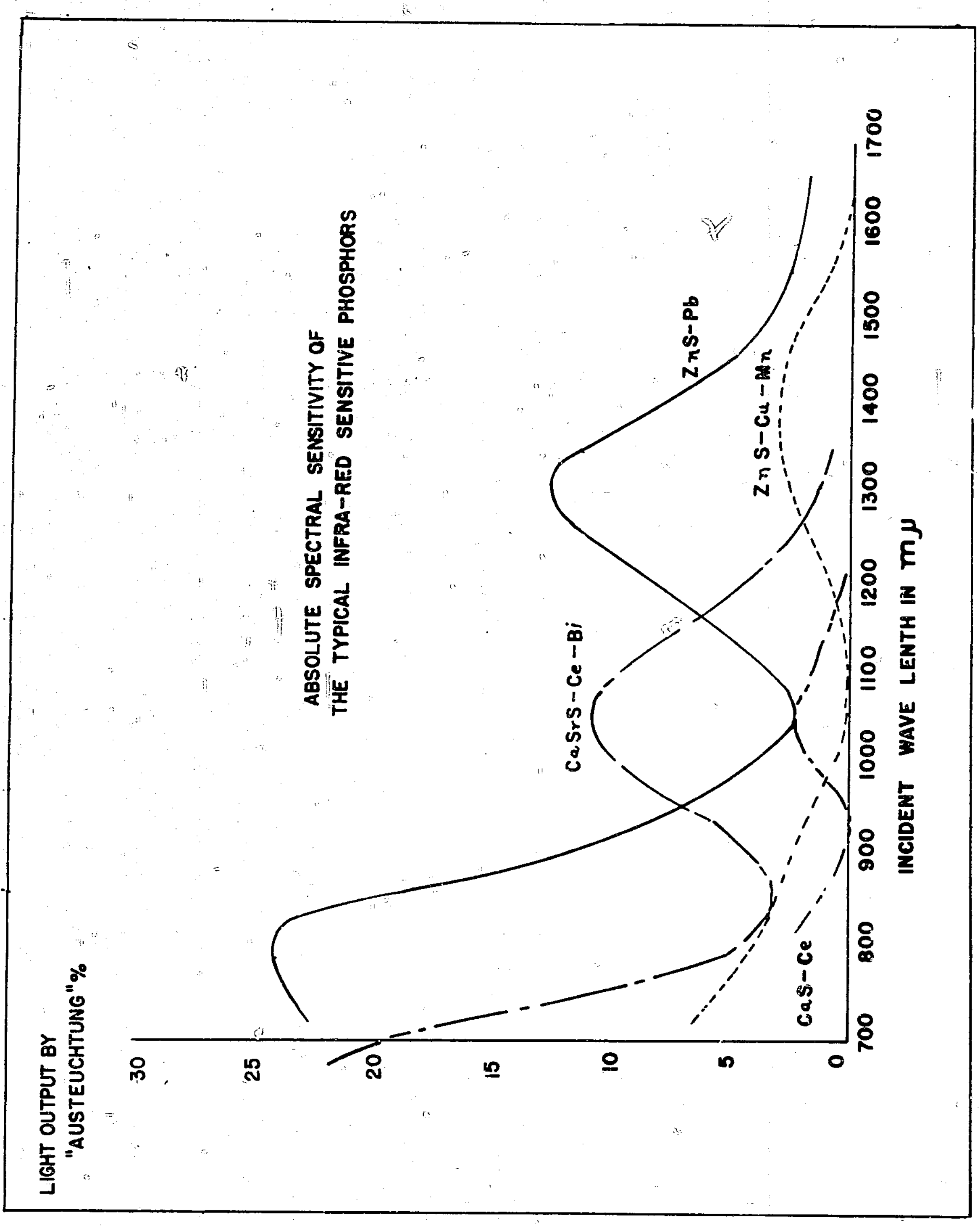
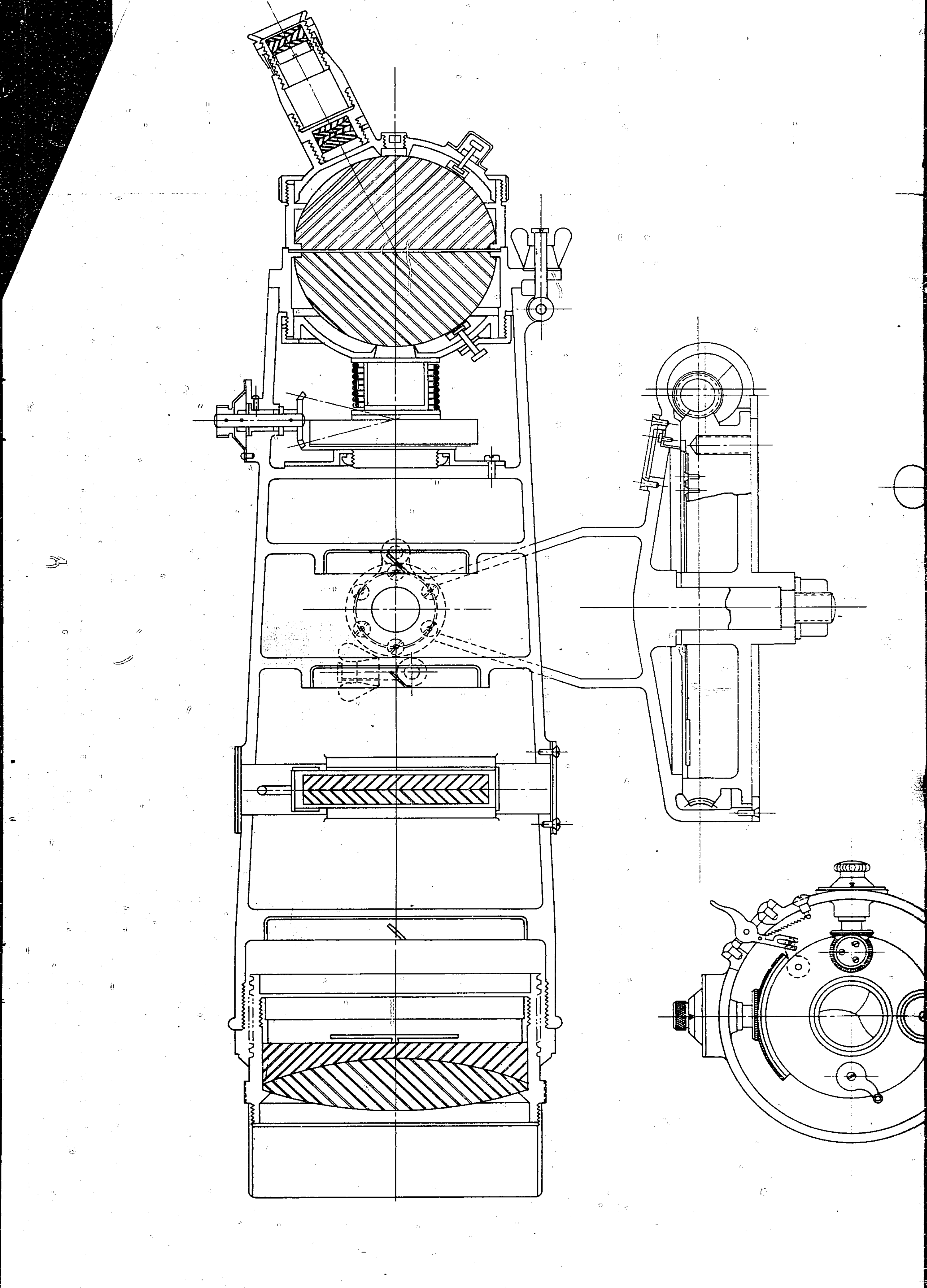
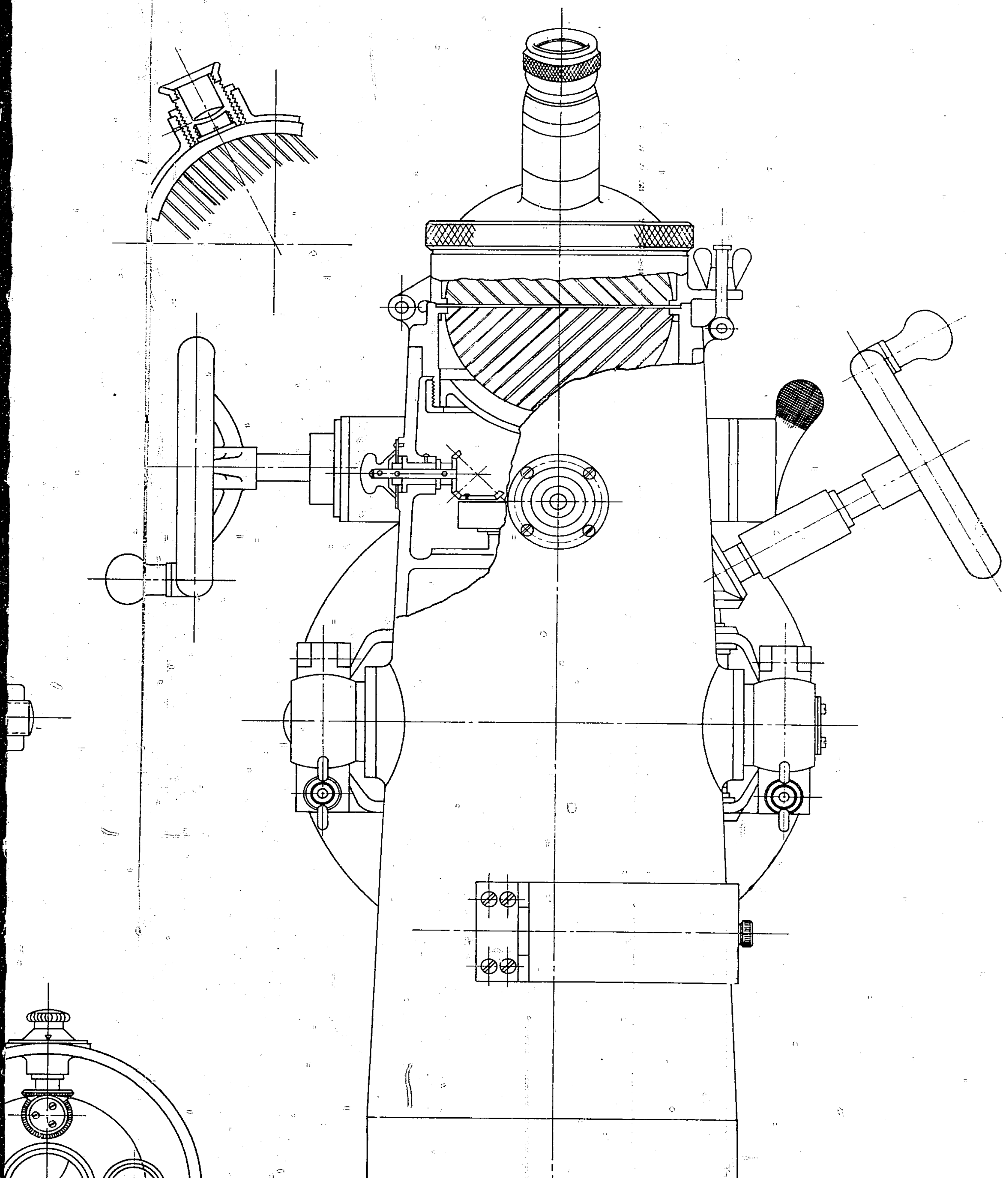


Figure 2(F)
ABSOLUTE SPECTRAL SENSITIVITY OF
THE TYPICAL INFRA-RED SENSITIVE PHOSPHORS

RESTRICTED





when the lamp is faintly recognized as a red spot by the naked eyes.

C. A head light of a motor car (6V-32 watt, with a reflector) covered with a Wratten No. 87 filter can be detected by the same detecting device as above at a distance of about 4000 meters.

D. The light of a city house at a distance of about 4000 meters can be detected by a combination of the ZnS-Pb screen and a wide apertured telescope (F/3.5, diameter of the objective 10cm) covered with a Wratten No. 87 filter. The structure of this specially devised telescope is shown in Figure 3(F). The screen is situated in the center of a collecting sphere. The scattering losses of the incident infra-red rays and the emitted light by "Ausleuchtung" are thus recovered, and concentrated at the center.

VI. Data for Some ZnS and ZnCdS Phosphors for the Noctovision Image Tube.

Relative Fluorescence Efficiencies by the Cathode Rays of very weak Current Density.

Phosphor Sample**	Color of Cathode Ray Fluorescence	Threshold Conditions for Fluoresence to Be Visible to Eyes			Light out-put under 4000 V, $10\mu A/cm^2$*	Remarks
		Voltage of Cathode Rays	Current Req.*			
			Density	Watt		
1. ZnS-Ag	blue-violet	715	12	1	1	degree of calcination small; Fluorescence with some afterglow.
2. Zn_2SiO_4-Mn	green	858	15	1.36	0.70	Commercial Product from U.S.A.
3. ZnS-Ag	blue-violet	1120	20	2.44	1.09	degree of calcination larger than 1.
4. ZnCdS-Ag	yellow	1240	22	2.91	0.52	Zn:Cd=7:3^{mol}
5. ZnS-ZmSe-Ag-Mn	yellowish white	1620	29	4.77	0.73	S:Se=7:3^{mol}
6. AnS-Ag	blue-green	3030	53	17.4	0.67	degree of calcination larger than 3

*Relative values. **Products of this Lab, except No. 2.

VII. ZnS-CdS Phosphors for Cathode Ray Tubes.

Excellent specimens were as follows:

ENCLOSURE (F), continued

A. Doubly activated ZnS-CdS phosphors

$$Zn:Cd = 0.9:0.1^{mol}$$

Activators: Cu $5 \times 10^{-5\text{mol}}$/mol ZnS
Ag $2 \times 10^{-4\text{mol}}$/mol ZnS

Fluxes: Mixtures of 2 mol % of KCl, NaCl, $CaCl_2$, $BaCl_2$ for mol ZnS

Calcination: Slowly heated up to 1200°C, where retained 2 hrs, then rapidly cooled.

B. Mechanical Mixture of ZnS-Ag and ZnCdS-Cu phosphors

ZnS-Ag, the blue component

$$Zn:Ag = 1:10^4 \text{ mol}$$

Flux: 3 mol % of KCl for mol ZnS

Calcination: Slowly heated to 1000°C, retained there about 5 hrs, then slowly cooled.

* * *

ZnCdS-Cu, the yellow phosphorescent component

$$Zn:Cd:Cu = 0.9:0.1:10^4 \text{ mol}$$

Fluxes: Mixtures of 5 mol % of KCl and 2 mol of $BaCl_2$ for mol ZnS.

Calcination: Rapidly heated to 1300°C, retained there 1.5 hrs, and then rapidly cooled.

Mixing ratio of the blue to the yellow component from 2:8 to 4:6.

VIII. List of Phosphor Samples and Methods of Spreading on Plates, Tubes, Etc.

1.	ZnS-Pb for infra-red ray detection by "Ausleuchtung".	Solid paraffin, Zapon lacquer (a kind of cellulose lacquer), artificial resins can be used as binder.
2.	CaSrS-Bi-Ce for the samp purpose as above.	This sample is very weak to moisture. Only solid paraffin or artificial resins are used as binder.
3.	Zn-Cu-Co for infra-red ray detection by "Tilgung".	The treatment is the same as 1.
4.	ZnS-Cu for cathode ray image tube for noctovision.	Sulphur, water glass, and boric acid are preferably used as binder. Precipitation method or dusting method are usually adopted.
5.	ZnCdS-Ag-Cu for cathode ray radar tube.	The treatment is the same as 4.

ENCLOSURE (F), continued

6.	ZnS-Cu for long life phosphorescence by ultra-violet ray (color: green).	The treatment is the same as 1.
7.	ZnCdS-Ag for ultra-violet ray use, characterized by the green **fluorescence with rapid** response to excitation.	The treatment is the same as 1.

ENCLOSURE (G)

SENSING UNIT OF HEAT HOMING BOMB

Extracts from NavTechJap Report, "Japanese Infra-Red Devices, Article I - Control for Guided Missiles", Index No. X-02-1.

A. Head Unit: The head unit was a wooden frame in which were mounted the bolometer, mirror, motor, distributor, amplifier, relay box, and battery case.

B. Window: The heat transparent window in the front of the bomb was a membrane of chloride of rubber 10 microns thick, and 40cm in diameter. Support was provided by a mesh of piano wire forming 40 one-centimeter squares directly behind the window. Transmission of the window substance was given at 80% throughout the infra-red spectrum with a slight drop in the 10 micron region. It was stated that little harm was done by direct sunlight.

C. A rotating eccentric mirror was set in the back of the head. It was driven by a small electric motor mounted directly behind the mirror. This motor also operated the revolving contact of the distributor. The scanning angle of the focal axis could be altered between 15 and 30 degrees from the bomb's axis of flight.

D. Bolometer:

1. Construction and composition of bolometers for the heat homing bomb were said to have been similar to those used in the Heat Ray Detector, for which the following data was obtained:

Composition: Nickel

Thickness: 2 Microns

Sensitivity: 1/30°C at 1 Meter: laboratory test man's face at 100 meters (327 ft) 1000-ton ship from 2000 meters (6,600 ft) under ideal conditions.

Background for Research: Paper by Dr. Strong at Naval Research Laboratory, 1932.

2. In B-1 bombs, the bolometer strips were mounted behind a rock salt window 1.5mm thick in an air tight case. Individual strips were mounted in a bakelite base by brass pins. Various configurations were used or contemplated. The head found at Matsumoto used four strips.

3. Heat concentrations located between the 40 degree cone maximum view and the 15 degree blind spot cone were focused upon the bolometer head by the mirror system of the bomb. The locus of a single heat spot ahead of the bomb focused on the bolometer head as a circle around the outside of the head. A resistance change in a bolometer strip caused by an off center heat signal upset the balance of a Wheatstone Bridge, allowing a signal from a local oscillator to be fed to an amplifier.

E. Control System. The amplifier was contained in a metal case mounted in the head frame behind the mirror. Four control relays known collectively as the "Second Relay" were mounted on a chassis fastened to that of the amplifier. Batteries supplying power for the amplifier and motor were located in the rear of the head frame, directly before the warhead.

A local oscillator impressed a signal of 2000 cycles across the Wheatstone Bridge. A change of resistance in a strip upset the bridge, allowing a portion of the oscillator signal, proportional in amplitude to the change of

ENCLOSURE (G), continued

resistance (hence intensity of heat signal), to be fed to the amplifier. Miscellaneous frequencies such as random noise would not be passed by the amplifier which was tuned to the oscillator frequency of 2000 cycles. When a signal caused over 1 ma plate current to flow through the final stage, the first relay would close. A "threshold" potentiometer was located in the previous stage determining the amplitude of signals required to activate the first relay. The closing of this relay grounded the rotating arm of the distributor, causing one of the four second relays to close. The distribution arm and mirror were driven together by the same electric motor, (1 1/2 RPM) and the practicular circuit with which the arm was in contact at any instant was the one whose activation would alter the course of the bomb towards the direction the mirror was looking. Thus, the second relay closed and energized a solenoid, which through a mechanical link controlled an oil valve on the servo controls to steer the bomb in the required direction.

ENCLOSURE (H)

METHOD OF MANUFACTURING IMAGE TUBES AT HAMAMATSU HIGHER TECHNICAL SCHOOL

A report of the interrogation of Prof. T. HORII, and assistants, giving a detailed account of steps in the manufacture and principal acceptance tests for the Army type image tubes.

Personnel Interrogated: Prof. Takashi HORII
Asst. Prof. Ryoso NISHIDA
Asst. Prof. TAKAGI.

1. A detailed account of the process for making image tubes was obtained, as follows:

a. <u>Preparation of Material for Fluorescent Screen (Zn_2SiO_4 Activated With Mn)</u>. Zinc nitrate ($Zn(NO_3)_2$) is mixed in ethyl silicate ($(C_2H_5)_4SiO_4$) and manganese nitrate ($Mn(NO_3)_4$) added. The mixture is then placed in a crucible and sintered at 900°C for one hour. The maximum sensitivity of the phosphor for the exciting wavelength is a function of the ratio $ZnO:SiO_2$ by weight in the phosphor mixture. For maximum sensitivity to ultra-violet radiation, this ratio should be about 1:1; whereas, for mamimum sensitivity to electronic excitation, this ratio should be 2:1.

b. <u>Deposition of Screen</u>. The phosphor is suspended in water, no binder being used. The screen end (about 15cm long) of the tube is filled with the liquid and allowed to stand for about 15 hours. The remaining liquid is then decanted off, and the screen is dried slowly at 100°C in an oven. The size of the deposited particles is about 10 mu; the colloidal particles do not settle out.

c. <u>Manufacture of Electrodes</u>. The photo-cathode end of the tube is cut from a selected portion of a borosilicate glass spherical flask 45mm in radius, 1.0 to 1.5mm in shell thickness. The cathode is not ground or polished. The anodes are cut from a glass tube of the proper diameter and the edges are carefully ground. Liquid gold (colloidal gold dissolved in lavender oil, made by Hanovia, in U.S.A.) is painted onto the interior and edges of the rings with a brush, and baked at 500°C for several hours. A loose sleeve of mica is fitted so as to cover the openings between the anodes.

d. <u>Assembly of Envelope</u>. The anodes are fastened to the cathode half of the tube by small glass columns. The cathode lead is connected to the end of the tube with a graphite spot. All leads are of tungsten, and the contacts of nickel-plated bronze. The contacts are attached with gypsum, after sensitization of the cathode. Two side tubes are added to supply the calcium and silver for the photocathode sensitive surface. The one tube has a small neck or nozzle protruding inside of the noctovision tube, surrounded by a tungsten heater coil and aimed at the photocathode surface, and contains a small nickel capsule of calcuim chromate and silica in the side tube. The other contains a silver nodule on a tungsten heating coil in a glass cup also aimed at the photocathode surface.

e. <u>Alignments of Tube Ends</u>. The two ends of the tube are then aligned accurately, fused together, and the tube connected to a high vacuum pump through a liquid-air-cooled trap. A rotary pump reduces the pressure to 10^{-3}mm of mercury, and an oil diffusion pump further reduces it to 10^{-6}mm.

f. <u>Sensitization of Cathode</u>.

ENCLOSURE (H), continued

(1) Deposition of silver. The silver is evaporated by heating the tungsten coil. The proper thickness of silver is most important and is judged visually by the color change of the cathode. A lamp is placed beside the tube, and the color of the transmitted light observed. The color successively becomes reddish-yellow, yellow, orange, violet, cobalt blue, blue; the process is stopped as the color changes from violet to cobalt blue, at which point the light transmission is at a minimum and the sensitivity (emissivity) at a maximum; the thickness of the silver layer is about 8 millimicrons. The theory is that thinner layers are granular in texture and hence have low electrical conductivity, whereas thicker layers reduce the total emission.

(2) Oxidization. The stopcock leading to the pumps is closed, and a high frequency voltage (1700 kc, 500 v) is applied between the cathode and the anodes, which are connected together. Oxygen is introduced by heating potassium permanganate, from a flask connected to the system. When the cathode color disappears and it becomes perfectly transparent, the oxidization is stopped, and the tube again evacuated.

(3) Caesiation. The side tube containing caesium chromate is heated by an induction coil, causing caesium vapor to be deposited on the walls of the side tube. The tungsten coil is then heated and the caesium evaporated and deposited on the silver-oxide surface. The proper amount of caesium is important, and is again determined visually. A lamp is placed near the end of the tube and the color of the reflected light observed. This color successively becomes dark red, brown, golden yellow, cobalt blue. Caesiation is stopped when the cobalt blue color is obtained.

(4) Baking. The caesium chromate side tube is wrapped in asbestos paper soaked in water. (It is not removed at this time, since additional caesium may be required later in the process.) A light source of about 1 lumen is placed in front of the cathode (must be less than 5 lumens in order not to affect sensitivity) and the cathode and anodes (together) connected to a microammeter and 100 volt battery so as to measure photocurrent. An electric oven is placed over the tube, which is heated to 140°C for 20 minutes, and then allowed to cool to room temperature. The dark current is an important factor in measuring the effect of this "after treatment", and is a measure of the proper quantity of caesium. It should be from 5 to 15 microamperes for a 30mm cathode; if greater, more caesium is required, and is evaporated from the side tube.

(5) Evaporation of silver. Silver is again evaporated from the side tube. The quantity is not important. During this process the photocurrent will increase 10 to 20% (to 12 microamps).

(6) Baking. The oven is replaced and the tube heated to 140°C for 5 to 10 minutes and then cooled to room temperature. The exact timing is not critical. The photocurrent builds up (17 microamps).

(7) Heating. The entire tube, except for the cathode, is heated with a bunsen burner. This removes the free caesium from other parts and deposits it on the cathode. The photocurrent drops sharply because of the excess of caesium (to 6 microamps).

(8) Oxidation. Oxygen is again admitted as in step (2); the amount is very critical, and is determined by observing the photocurrent.

ENCLOSURE (H), continued

After passing a maximum, the photocurrent decreases abruptly (to 8 microamps); as soon as this takes place oxidation is stopped. (The ratio of caesium to oxygen should be 2:1). The tube is again evacuated.

(9) Baking. The tube is again baked at 140°C for about 10 minutes, then cooled to room temperature. During baking, photocurrent builds up to a new maximum (19 microamps).

(10) Evaporation of silver. Silver is again evaporated from the side tube. The photocurrent again increases 50% to 100% (29 microamps).

(11) Baking. The oven is replaced and the tube baked for a short time for stabilization.

(12) Oxidization. Oxygen is again admitted, and when the photocurrent reaches a maximum, the oxygen is stopped and the excess oxygen pumped off. No getter is used. At this time the photocurrent should be about 26microamperes, or with a standard IRD-1 filter, about 6 microamps per lumen.

g. Sealing of Tube. The tube is sealed off and the caesium chromate side tube removed. The tube is held in a vertical position with the cathode end up and tapped gently so that the mica ring falls down inside the largest anode. The tube is now complete.

2. Every tube is tested for sensitivity, flash voltage, and resolution, as follows:

a. Sensitivity. A standard lamp (furnished by the Army as standard, probably about 0.6 lumen, 2700°K.), is filtered by a standard IRD-1 filter, 3mm thick, full voltage applied, and the photocurrent measured. The minimum acceptable is 3 microamps per lumen; the maximum obtained 6.6 microamps per lumen.

b. Flash voltage is tested, minimum acceptable 7000 volts.

c. Resolution is measured with a lined screen projected on the photocathode. The standard pattern had black and white lines of equal width. The minimum acceptable was 0.3mm wide (17 lines/mm), the maximum obtained was 0.2mm wide (25 lines/mm).

(1) The length of life of the tubes was stated to be indefinite. In the only test run, after 90 hours of operation at full voltage with the cathode illuminated, no drop in sensitivity had occurred. The long wave length cut-off of the average tubes was 1200 mu. The operating voltages on the anodes was 100 (variable) - 200 - 3000 volts. In the latest tubes the high-voltage anode was operated at 7000 volts, this improvement resulting from the use of the mica ring during caesiation.

(2) Some work was done on infra-red iconoscopes, which were simply noctovision tubes combined with image iconoscopes. The best plate material was found to be Al_2O_3. This work had not reached a successful stage before the end of the war.

3. A graph showing the effect of the various steps in sensitization on the photocurrent is shown in Figure 1(H) and a sketch of the sensitization apparatus in Figure 2(H).

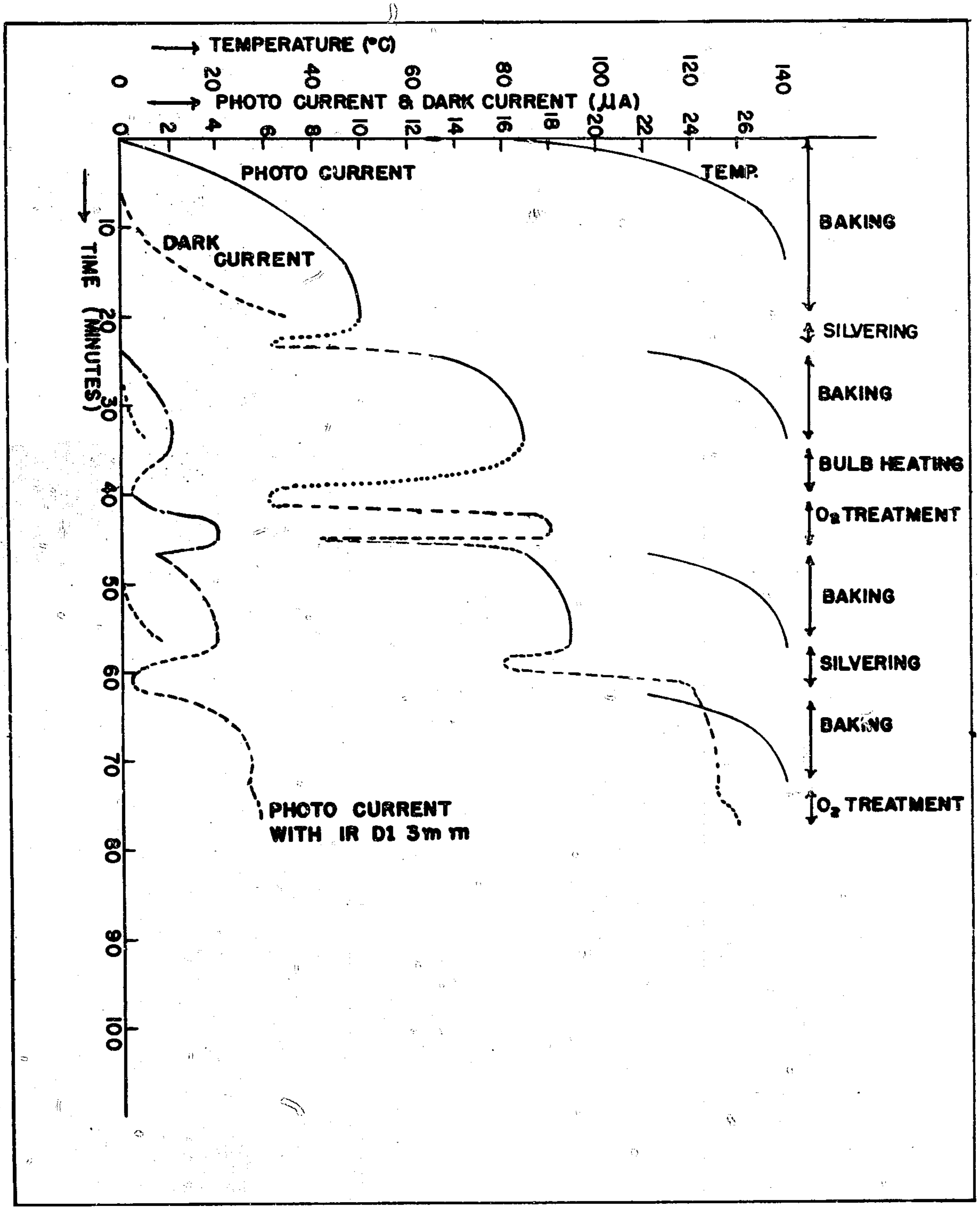


Figure 1(H)

EFFECT OF "AFTER TREATMENT" AS MEASURED BY PHOTO CURRENT

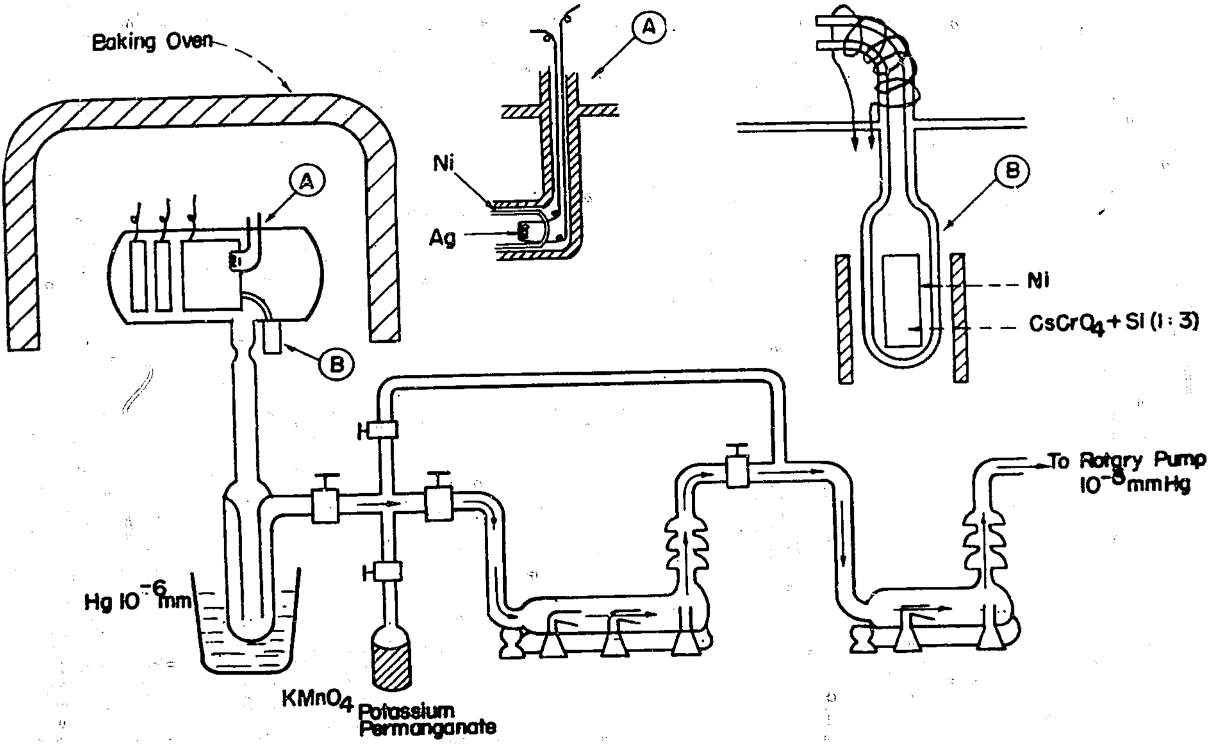


Figure 2(H)

APPARATUS FOR SENSITIZATION OF PHOTOCATHODE

ENCLOSURE (I)

METHOD OF MANUFACTURING IMAGE TUBES
AT TOKYO SHIBAURA ELECTRIC CO.

Detailed account of steps in manufacture for the Navy type tubes.

Personnel Interrogated: Dr. S. HAMADA
Dr. M. NAGASHIMA

The following are the steps in the sensitization:

a. Evaporate silver, the amount being gauged by judgment of color, which is successively yellow, blue, transparent, and silver. The evaporation is stopped at the end of the "transparent" period.

b. Oxidize silver until cathode is completely transparent.

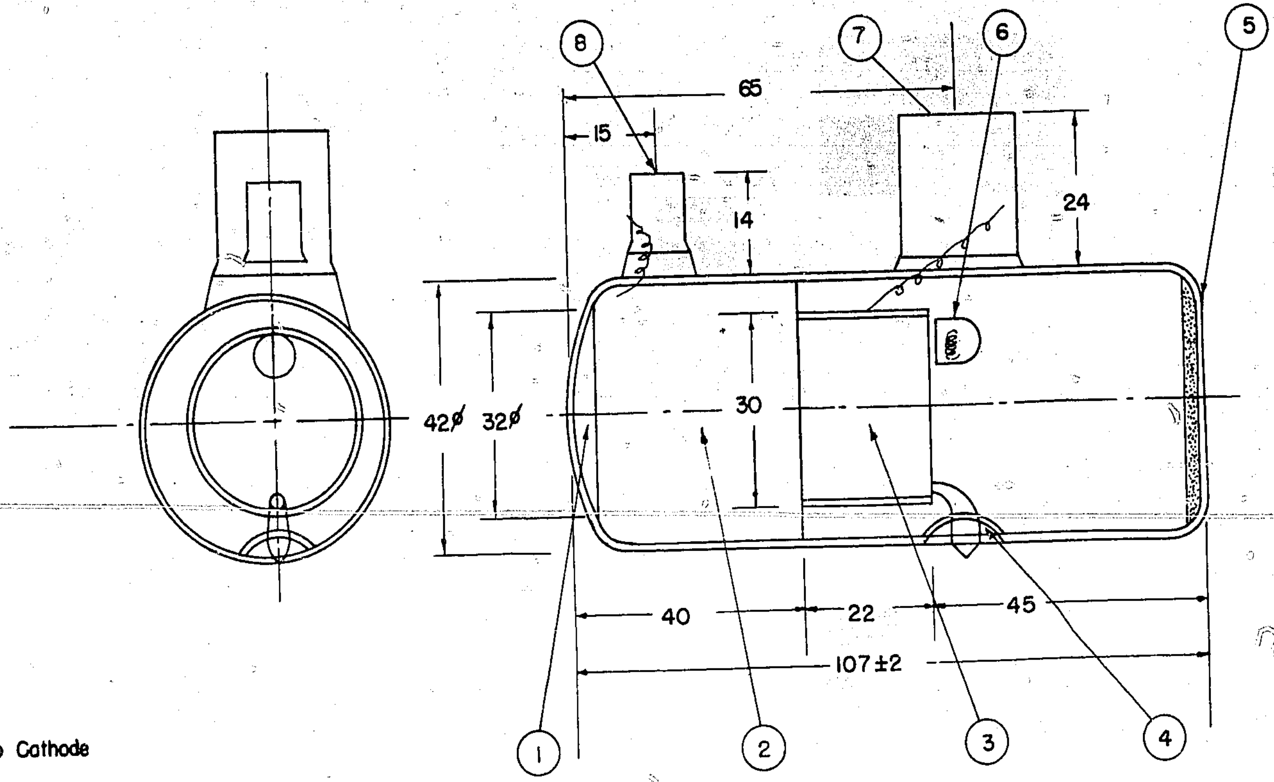
c. Evaporate caesium, (amount predetermined by weight in side capsule). Evaporated in induction furnace, and deposited on platinum of electrode.

d. Cut off side capsule and remove vacuum pump.

e. Store for 24 hours. Caesium will move by vapor pressure to silver of cathode. (This statement in question, as tubes contain heating wire for driving caesium from side tube onto cathode.)

f. Evaporate silver at 150°C, 30mm pressure.

g. Flash getter - Barium-tantalum (Batrium). Production tests were conducted to measure luminous output (min. 4 microamps/lumen), break-down voltage (min. 6000 volts), and resolution (min. 12 lines/mm). The overall yield was stated to be 50%, although NAGASHIMA admitted that he was unable to produce the tubes in quantity. Lack of "sensitivity" was stated to be the principal cause of rejection, the lack caused by low luminous output of the cathode or by an inaccurately placed anode. It was recognized that higher voltage would produce better results, but the construction of the tube did not permit more than 6000 volts. The latest step to increase insulation and decrease cold cathode discharge was to place an aquadag ring around the cathode and coat the outside surface of the tube with paraffin. A sketch of the general arrangement of the image tube is shown in Figure 1(I).



① Photo Cathode
② Cathode Ring
③ Anode Ring
④ C_s Introducing Tube
⑤ Fluorescent Screen
⑥ Silver Capsule
⑦ Anode Terminal
⑧ Cathode Terminal

Figure 1(I)
GENERAL ARRANGEMENT OF TOKYO SHIBAURA IMAGE TUBE

ENCLOSURE (J)

INFLUENCE OF THICKNESS OF INITIAL SILVER LAYER ON SENSITIVITY OF PHOTOCATHODES

A report of experiments conducted at Kyoto University

By: S. KATO
Y. OTANI
N. INOUE

Kyoto Imperial University, March 1943

1. Introduction

Semi-transparent photocathodes are generally used for image tubes, as they are the most suitable from the viewpoint of electron optics. The sensitivity is generally proportional to the transparency of the sensitive film, particularly for thin films of the base metal silver. Thus, it would appear that the silver film should be as thin as possible. However, if the layer is too thin, the electro-conductivity of the film decreases, and accordingly the number of emitted electrons and, hence the sensitivity, also decreases. In order to determine the optimum thickness of the film, we measured the spectral transmission and electro-conductivity of various thicknesses of silver film.

2. Apparatus Used in the Experiment

Figure 1(J) shows the general layout of the apparatus used. "A" is a glass plate 10mm x 40mm x 1mm, shown in detail in Figure 2(J). Silver or aluminum electrodes were previously deposited by evaporation onto each end. Electrical contact is made by metal springs, with graphite on the contact surfaces. "B" is a filament used for vaporizing the silver. A pair of quartz windows are let into the tube parallel to and opposite the test plate, for measuring the transparency of the silver film.

The tube is evacuated to less than 10^{-5}mm. Hg and silver are gradually evaporated. The electrical resistance and coefficient of spectral transmission are measured at every stage of silver deposition. Under 10,000 ohms the resistance is measured by a Wheatstone bridge; over 10,000 ohms it is measured by comparison with a standard resistance.

The apparatus shown in Figure 3(J) is used for measuring the spectral transmission. "Q" is a 500 watt tungsten lamp; "sp" is a quartz monochrometer; "Te" is a thermopile; and "G" is a galvanometer.

It proved very difficult to measure the thickness of the silver film directly, and the following method was developed. The weight of the silver nodule to be evaporated was determined as accurately as possible before being placed in the apparatus. When the filament is first heated the silver does not evaporate, but begins after 2 or 3 seconds. The amount evaporated can be assumed to be proportional to the time of heating. We also assumed that the silver would be deposited evenly on a spherical surface, with the nodule at its center.

If D is the distance between silver nodule and surface to be silvered
m is the weight of silver to be evaporated
d is the density of silver
t is the mean thickness of film when all of silver is evaporated

Then
$$t = \frac{m}{4\pi D^2 d}$$

To check this calculation, we completely evaporated definite amounts of silver, and measured the thickness, resistance, and transparency.

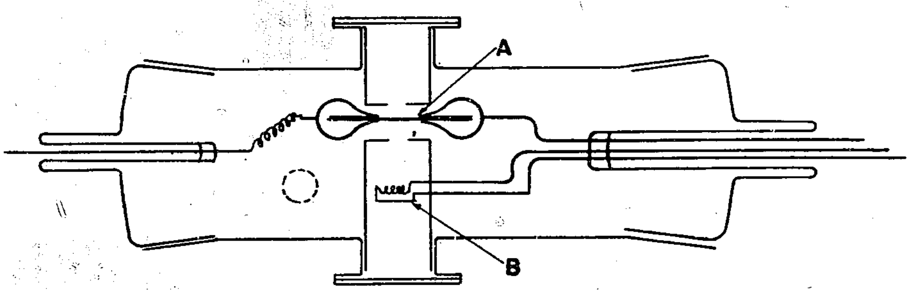


Figure 1(J)

APPARATUS FOR MEASURING SPECTRAL TRANSMISSION AND ELECTROCONDUCTIVITY OF SILVER FILM

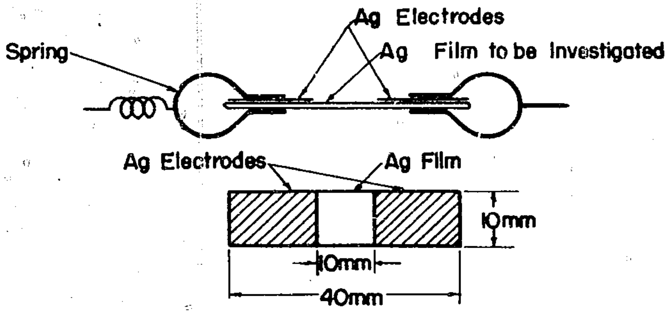


Figure 2(J)

DETAIL OF TEST PLATE

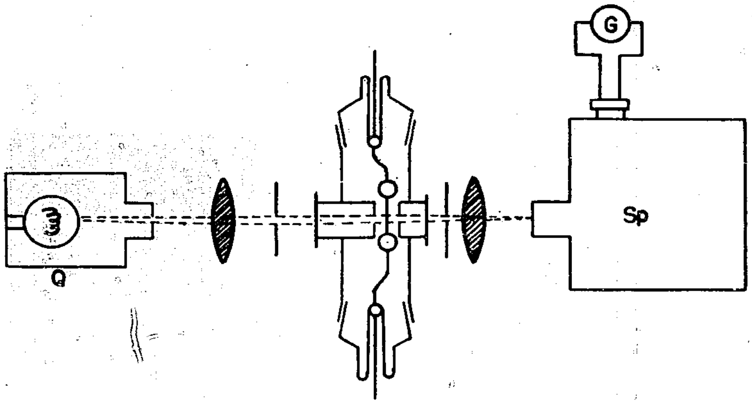


Figure 3(J)

APPARATUS FOR MEASURING SPECTRAL TRANSMISSION

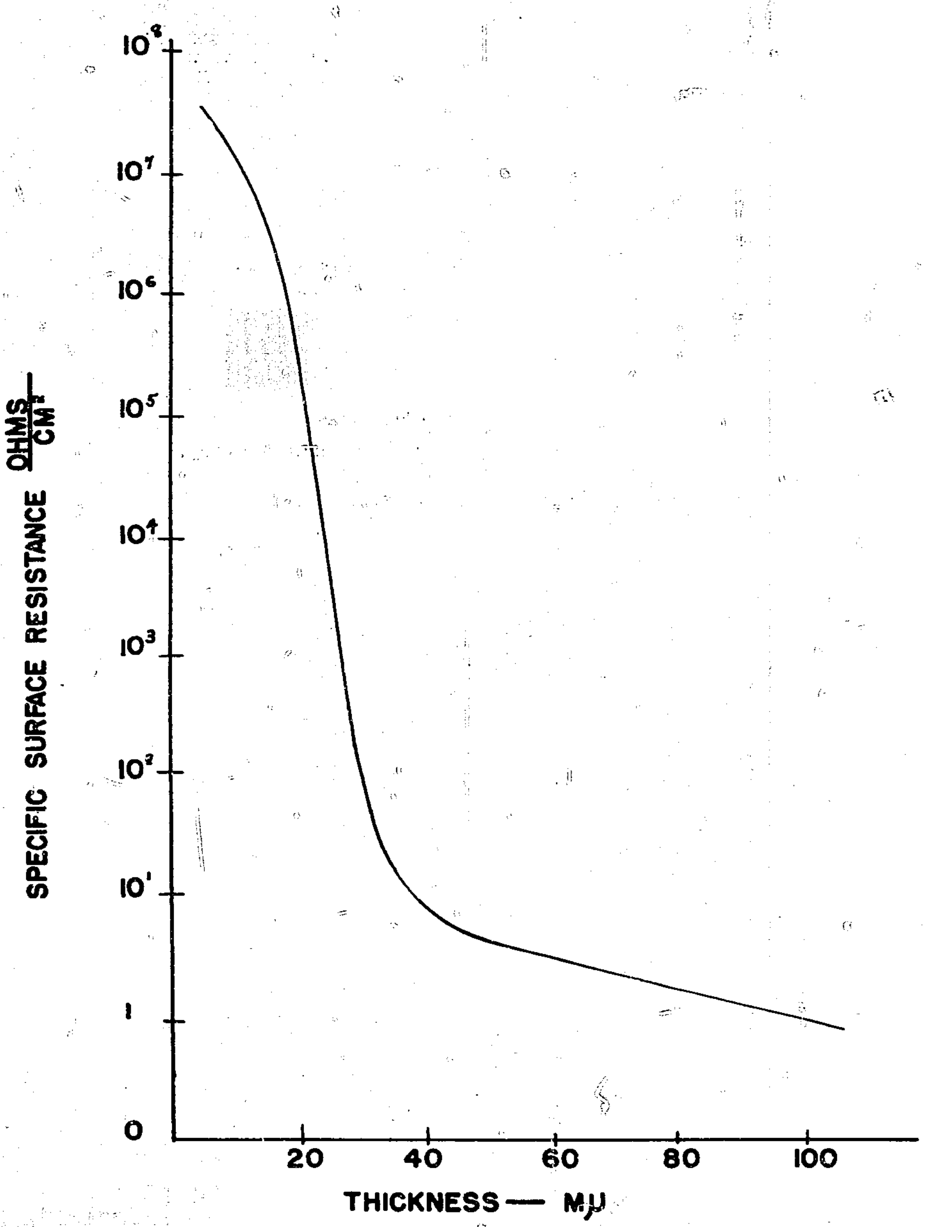


Figure 4(J)

RESISTANCE - THICKNESS OF Ag FILM

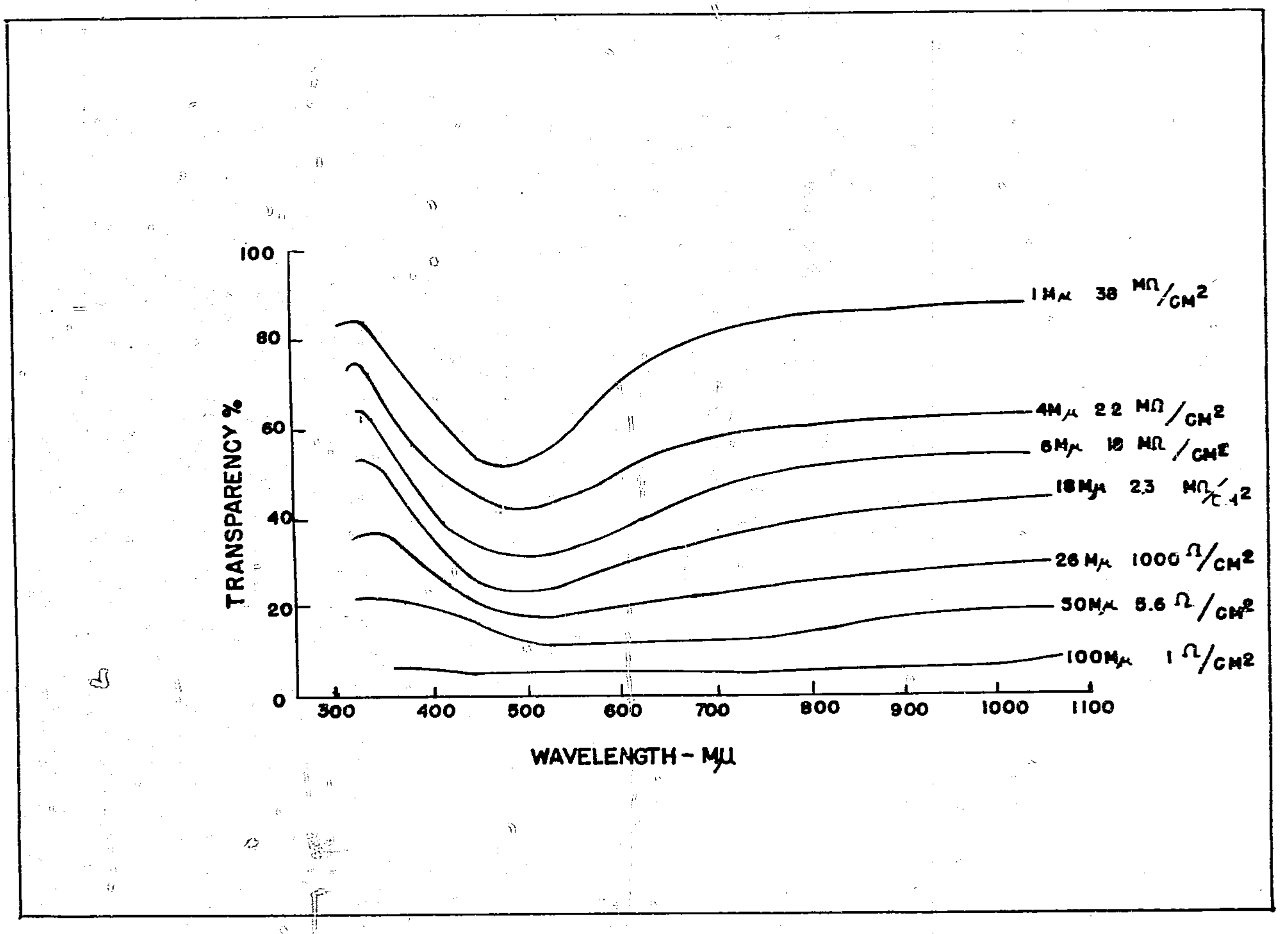


Figure 5(J)

COEFFICIENT OF SPECTRAL TRANSMISSION OF SILVER FILM

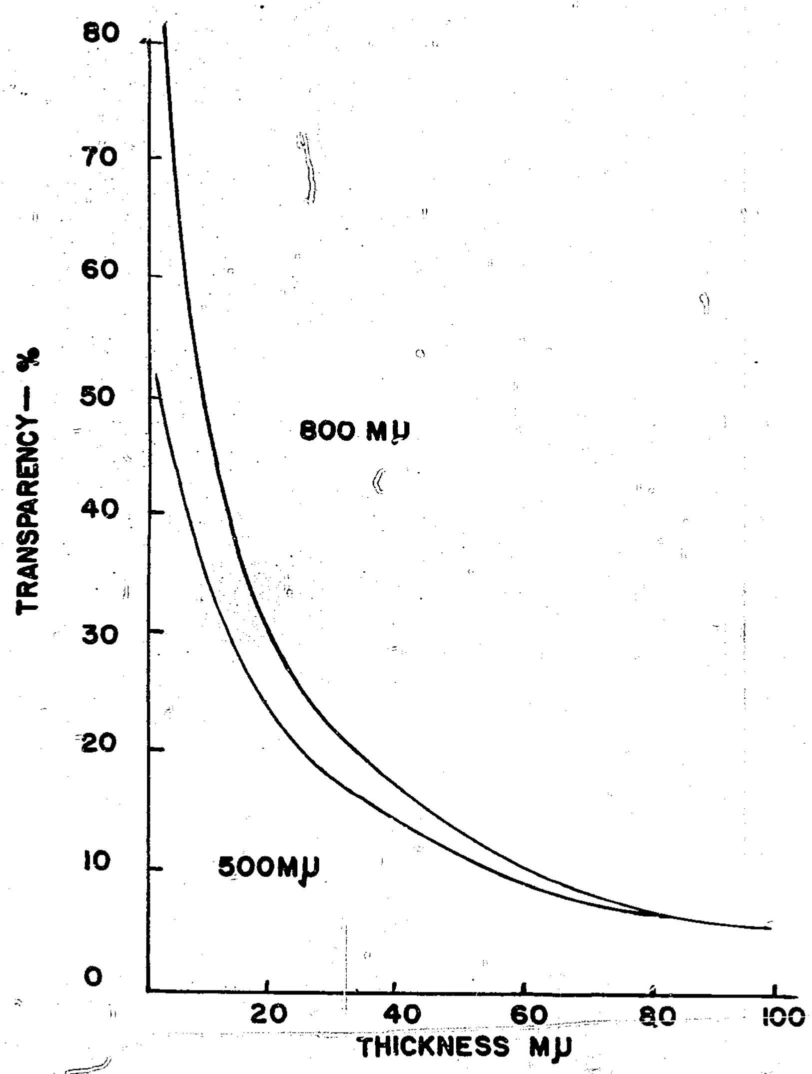


Figure 6(J)
TRANSPARENCY AND THICKNESS OF Ag FILM

ENCLOSURE (J), continued

3. Experimental Results

All measurements were repeated at least 10 times, and the results considered most correct are shown in the following figures. Figure 4(J) shows the relationship between the thickness of the film and the specific surface resistance. It can be seen that when the layer is more than 10 millimicrons thick the resistance falls off rapidly, and when more than 30 milimicrons thick it decreases more slowly. The value of the resistance also varies with aging. When the thickness is less than 30 millimicrons the resistance increases with time, and reaches a stable value after 10 minutes, thinner layers taking longer time to reach a stable value. When the thickness is greater than 40 millimicrons the resistance decreases with time, and thicker layers reach a stable value more quickly. Figure 5(J) shows the coefficient of spectral transmission for various thicknesses of silver film and Figure 6(J) shows the relation between the coefficient of spectral transmission and the thickness of the silver film for specific wavelengths. It will be noted that when the film is thin, the spectral transmission curves have a peak under 400 millimicrons and a valley near 500 millimicrons. There is no such selective transparency in the infra-red region.

4. Discussion of the Results

In making up photosensitive surfaces, silver is first evaporated, and, after oxidation, caesium is evaporated on to the film. The film is then heat treated, more silver evaporated, and then again heat treated. Usually the silvering and heating is repeated, and the surface is completed. The oxidation of the silver produces Ag_2O, which is a semi-conductor and nearly transparent, so that electro-conductivity decreases and transparency increases. After the addition of caesium and heat treatment, the Ag_2O is reduced and granular Ag is formed in Cs_2O. By additional evaporation of silver and heat treatment, some of the silver goes into the middle layer, so that the electro-conductivity increases and the transparency decreases. When the process is completed, the electro-conductivity and transparency do not, of course, have the same values as those of the original film. Nevertheless, the thickness of the initial film is most critical in determining the quality of the photosensitive surface.

We will further consider the influence of the thickness of the initial film on the sensitivity. If it is assumed that the "after treatment" (i.e. after the first oxidation) be kept the same, then the sensitivity will be proportional to the thickness of the silver film. When this film is thick, the intermediate layer of Cs_2O also is thick. (In this case oxidation must proceed so that the Ag_2O and Cs_2O layers are thick, but the base Ag film remains thick enough to maintain electro-conductivity.) Then the number of active spots on and in the intermediate layer increases as do the number of caesium atoms which are the centers of photoemission; hence the sensitivity increases.

The sensitivity of the photoelectric surface is proportional to the transparency of the film, when the light is incident on the side next to the glass. As the light intensity increases the number of photoelectrons emitted also increases. The transparency of the entire photosensitive layer can be assumed to be proportional to the transparency of the initial layer, and hence the sensitivity is proportional to the transparency of the initial layer.

If S is sensitivity
t is thickness of the initial silver film
I is intensity of light after passing through the initial silver film only

Then $S = AtI$ (A = proportional constant)

ENCLOSURE (J), continued

If I_o is intensity of the incident light
a is coefficient of absorption of silver film

Then $$I = I_o e^{-at}$$

or $$S = AtI_o e^{-at}$$

When I_o is constant, S will have a maximum value when $t = \frac{1}{a}$
(Calculated from $\frac{ds}{dt} = 0$)

We can calculate a from Figure 6(J).

If P is the transmission coefficient in percent

Then $$P = \frac{I}{I_o} \text{ x } 100 = 100e^{-at}$$

$$a = \frac{2.3}{t} (2 - \log_{10}P)$$

For 800 millimicrons, from Figure 6(J), we have

$$P = 70\% \quad t \doteqdot 5m\mu \quad a = 0.69 \text{ x } 10^6 \text{ cm}^{-1}$$

$$P = 50\% \quad t \doteqdot 10m\mu \quad a = 0.69 \text{ x } 10^6 \text{ cm}^{-1}$$

$$P = 30\% \quad t \doteqdot 20m\mu \quad a = 0.69 \text{ x } 10^6 \text{ cm}^{-1}$$

$$\text{mean } a = 0.66 \text{ x } 10^6 \text{ cm}^{-1}$$

So that $$t = \frac{1}{a} = 15 \text{ millimicrons}$$

At this thickness the transmission coefficient for 800 millimicrons is about 40% and the resistance some megohms per sq. cm. The value of the resistance seems rather large, but it varies with the treatment, and in the real tube, the photocurrent is in the order of microamps and the anode voltage several kilovolts, so that the potential drop at this resistance does not greatly affect the electron supply. On the other hand, the adequate potential distribution over the surface seems to have a good effect on the aberration of the electron lens.

5. Conclusions

From the above experiments and calculations it can be concluded that the optimum thickness of the initial silver layer is 15 millimicrons. Experimental tubes built with such layers have given good results.

In this experiment, we have only investigated the thickness of silver film. We now plan to investigate the oxidation, caesiation, heat treatment, and sensitization, by measuring the electro-conductivity and spectral transparency at every stage. By this study we will be able to find out the optimum thickness of silver film, and also learn more about the mechanism of photoemission.

It is clear from the results that a silver film has some defects as a base metal, both in transparency and in electro-conductivity. We plan to investigate other base metals, particularly platinum. We intend to deposit sufficient platinum on a glass plate to give the surface conductivity, and then to deposit silver and by a heat treatment make a silver film mosaic and then sensitize the film. By this treatment, we expect to increase the transparency and the area of the sensitive surface, and hence the sensitivity will also increase.

ENCLOSURE (K)

INFLUENCE OF AMOUNT OF CAESIUM ON SENSITIVITY OF PHOTOCATHODES

A report on experiments conducted
at Kyoto Imperial University

By: S. KATO
Y. OTANI
N. INOUE

March 1943

1. Introduction

In our first report Enclosure (J), we described the method of preparing non-transparent and semi-transparent cathodes, and the effect of the initial silver layer on photosensitivity. In this paper we will discuss the research on the relationship of the amount of caesium to the sensitivity of the photocathode.

The best photocathode now known is the so-called caesium photocathode, which has a composition Ag-Cs_2O-Cs-Ag-Cs. The steps usually followed in preparation of this cathode are (a) deposition of silver, (b) oxidation, (c) caesiation, (d) heat treatment, and (e) sensitization by deposition of silver. In these experiments we kept constant the conditions of oxidation and heat treatment and changed only the amount of caesium and measured its effect on the sensitivity.

2. Method of Experiment

A spherical test cell, as shown in Figure 1(K), was used for this experiment. Silver was evaporated onto the cathode surface and oxidized until the interference color reached the first red-brown. Then caesium was introduced and the tube heated at 120°C for 30-40 minutes. Silver was then introduced for sensitization and the heat treatment and silver evaporation repeated several times as necessary.

3. Amount of Caesium and Sensitivity

a. Non-transparent photocathode. After oxidation of the silver film, the tube was evacuated and caesium introduced. A powdered mixture of caesium chromate and silicon is contained in a nickel crucible in a side tube. This side tube is heated by a Bunsen burner from the outside, and caesium is reduced and deposited on the glass of the side tube. Then the side tube is heated and the caesium gradually driven into the main tube, where it is deposited on the oxidized silver surface. During this process we measured the photocurrent, with white light flooding the cathode. The photocurrent increases gradually to a maximum value as the caesium increases, and then falls off gradually. The color of the photosurface also changes, through reddish-brown, dark brown, green, blue, to reddish-yellow. (See Figure 2(K).) If the caesium is introduced too abruptly, the color changes too rapidly to be observed. The photocurrent reaches a maximum when the color is blue. At this point, it is believed, the reduction of silver oxide is ended, and caesium atoms begin to adhere to the surface of the film. As more caesium is added, the color changes to reddish brown and golden yellow, and does not change further. This indicates that the silver oxide is completely reduced and caesium atoms are accumulated on the Cs_2O.

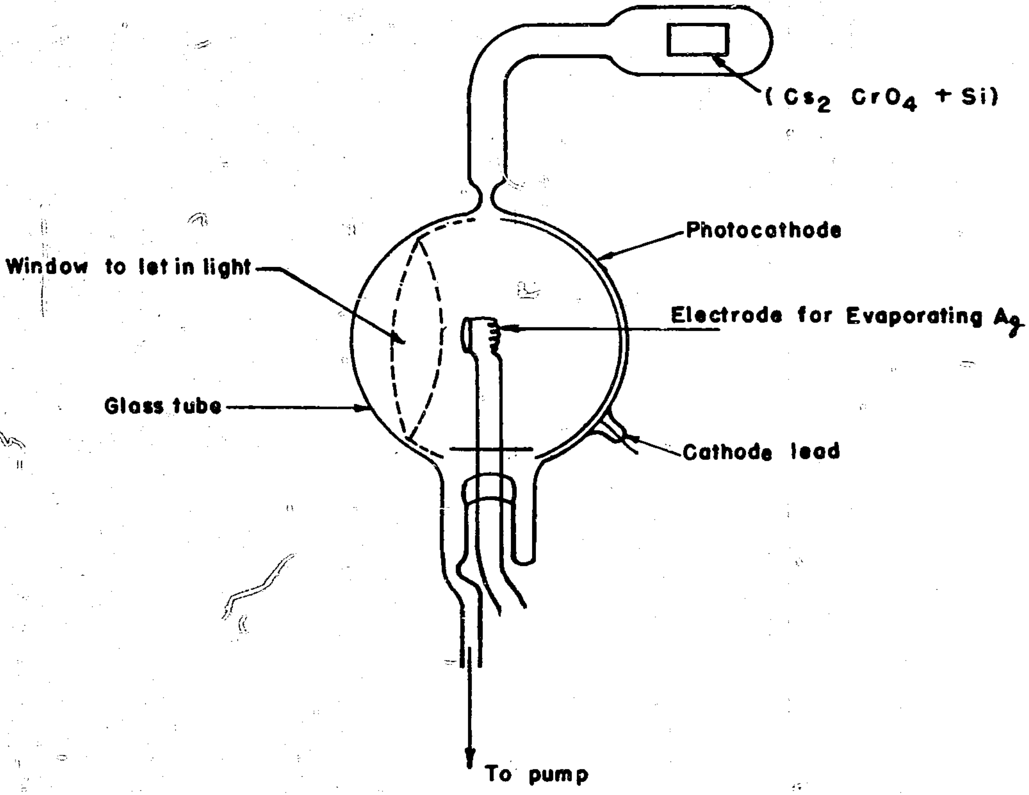


Figure 1(K)
APPARATUS FOR SENSITIZATION OF PHOTO CELL

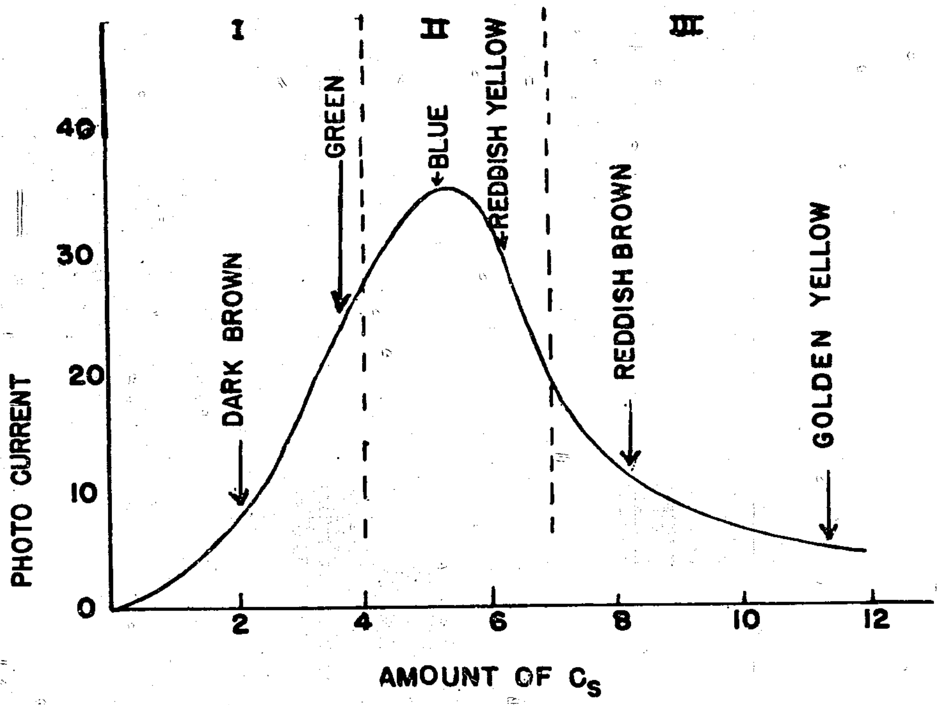


Figure 2(K)
NON-TRANSPARENT PHOTOCATHODE

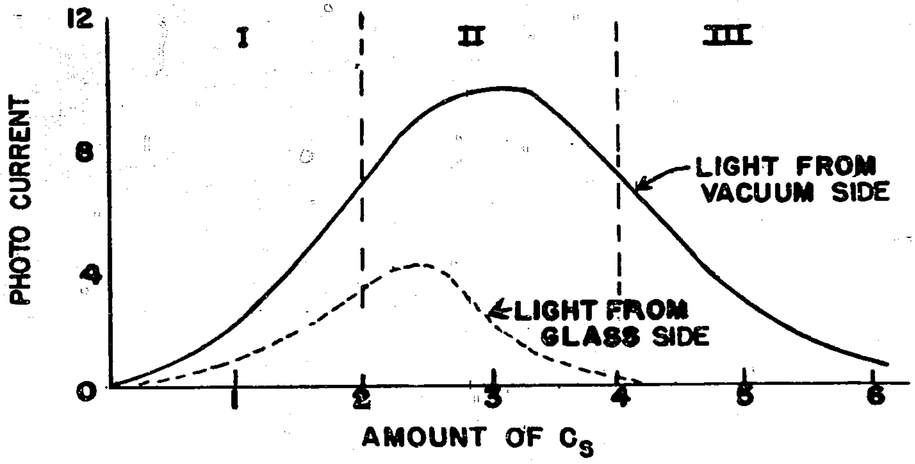


Figure 3(K)
iI-TRANSPARENT PHOTOCATHODE

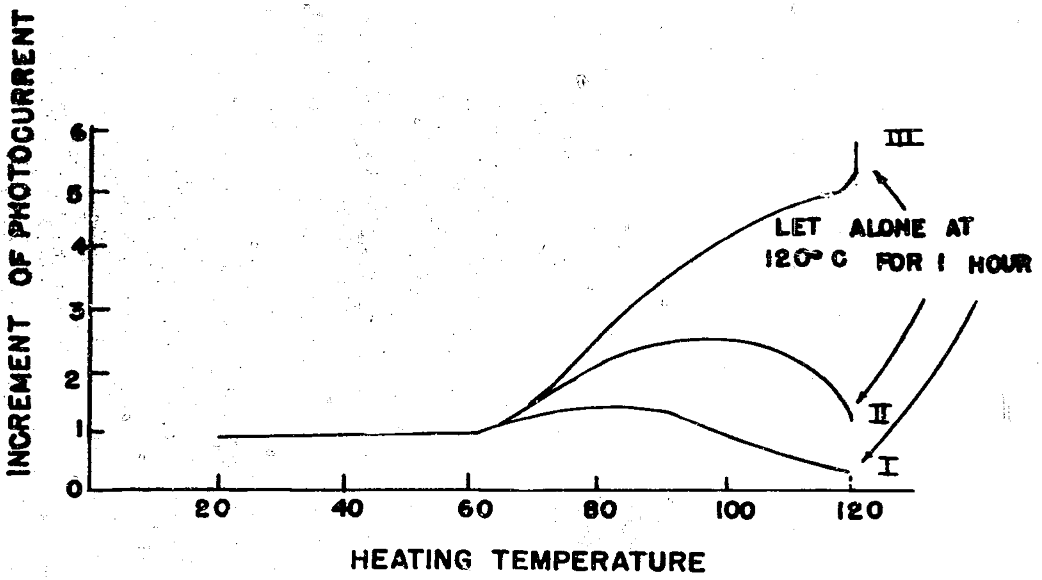


Figure 4(K)
NON-TRANSPARENT PHOTOCATHODE

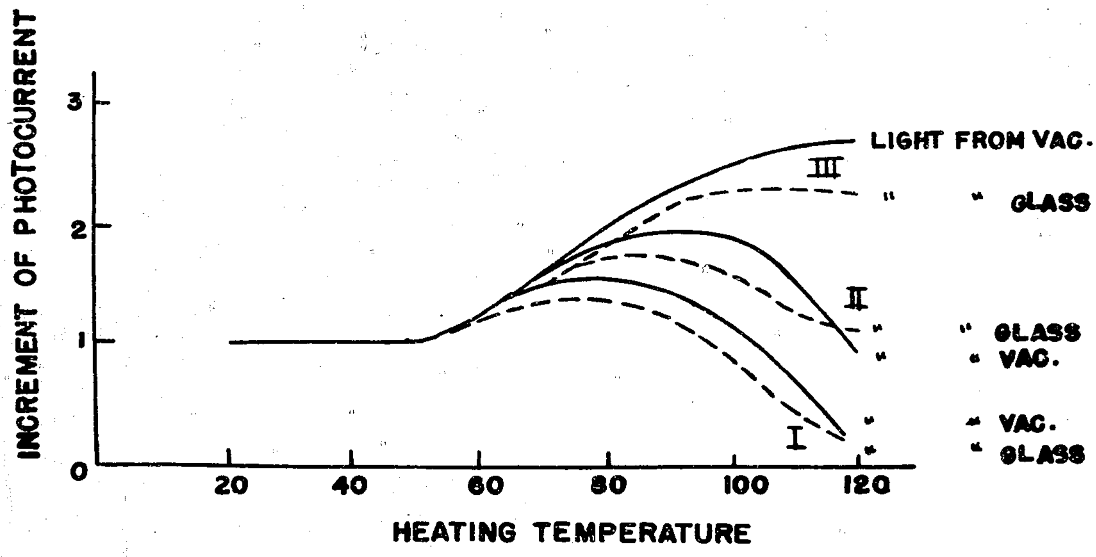


Figure 5(K)
SEMI-TRANSPARENT PHOTOCATHODE

b. Semi-transparent photocathode. In this case the silver film is thinner, and the color change is not as distinct during the process of oxidation and caesiation, and more care is required to observe the color change. Figure 3(K) is similar to Figure 2(K). Tests were made with white light incident from each side of the photocathode. It was found that the maximum point was different for each, and that the sensitivity was higher for light incident on the vacuum side. We consider this phenomenon as follows: The number of silver atoms set free by the reduction process increases with the amount of caesium introduced. The transparency to light from the glass side is therefore decreased, and the light from the vacuum side is scattered or reflected by the silver grains, and more light is utilized in the emission of electrons.

4. Heat Treatment and Sensitization

We consider three different cases where varying amounts of caesium were introduced: I, II, and III, as shown in Figures 2(K) and 3(K). This means in case I, caesium is introduced until the color is green, in case II, reddish green, and so on. We then measured the photocurrent while heating the tube from room temperature to 120°C. (See Figures 4(K) and 5(K).) For both non-transparent and semi-transparent cathodes, the increment in photo-current is greatest in case III; i.e., the amount of caesium is too large. In case I, the photo-current reaches its maximum at a relatively low temperature. The increment of photocurrent is smaller in all cases for the semi-transparent cathode. In case III the photo-current increases when let alone for one hour, in other cases it decreases. In case III the photocurrent increases, or at least does not decrease, when cooled to room temperature; in the other cases it usually decreases.

After the heat treatment was completed, the cathodes were sensitized with silver, and the following sensitivities measured for white lights.

Non-transparent	I	2 microamps/lumen	
	II	12 microamps/lumen	
	III	40 microamps/lumen	
Semi-transparent	I	1 microamps/lumen	(Light incident on vacuum side.)
	II	2 microamps/lumen	
	III	6 microamps/lumen	

5. Conclusion

From the above results, we found that the amount of caesium should be rather large. Of course it is related to the degree of oxidation, temperature, and time of heat treatment, and method of sensitizing with silver, but we chose the best conditions known.

The thickness of the silver film of the semi-transparent cathode was about 20-30 millimicrons.

ENCLOSURE (L)

NON-TRANSPARENT PHOTOCATHODE TYPE NOCTOVISION TUBES

A report on experiments conducted at Kyoto University

By Prof. N. KATO and Asst. Prof. Y. OTANI
Department of Electrical Engineering
Kyoto Imperial University
26 November 1945

Image tubes having semi-transparent cathodes are the type commonly employed in noctovision telescopes. However, in comparison to non-transparent photocathodes, the sensitivity is only half as great. Furthermore, it is difficult to manufacture semi-transparent cathodes with high sensitivity.

In Figure 1(L) there is shown a comparison of the spectral sensitivity curves of both types of photocathodes. The sensitivity shown is that of the best phototube of each type produced to date. As the drawing shows, the non-transparent photocathode has the greater peak sensitivity, and also is sensitive to longer wave lengths. In analysis, it is seen that the semi-transparent photocathode has two conflicting requirements: The metal film must be thin in order to be transparent, and yet must be solid enough to have electrical conductivity.

Two earlier types of non-transparent photocathode image tubes are shown in Figure 2(L) and 3(L). In the type shown in Figure 2(L) the optical distortion is great, since the image is projected at an angle. In the type shown in Figure 3(L) the electron image is turned through a right angle by means of a magnetic field, and there is again distortion. In other types an inverted or a mirror image is formed.

In the present experiments, attempts were made to improve the quality of the photocathodes and to find an optical system which would eliminate the above mentioned defects. In early 1944, the principles of the system shown in Figure 4(L) were planned. A Schmidt optical system and a special image tube were designed, so that the non-transparent cathode is placed at the focus of the mirror. The electrostatic lens is of the reducing magnification type, so that the brightness of the fluorescent image is great. The resulting image is seen in its true location and aspect, and the overall magnification is approximately 1:1. However, there are still certain flaws in the optical image produced. In order to produce reducing magnification type electron lenses with small aberrations, special design is required for their shape, orientation, and for the outer shape of the glass envelope. The electron lenses must interfere as little as possible with the reflected rays from the mirror, both as to casting shadows and as to reflecting stray radiation. The curvature of the optical image produced by the Schmidt system is directly opposite to that required to fit the cathode.

To correct the above difficulties, experiments were conducted on several additional types and shapes of tubes. The results are summarized below, and the tubes are sketched in Figures 5(L) to 13(L), inclusive.

<u>Type I and II</u>. The aberration of the electron lens system is small, the lens magnification factor being M=1. But the shape of the glass surface on which the light reflects is not adequate In Type II, semi-transparent glass electrodes (aluminum or platinum film) are used, but cause many optical distortions.

<u>Types III, IV, and V</u>. The optical distortion, in comparison to the other types, is small, but depends on fine workmanship in the glass. In the electron lens system, even if a plane cathode is used, there is a fairly large

area where there is a rather sharp image. In order to harmonize the curvature of the optical image and the cathode, the cathode faces the electron lens and is concave, so that pincushion distortion is reduced. Type V depends less than Type II on a high quality glass envelope surface. The glass electrode should be constructed so that it is perpendicular to the optical path in order to minimize distortion.

Type VI. This design is quite different from the others. The reducing magnification is much smaller, being about M=0.35. The electron lenses are removed from the optical path. Aberration of the electron image is rather large, and cold emissions from the cathode are numerous.

Type VII. Using three anodes at nearly the same potential, the aberration is small. Good optical images were obtained in comparison with previous types.

Type VIII. One anode of Type VII is used. The effective area of the cathode was spread out, the fluorescent screen enlarged, the field of view increased, and fairly good results were obtained.

In accordance with the theory of aberration of electron lenses, the chromatic aberration is largest near the cathode. If the work function of the cathode metal is V_0 volts and the potential gradient of the cathode is E_0, the limit of resolving power "d" is given in the following equation:

$$d = \frac{V}{E}$$

Therefore, if "E" is large, "d" is small, and the first anode should be near the cathode and the potential gradient should be large.

Type IX. In order to match the curvature of the optical image and a plane cathode, the effective area of the cathode must be small. In order to have small aberrations with a plane cathode, the electropotential surface must change slowly, and a large number of electrodes are required. These electrodes must be of a size and shape which do not interfere with the optical path, and considering this point, type IX was made for trial. In this, the image tube was designed together with a Schmidt lens system of the design shown in Figure 14(L). Since the resolving power of the Schmidt system was not measured, absolute values were not obtained, but the resolution at the axis of the combined system was under 0.1mm.

Improved Type. In the next improved type, the glass quality was improved through casting so that optical distortion was small. The dark current was also decreased and the fluorescent image consequently was made brighter. Since it was possible to use a higher voltage, the unnecessary area of the cathode was decreased. It was also possible to use an f 0.75 or f 1 Schmidt optical system, but the war ended.

Any one of the above mentioned types can be used in the Schmidt system shown in Figure 14(L). If a magnetic lens be used, the aberration is small, even in the case of a plane cathode. Since the number of accelerating electrodes is small, there is little interference with the optical image. However, since the negative coil must be placed outside the image tube, it blocks the line of reflection to the spherical mirror, and there is much loss of light.

Since there are many defects in the image tube, it is not thought necessary to use an optical system of the high efficiency of the Schmidt design.

Methods of Measuring Resolution. The above-mentioned resolution "d" is measured in accordance with the following procedure. In Figure 15(L), the widths "a" of the black and white lines are the same. Patterns of varying values of "a" are drawn up on a dry photoplate and this is placed in front of a source of light so that the image is projected by an optical system onto the photocathode of the image tube. If, in the image on the fluorescent screen, a set of black and white lines are indistinguishable, or if they appear flat, the limit "d" of the resolution is defined as the width of the black line "a".

Photocathodes. Making an image tube with a Cs_2O-Ag photocathode of good sensitivity is a problem which requires technical skill. Fairly good sensitivity has been obtained in photocells 80 microamps/lumen to white light and 10 to 20 microamps/lumen to infra-red light. The sensitivity of image tubes is less than half this amount; 30 to 40 microamps to white light and 5 to 10 microamps to infra-red light. These sensitivity measurements are made with a tungsten lamp of color temperature about 2700°K and an infra-red filter, type IRD-1, 3mm thick.

The construction of the caesium photocathode is given in another report. In the latest process, a small amount of oxygen is introduced into the tube after silver activation and before the last heating. Another improvement can be attained by heating the entire tube, with the exception of photocathode, just before the oxygen activation; this drives off the caesium that has been deposited on the electrodes and walls of the tube, and redeposits it on the cathode. The excess caesium on the cathode must then be re-oxidized.

The fluorescent screen must have a high brightness, and a sharpness of contrast. Thus it is necessary that the dark current be small. It varies with the construction of the photocathode, and at room temperature it is between 10^{-11} to 10^{-12} amperes/cm^2, being proportionate to the infra-red sensitivity. For the purpose of decreasing the dark current, the temperature of heating after introduction of caesium was raised from 140-150°C to 180-200°C.

In Figure 16(L) are shown the effects of the heating process after the introduction of caesium. On the abcissa are plotted temperature (T) and current (i); on the ordinate is plotted time. The photocurrent is shown in curve "ip"; the dark current in curve "id". As the heating temperature is raised, "ip" increases and reaches a maximum at $T = 140$-$150°C$, after which it starts to decrease. The "id" continues to increase up to a maximum at 180°-200°, after which it also decreases. Further heating decreases the dark current below 10^{-12} amp/cm^2. The silver activation usually reduces the dark current and increases the photocurrent. Also, a sufficient amount of caesium will reduce the dark current.

The infra-red sensitivity is greatly decreased by impurities in the caesium. The most common impurities in caesium chromate are potassium and rubidium. Silicon or aluminum is placed in the side tube containing the caesium chromate as reducing agents. The temperature of heating the side tube must be carefully controlled, so as to drive off caesium, but not potassium or rubidium.

The electrical materials used for the electrodes are steel, monel metal, and colloidal gold or platinum painted on glass. The glass electrodes are preferred. Aluminum or platinum paint is used for the semi-transparent electrodes.

ENCLOSURE (L), continued

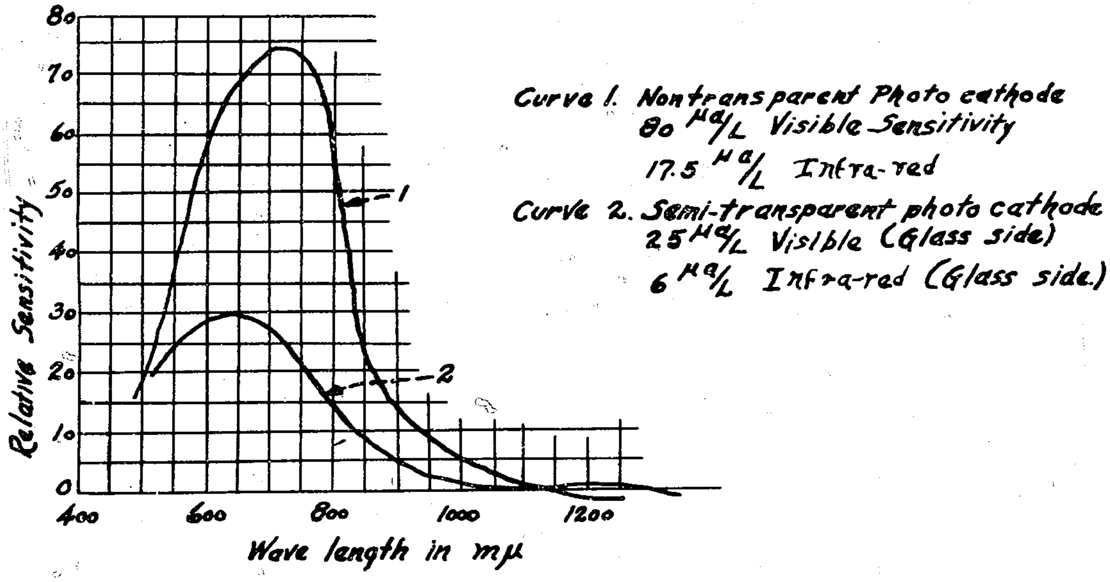
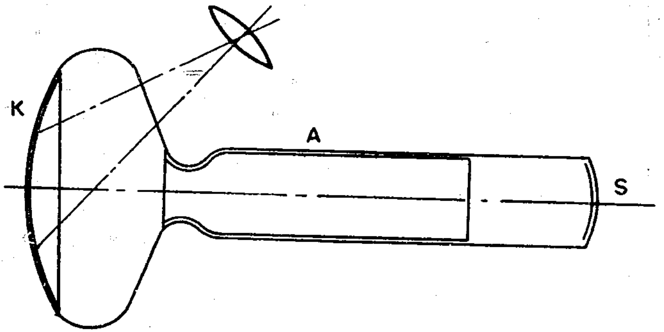


Figure 1(L)

SPECTRAL SENSITIVITY OF AG-Cs_2O-Cs-Ag-Cs



K Photocathode (non-transparent type)
A Anode
S Fluorescent screen

Figure 2(L)

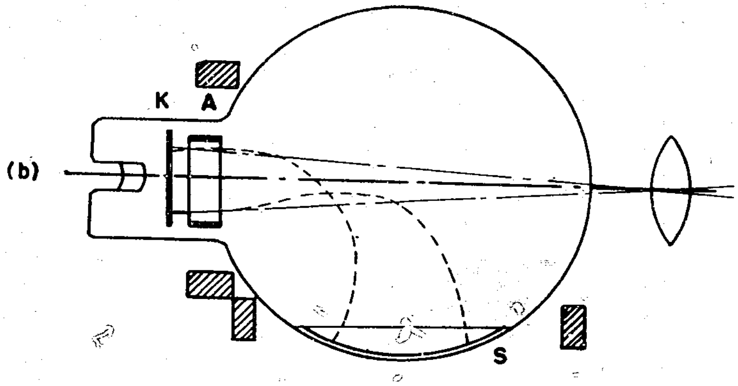
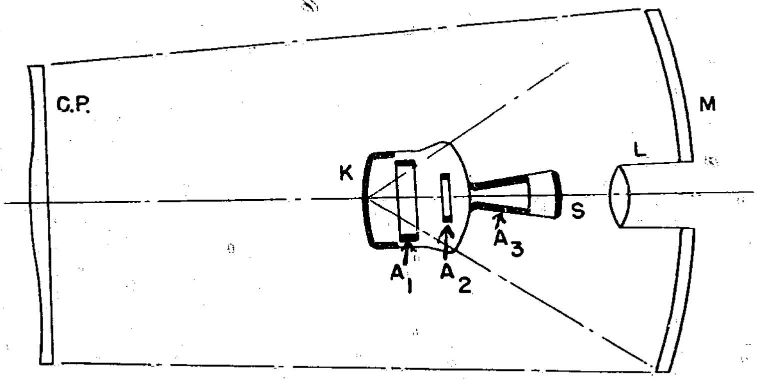


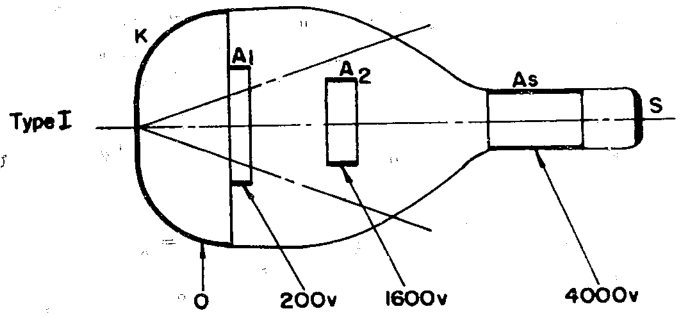
Figure 3(L)

EARLY TYPES OF NON-TRANSPARENT PHOTOCATHODE IMAGE TUBES



C.P.	Correcting plate of Schmidt camera.
M	Spherical mirror of Schmidt camera.
L	Eye piece
K	Non-transparent photocathode
A_1, A_2, A_3	Anodes
S	Fluorescent screen

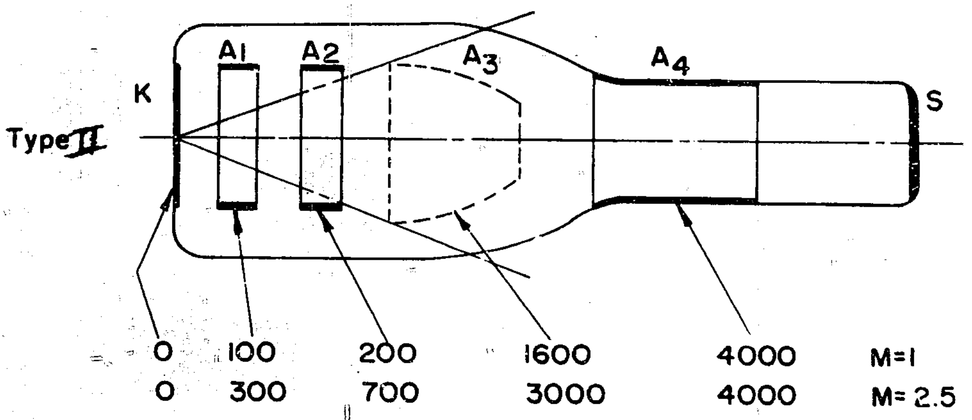
Figure 4(L)



M=1 (Magnification factor of electron lens)

Figure 5(L)

EXPERIMENTAL NON-TRANSPARENT PHOTOCATHODE IMAGE TUBES



A_3 Semi-transparent electrode (glass electrode)

Figure 6(L)

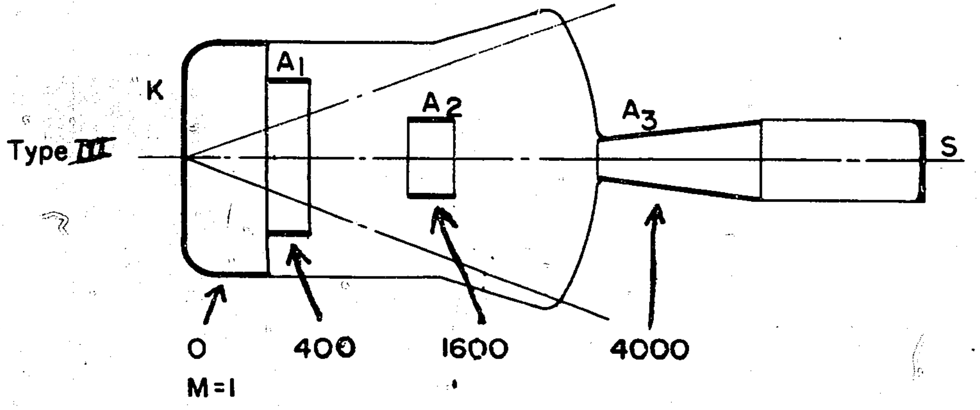


Figure 7(L)

EXPERIMENTAL NON-TRANSPARENT PHOTOCATHODE IMAGE TUBES

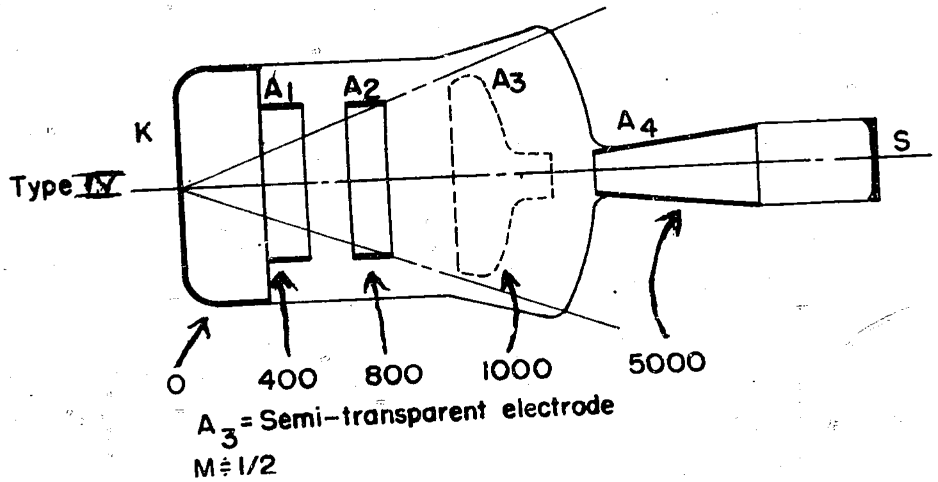


Figure 8(L)

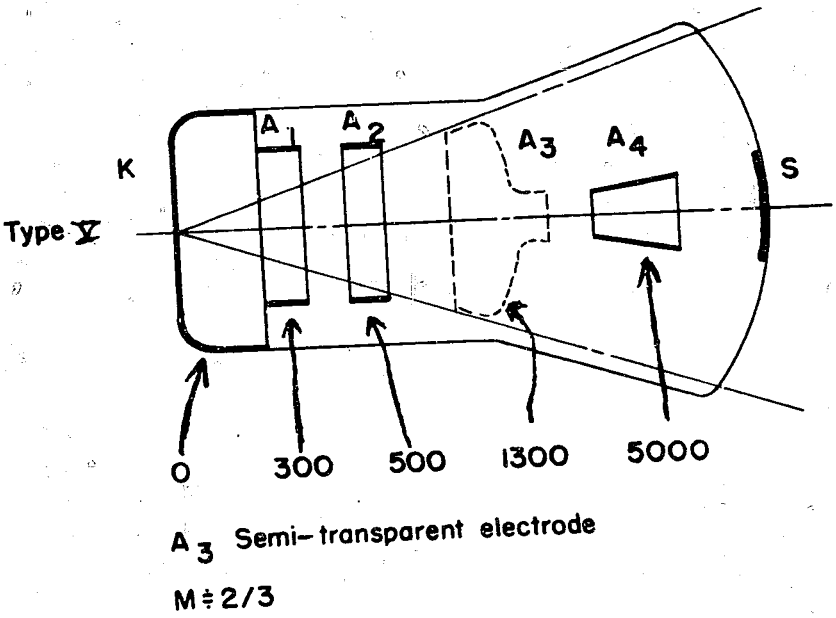


Figure 9(L)

EXPERIMENTAL NON-TRANSPARENT PHOTOCATHODE IMAGE TUBES

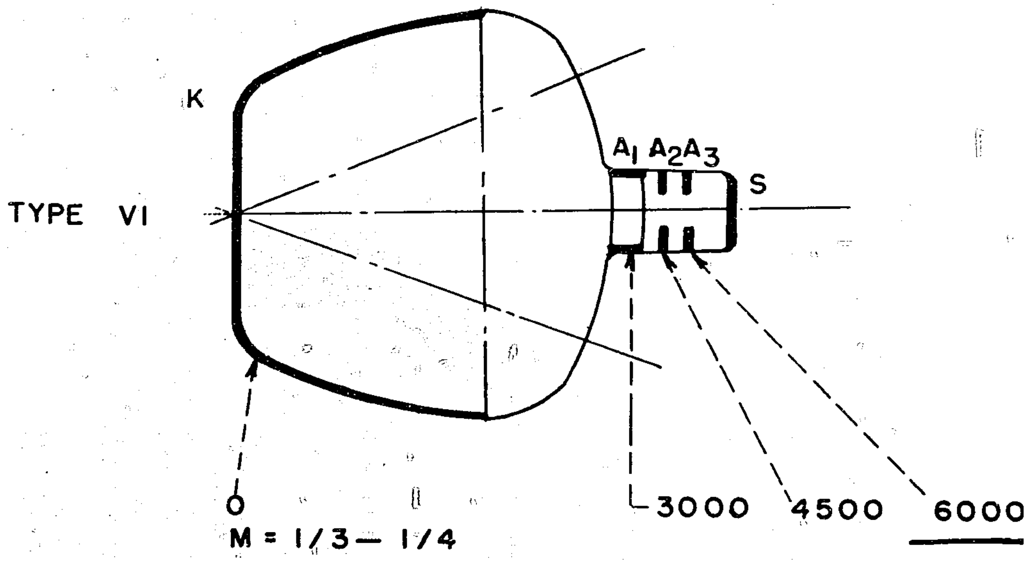


Figure 10(L)

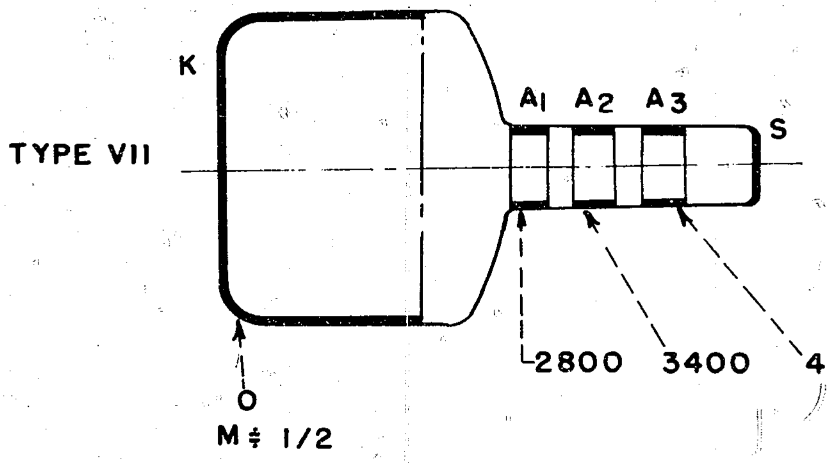


Figure 11(L)

EXPERIMENTAL NON-TRANSPARENT PHOTOCATHODE IMAGE TUBES

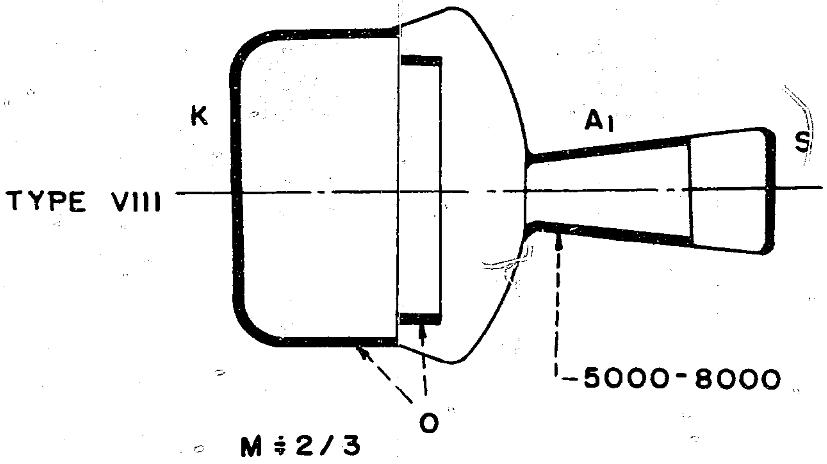


Figure 12(L)

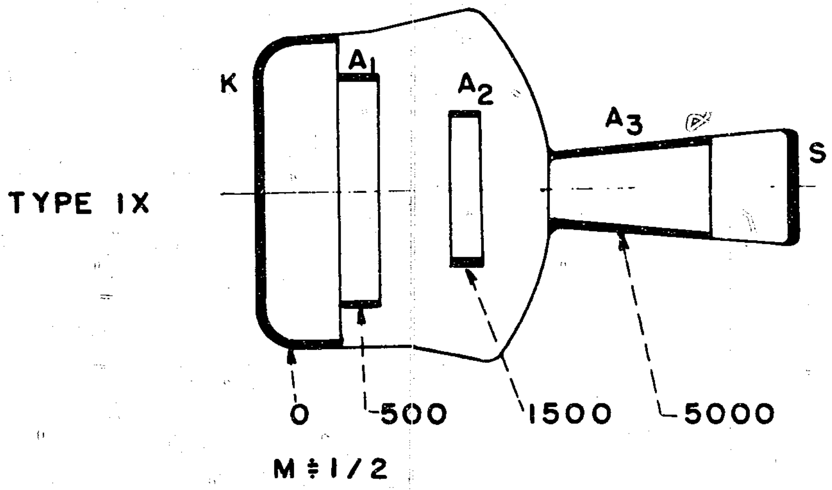


Figure 13(L)

EXPERIMENTAL NON-TRANSPARENT PHOTOCATHODE IMAGE TUBES

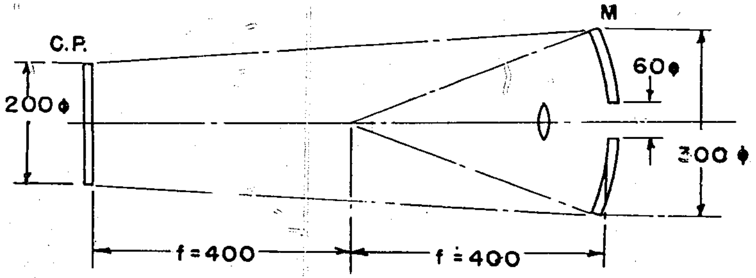


Figure 14(L)

SCHMIDT OPTICAL SYSTEM USED WITH NON-TRANSPARENT PHOTOCATHODE IMAGE TUBE

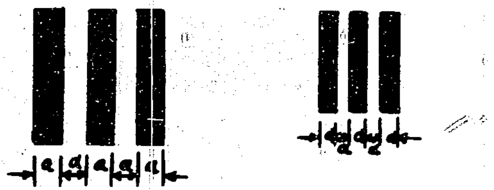


Figure 15(L)

RESOLUTION PATTERN

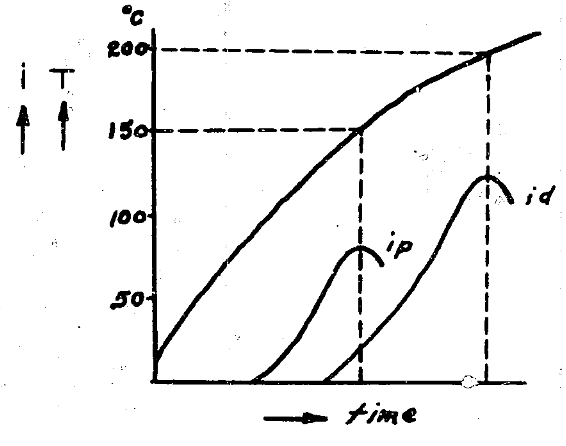


Figure 16(L)

DARK CURRENT VS TIME OF HEATING

ENCLOSURE (M)

RESEARCH ON ELECTRON LENSES

By: S. KATO
Kyoto Imperial University

Calculation of spherical aberration in lenses of reducing magnification.

Assume the potential distribution to be as shown in Fig. 1(M). This is explained simply by the exponential function:

$$\left.\begin{array}{lll} \phi = \phi_0\, e^{4\lambda_0 x} & x \leqq 0 & \lambda_0 > 0 \\ \phi = \phi_0\, e^{4\lambda_1 x} & x \geqq 0 & \lambda_1 < 0 \end{array}\right) \text{———} (1)$$

For simplicity, the calculations are made when $_1 = 0$. In this case, a potential distribution similar to that in a Zworykin type image tube is considered.

Thus the potential distribution is

$$\left.\begin{array}{ll} \phi = \phi_0\, e^{4\lambda_0 x} & x \leqq 0 \\ \phi = \phi_0 & x \geqq 0 \end{array}\right) \text{———} (2)$$

In the electron orbit equation

$$r'' + \frac{\phi'}{2\phi} \quad r' + \frac{\phi''}{4\phi} \quad r = 0 \text{ ———} (3)$$

If we introduce equation No. (2), and solve in terms of r_{ao} and r_{bo} then

$$\left.\begin{array}{ll} r_{ao}\ (A) = 1 & r_{ao}'\ (A) = 0 \\ r_{bo}\ (A) = 0 & r_{bo}'\ (A) = \beta \end{array}\right) \text{———} (4)$$

The relationship between the object and the image is assumed to be as shown in Fig. 2(M). The iris is assumed to be located at a point so that $X = B = 0$. and the electric field to lie between $A \leqq X \leqq B$.

To place the image as in Fig. 2(M), it must be

$$R'_{\beta o} < 0 \text{ ———} (5)$$

and also

$$\frac{3}{4}\pi > -\sqrt{3}\lambda_0\ A > \frac{\pi}{3} \text{ ———} (6)$$

Then solving equation (3), we have

$$\left.\begin{array}{l} r_{ao}\ (0) = \frac{2}{\sqrt{3}}\ e^{\lambda_0 A}\ SIN(-\sqrt{3}\ \lambda_0\ A + \frac{4}{3}\pi) \\ r_{ao}'\ (0) = \frac{4\lambda_0}{\sqrt{3}}\ e^{\lambda_0 A}\ SIN(-\sqrt{3}\ \lambda_0\ A) \\ r_{\beta o}\ (0) = \beta\, \frac{e^{\lambda_0 A}}{\sqrt{3}\lambda_0}\ SIN(-\sqrt{3}\,\lambda_0\ A) \\ r_{\beta o}'\ (0) = \beta\, \frac{2}{\sqrt{3}}\, e^{\lambda_0 A}\ SIN(-\sqrt{3}\,\lambda_0\ A - \frac{\pi}{3}) \end{array}\right)$$

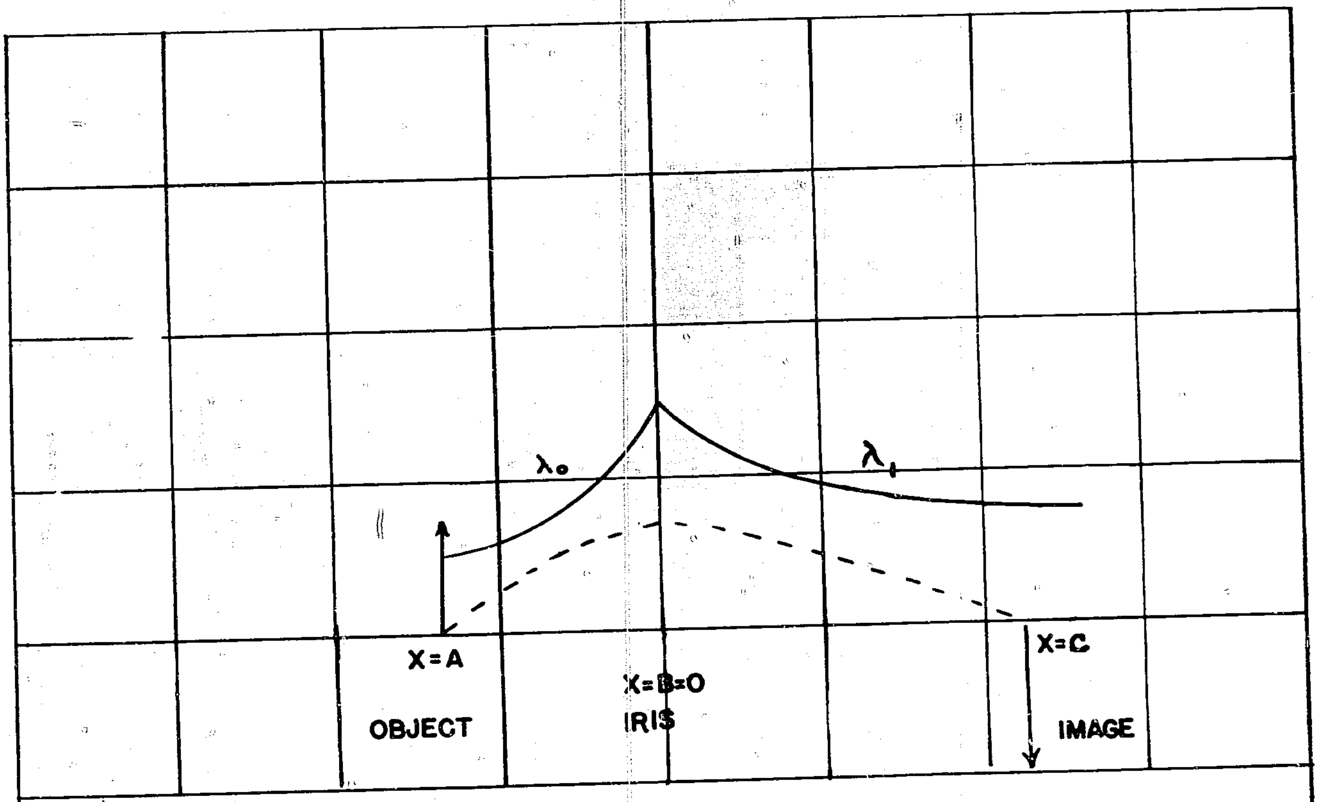


Figure 1(M)
ASSUMED POTENTIAL DISTRIBUTION

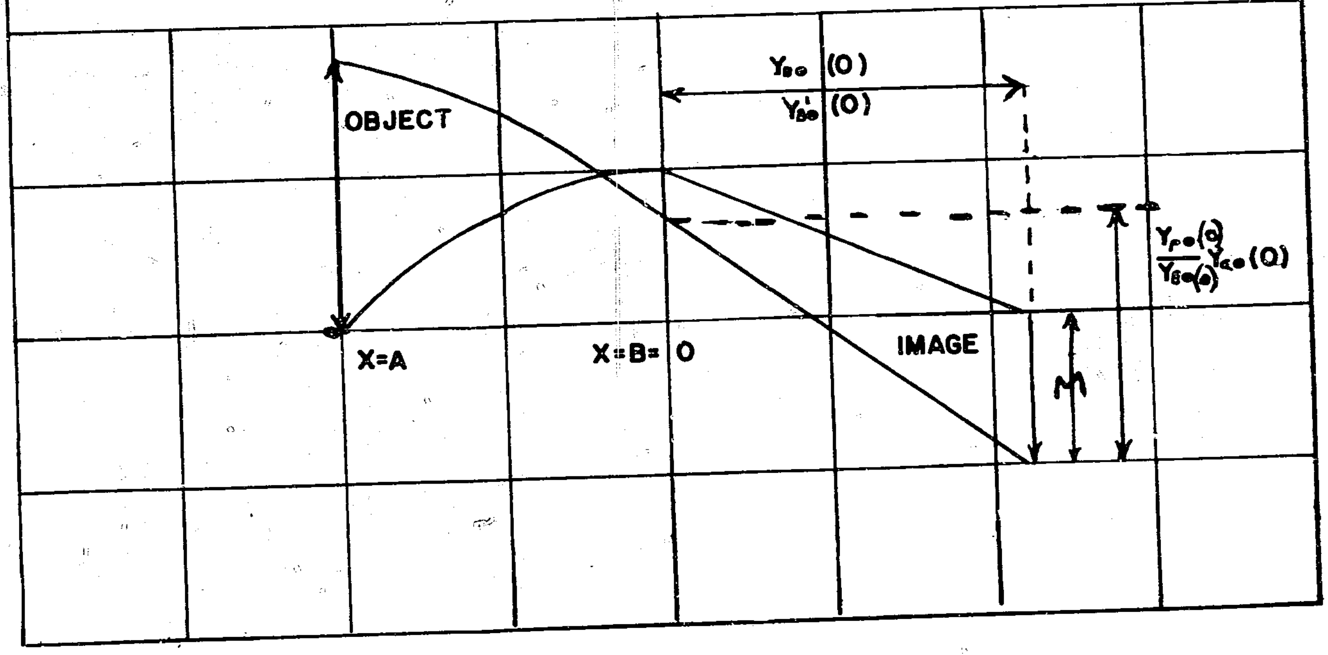


Figure 2(M)
ASSUMED LOCATION OF ELECTRON IMAGE

ENCLOSURE (M), continued

From these equations, the value of the magnification "M", the focal length "F", and the spherical aberration "B" can be determined. When $A = -10$, it means that the distance between the image and the lens is -10 cm. The calculated results will be as follows:

$$\frac{2\pi}{15\sqrt{3}} > \lambda_0 > \frac{\pi}{30\sqrt{3}}$$

$$r_{a_0}(0) = \frac{2}{\sqrt{3}} e^{-10\lambda_0} \mathrm{SIN}(10\sqrt{3}\lambda_0 + \frac{\pi}{3})$$

$$r'_{a0}(0) = \frac{4\lambda}{\sqrt{3}^{0}} e^{-10\lambda_0} \mathrm{SIN}(10\sqrt{3}\lambda_0)$$

$$r_{\beta 0}(0) = \beta \frac{e^{-10\lambda_0}}{\sqrt{3}\lambda_0} \mathrm{SIN}(10\sqrt{3}\lambda_0) .$$

$$r'_{\beta 0}(0) = \beta \frac{2}{\sqrt{3}} e^{-10\lambda_0} \mathrm{SIN}(10\sqrt{3}\lambda_0 - \frac{\pi}{3})$$

$$F = \frac{\sqrt{3}}{4\lambda_0} e^{10\lambda_0} \left(\frac{1}{\mathrm{SIN}(10\ 3\lambda_0)}\right)$$

$$M = \frac{\sqrt{3}}{2} e^{-10\lambda_0} \frac{1}{\mathrm{SIN}(10\sqrt{3}\lambda_0 - \frac{\pi}{3})}$$

$$B = \frac{\lambda^2_0}{104\ \mathrm{SIN}(-10\sqrt{3}\lambda_0 + \frac{\pi}{3})\ \mathrm{SIN}^2(10\sqrt{3}\lambda_0)} [-156 + 81e^{2\lambda_0} + 26\sqrt{3}$$
$$\mathrm{SIN}\ 20\sqrt{3}\lambda_0 + \sqrt{3}\ \mathrm{COS}\ 20\sqrt{3}\lambda_0 - 7\sqrt{3}\ \mathrm{SIN}\ 40\sqrt{3}\lambda_0 - 3\ \mathrm{COS}\ 40\sqrt{3}\lambda_0]$$
$$-2\lambda_0^2 \frac{\mathrm{SIN}^2(-10\sqrt{3}\lambda_0 + \frac{\pi}{3})}{\mathrm{SIN}^2(10\sqrt{3}\lambda_0)}$$

When the value of "λ" is varied, the change for "f", "B", "M" and so on is as shown in Figs. 3(M), 4(M), and 5(M). To compare Figs. 4(M) and 5(M),

$\lambda_0 = 0.095$ $M = 0.66$ $B = -0.04$

$\lambda_0 = 0.155$ $M = 0.18$ $B = -4.0$

$\lambda_0 = 0.18$ $M = 0.16$ $B = -72808.6$

By these results, we know that, in the case of the Zworykin type electron lens, magnification less than 0.2 cannot be used because of spherical aberration.

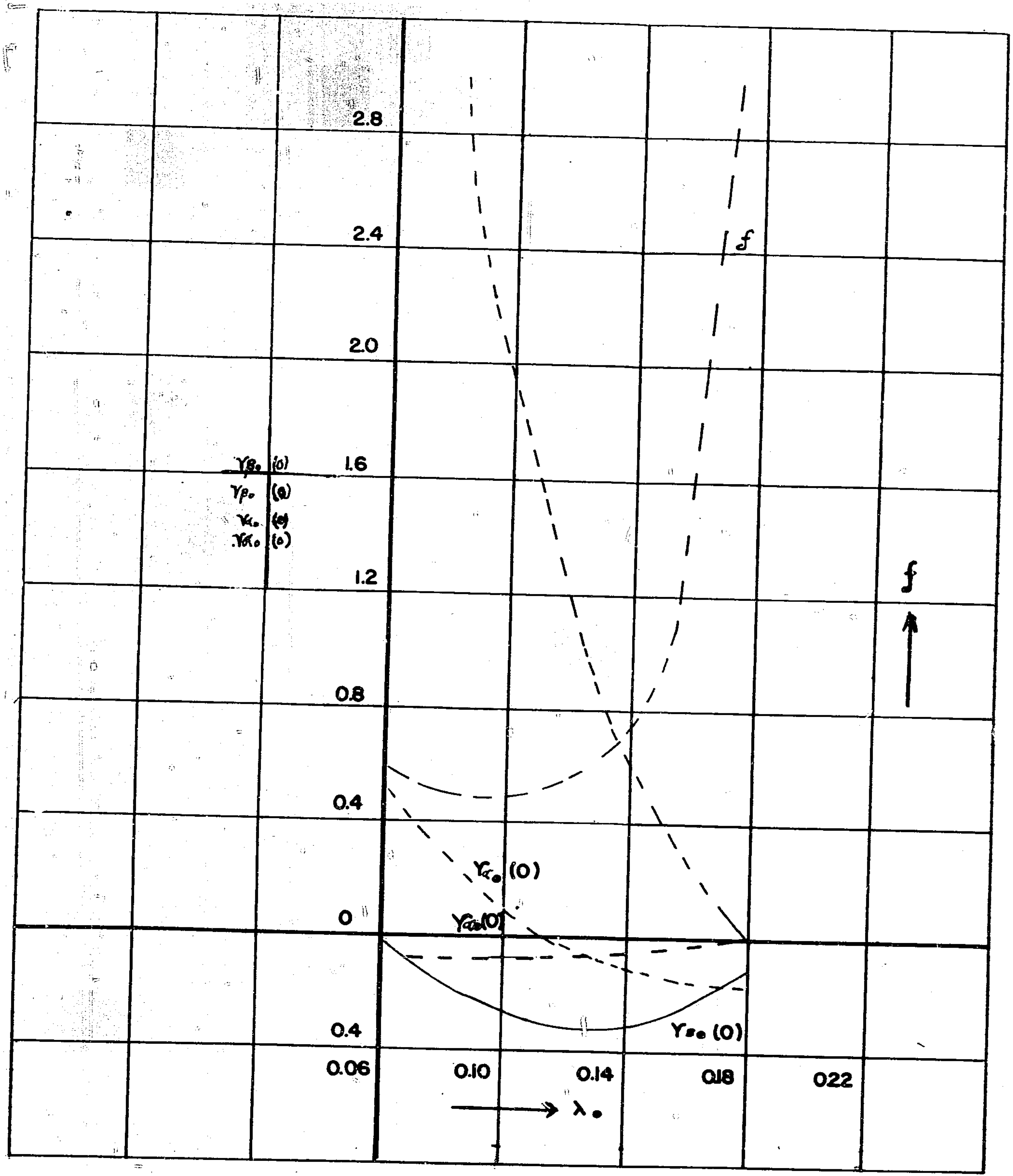


Figure 3(M)

VARIATION OF FOCAL LENGTH "f" WITH WAVE LENGTH OF LIGHT "λ_0"

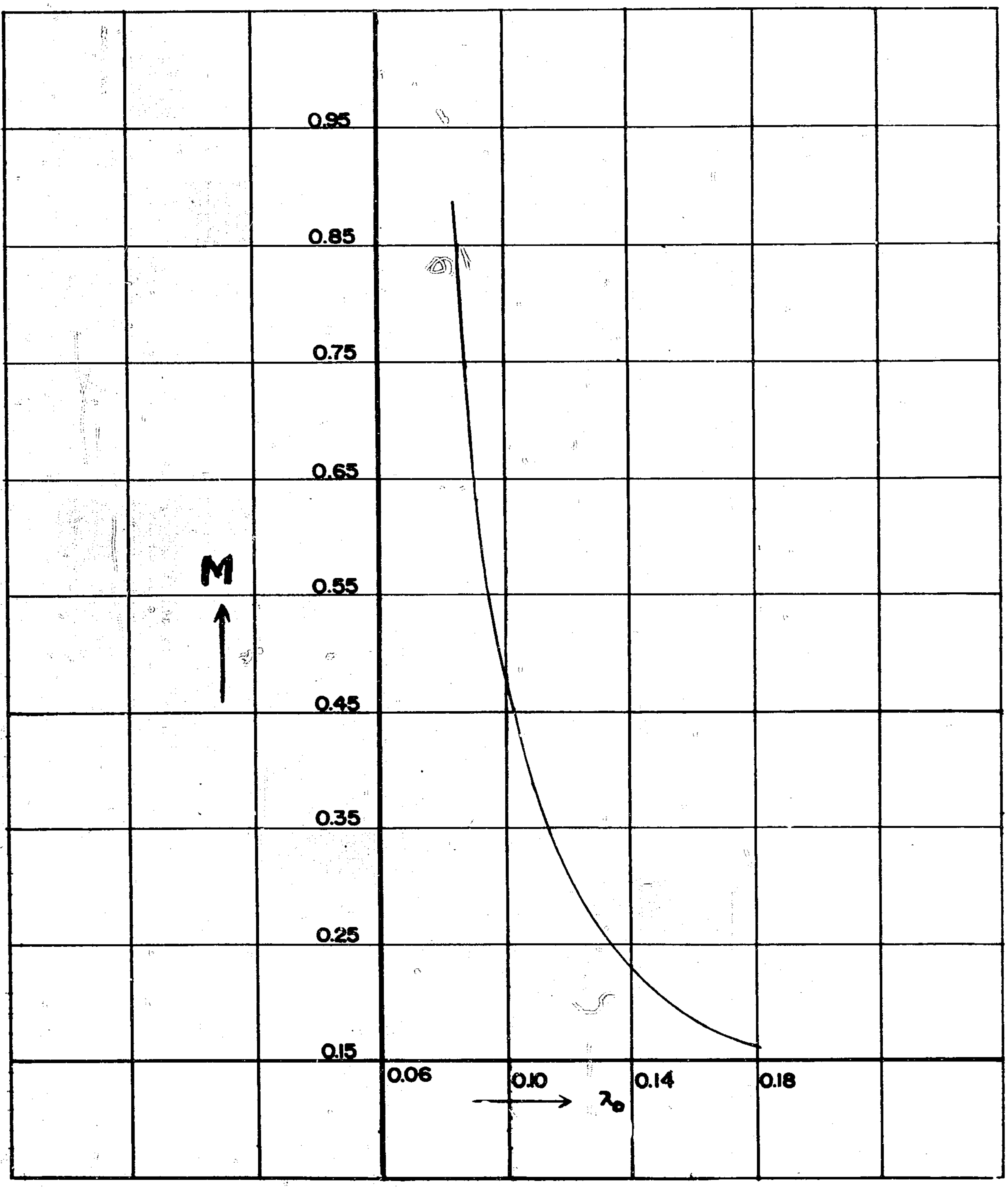


Figure 4(M)

VARIATION OF MAGNIFICATION "M" WITH WAVE LENGTH OF LIGHT "λ_0"

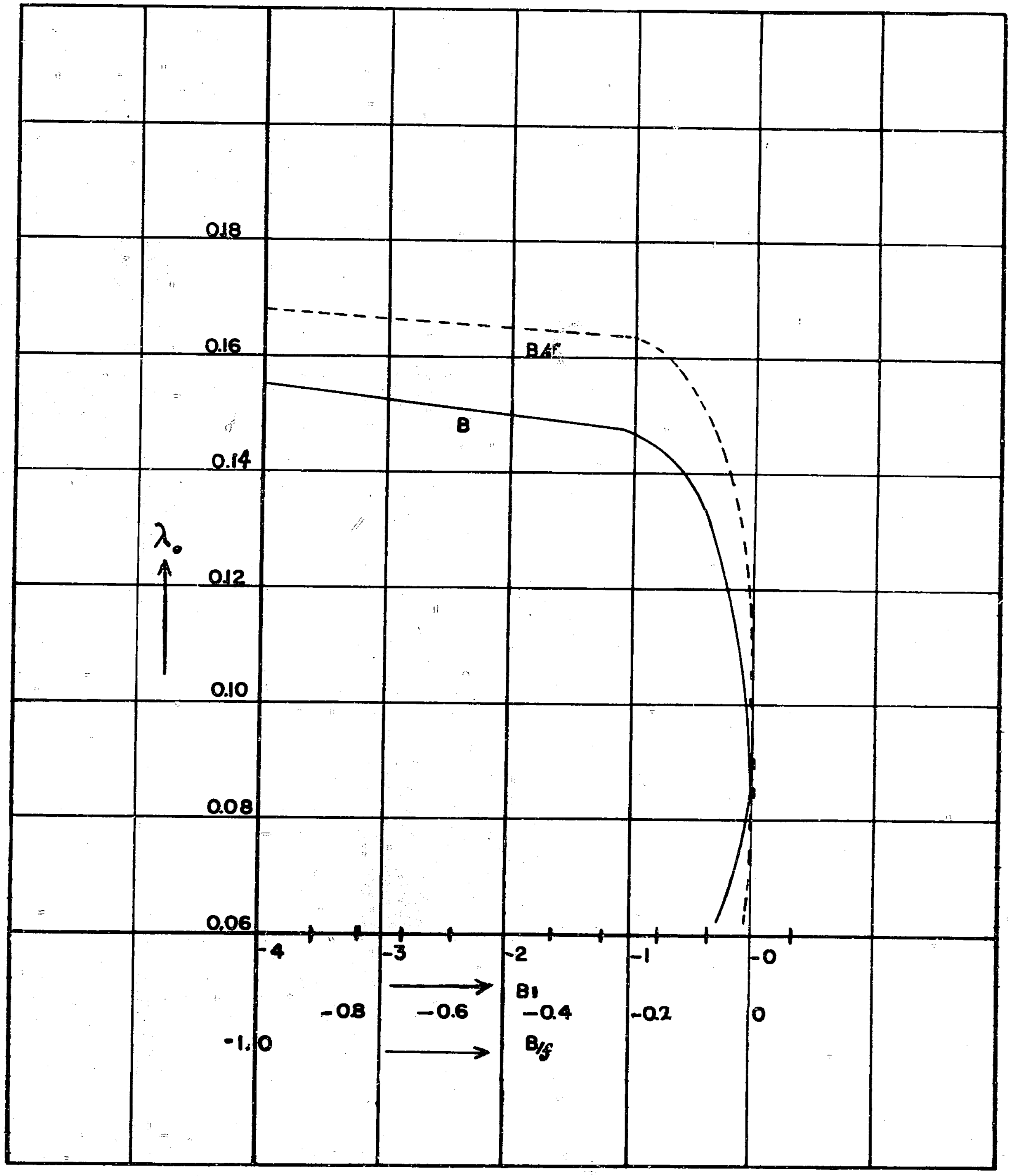


Figure 5(M)

VARIATION OF SPHERICAL ABERRATION "B" WITH WAVE LENGTH OF LIGHT "λ_0"

ENCLOSURE (N)

OPTICAL SYSTEMS USED WITH NOCTOVISION TUBES

An edited translation of a report prepared for the purposes of this investigation by Prof. S. KATO of Kyoto Imperial University. It contains a brief discussion of the advantages of Schmidt optical systems, the design and testing of Schmidt plates, and the fitting of optical images to curved cathodes.

By: S. KATO
Kyoto Imperial University
December 1945

1. Optical Systems Used for the Noctovision Tubes.

a. Optical systems used for the noctovision tube with semi-transparent photocathode.

(1) Schmidt optical system. We combined a Schmidt optical system as shown in Figure 1(N) with a noctovision tube shown in Figure 2(N). In the figure:

ϕ = diameter of Schmidt plate

f = focal length

D = diameter of main spherical mirror

d = diameter of plane mirror

l = length of image tube

b = diameter of image tube

c = diameter of photocathode

R = radius of curvature of photocathode

For example we used the following equipment:

$\phi = 200$, $f = 150$, $D = 300$, $d = 110$
(Numerical aperture $F = 0.75$)

(2) Image Tube (Units in mm)

$l = 160$, $b = 80$, $R = 75$, $C = 60$

total anode voltage .... 10,000 - 15,000 V
magnification of the electron lens 1:0.5
sensitivity of the photocathode for infra-red .. 5 microamps/lumen

(3) Eye Piece.

(a) magnification $m = 10$
focal length $f = 25$mm
field of view $\phi = 20$mm and 30mm

(b) Magnification $m = 5$
focal length $f = 50$mm
field of view $\phi = 20$mm and 30mm

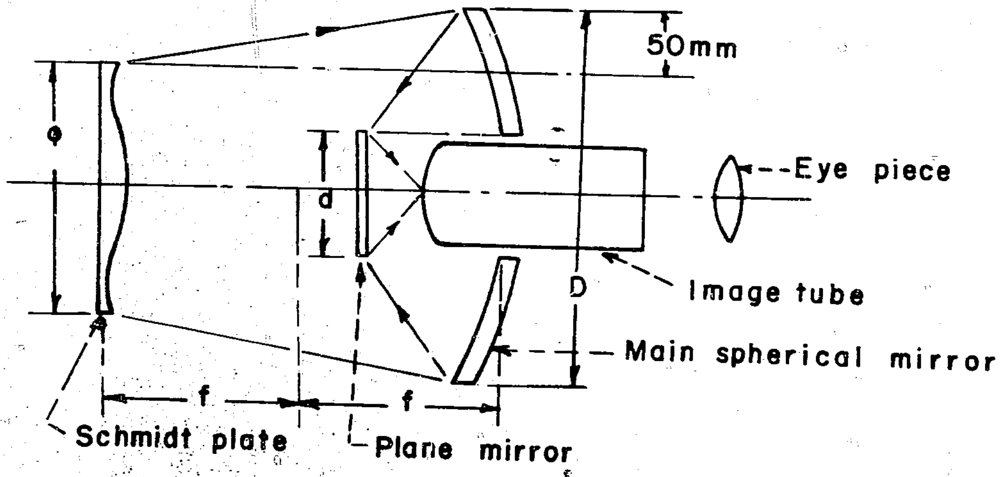


Figure 1(N)

SCHMIDT OPTICS FOR IMAGE TUBE WITH SEMI-TRANSPARENT PHOTOCATHODE

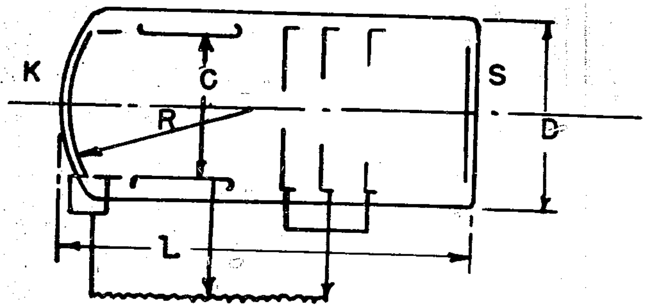


Figure 2(N)

LAYOUT OF IMAGE TUBE

ENCLOSURE (N), continued

b. Optical system used for the image tube with non-transparent photocathode. See Figure 3(N).

$$\phi = 200,\ f = 400,\ D = 300,\ F = 2.$$

2. Strong Points of Schmidt Optics. Schmidt optics have the following excellent points compared to usual lens.

a. It is easier to manufacture with large diameter (ϕ is large). Generally speaking, optical systems with large apertures are required for noctovision, but it is very difficult to produce on a large scale lenses that are more than 15cm in diameter, so we adopt a Schmidt optical system.

b. It is easier to manufacture one with large aperture and short focal length. (f is small.).

c. We can get a wider field of view.

d. Optical glass is needed for Schmidt plate only, so we are not restricted by shortage of optical glass.

e. It is fit for mass production. On the contrary, the weight and volume may be large compared to lenses, so it is more difficult to make the equipment portable.

3. How to Make and Test Schmidt Plate.

a. How to make it.

(1) Method of polishing, using Vacuum. We have invented a method of polishing, using vacuum, for mass production, and have conducted theoretical and experimental research on this method. We first make a circular plane-parallel glass plate from raw glass (Optical glass Bk 7 or white plate glass), and attach it to evacuating equipment. When it is evacuated the plate becomes curved in accordance with the pressure. At this stage we grind and polish the curved surface with spherical surface having an accurate radius. When put back to atmospheric pressure, the plate becomes a Schmidt plate.

In this method the physical properties of raw glass present a problem. We investigated on BK 7 and white glass and determined the thickness of the glass plate and degree of vacuum from calculation and experiment. We succeeded in making a Schmidt plate of 100cm diameter and $F = 2$, using white glass. The diameter of the circle confusion was smaller than 0.03mm (even to 0.0064mm). But the glass plates sometimes broke during polishing and it was difficult to make a plate as large as $\phi = 200$mm, $F = 0.75$ by this method.

(2) Method of mechanical polishing.

(a) Polishing by hand. We made a $\phi = 200$mm, $F = 0.75$ Schmidt plate by polishing by hand. We fixed a circular white glass plate 8mm - 10mm thick on a wooden circular plate which was attached coaxially to the rotating axis of a grinding machine. While rotating this axis at high speed, we polished the glass surface by hand, using emery powder to make the surface fit the metallic gauge plate having Schmidt curve. For finish polishing, the axis was rotated slowly and a semi-circular hard wood plate with soft pitch attached on its surface was moved to and

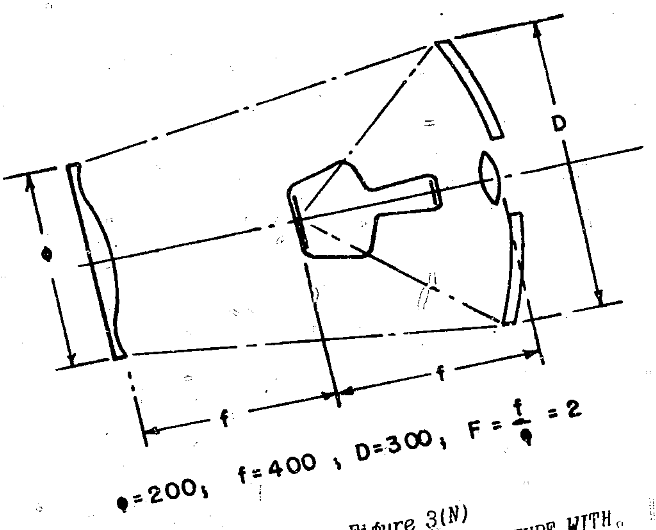


Figure 3(N)
SCHMIDT OPTICS FOR IMAGE TUBE WITH
NON-TRANSPARENT PHOTOCATHODE

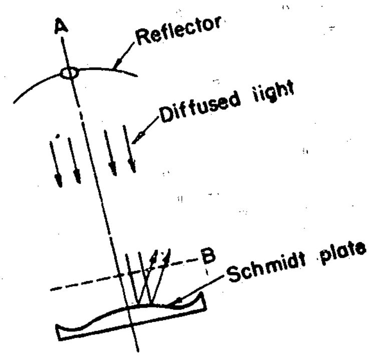


Figure 4(N)
SIMPLE METHOD OF TESTING SCHMIDT PLATE

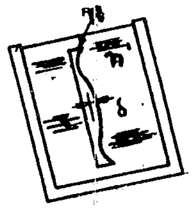
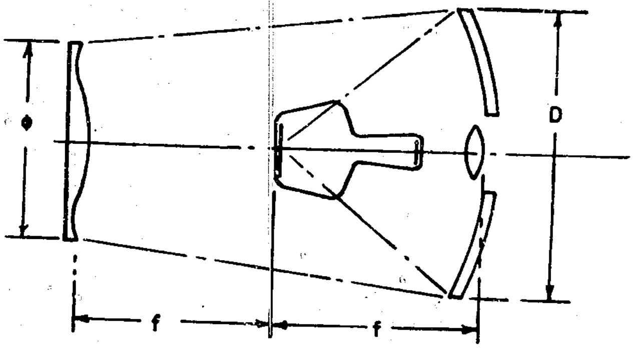


Figure 5(N)
MICHELSON INTERFEROMETER METHOD



$\varphi = 200;\quad f = 400;\quad D = 300;\quad F = \frac{f}{\varphi} = 2$

Figure 3(N)

SCHMIDT OPTICS FOR IMAGE TUBE WITH NON-TRANSPARENT PHOTOCATHODE

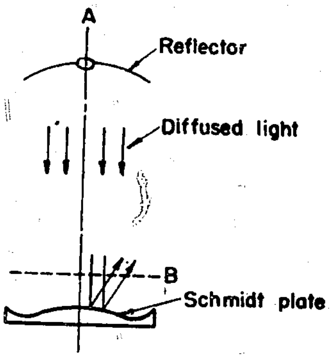


Figure 4(N)

SIMPLE METHOD OF TESTING SCHMIDT PLATE

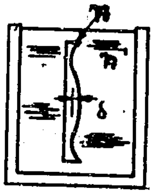


Figure 5(N)

MICHELSON INTERFEROMETER METHOD

fro straight way from central parts to outer edge gradually and polished the surface with Indian red. During the polishing, the plate was moved off and investigated optically to make sure that the spherical aberration was corrected.

(b) Mechanical grinding method. This was adopted for mass production. The circular glass plate was rotated and a grinding wheel (rotating at high speed) made of organic glass embedded with diamond powders was moved to and fro straight way from central region to outer, guided by a guide with Schmidt curve. After this grinding, we polished the surface for finish and correction.

b. Investigation Method.

We adopted the following methods and compared them with each other.

(1) Simple testing method for Schmidt plate.

(a) Method of using Foucalt's knife edge.
(b) Observing Newton-rings.
(c) Simple testing method.

(2) Precise testing method for Schmidt plate.

(a) By using Michelson interferometer.
(b) By photographing the interference fringes.
(c) Method utilizing interference.

(3) Testing of combined Schmidt camera.

(a) By measuring the resolving power using test pattern.
(b) By Hartman method.

Details are given as follows:

(1c) Simple testing method (See Figure 4(N). We put a screening disk on the Schmidt plate to be investigated. This had ring formed hollows with equal width and interval. Diffused light thrown from the upper side through the hollow is reflected back by the surface of the Schmidt plate and partly screened by the screening disk. When we see the reflected light at position "A" we may observe stripes of light and dark. Since we know how these stripes seem when the Schmidt plate is a correct one, we can see the state of the plate under investigation. This method may be used during polishing.

(2a) By using Michelson Interferometer. (See Figure 5(N).) We put the Schmidt plate in a glass vessel containing a liquid having refracting index "n" and, using Michelson Interferometer, photograph the interference pattern. The number of interference fringes "m" is given by the formula:

$$m = \frac{2\partial(n-n')}{\lambda}$$

∂ = amount shown in Figure 5(N).
λ = wavelength of light used.
n = refractive index of Schmidt plate.

By using adequate liquid (n' large), we can calculate "m" even when ∂ is large ; otherwise "m" will be very large and it may be difficult to number it.

ENCLOSURE (N), continued

(2b) By photographing interference patterns. By the arrangement as shown in Figure 6(N) we can photograph the interference pattern occurring between the light reflected from the upper and under surface of Schmidt plate. This is simple compared to Michelson interferometer and yet is suitable for precise investigation.

(2c) Surface test utilizing interference. (See Figure 7(N).

A = Optical flat
B = Metallic plane mirror
C = Glass plate
D = Rectangular prism
E = Telescope
F = Schmidt plate
G = Precision flat plate

When "F" is moved laterally, "B" moves up or down in accordance to the Schmidt curve of "F", and interference stripes occurring between "A" and "B" will move across the cross hair of the telescope "E". By calculating the number of stripes moved, we can easily measure the form of the surface of Schmidt plate. The accuracy of this method is about 1/10 of wave length used.

(3a) Measurement of resolving power. We can test the combined character of a Schmidt optical system by measuring its resolving power. For this purpose we use testing patterns, each consisting of three black stripes with equal width and distance, and each having different width and distance from others. (See Enclosure (L).) These patterns are illuminated and the images are focused by the Schmidt optics. We can calculate the resolving power from observation of which pattern cannot be resolved and the image becoming diffused.

(3b) Hartmann Test. By the method invented by Hartmann we can measure the spherical aberration of Schmidt optics. We found that the resolving power obtained by the above mentioned pattern test was nearly equal to the radius of the circle of confusion calculated from the spherical aberrations obtained by the Hartmann test. Following is one of the results on Ø = 200mm, F 0.75 lens.

Wave Length	Radius of Circle of Confusion or Resolving Power
500 mu	0.021mm (measured)
650 mu	0.037mm (measured)
800 mu	0.046mm (presumed)

Schmidt optical systems manufactured for test work had resolving power about 0.03mm average.

4. How to Reduce Optical Distortion.

a. Use of correcting lens. The image surface of the optical system should completely coincide with the photosensitive surface of the image tube. In a Schmidt optical system the radius of curvature of image surface is nearly equal to the focal length. For example, it is 150mm in a Ø = 200mm, f = 150mm Schmidt system. An image tube to be combined with this system must have a radius of curvature of photosensitive surface of 75 - 100mm. So we have to use some auxiliary equipment to match these two surfaces. For a semi-transparent image tube we may put one optical lens between the plane mirror "A" and the tube as shown in Figure 8(N).

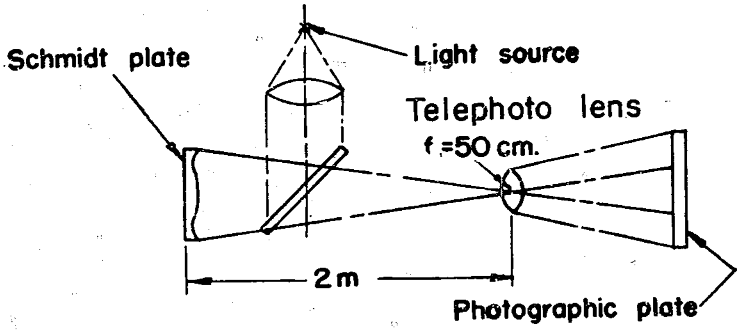


Figure 6(N)
PHOTOGRAPHING OF INTERFERENCE RINGS
FOR TESTING SCHMIDT PLATE

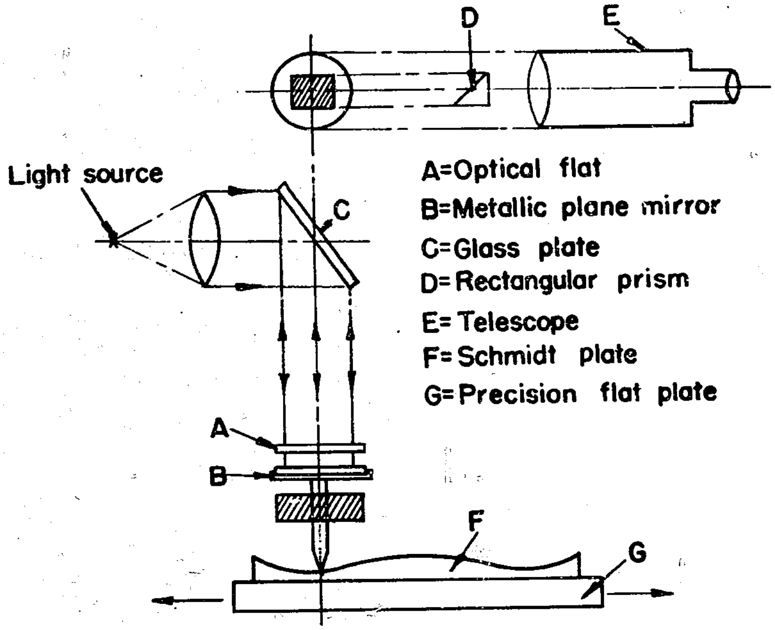


Figure 7(N)
OPTICAL STUDY OF INTERFERENCE RINGS
FOR TESTING SCHMIDT PLATE

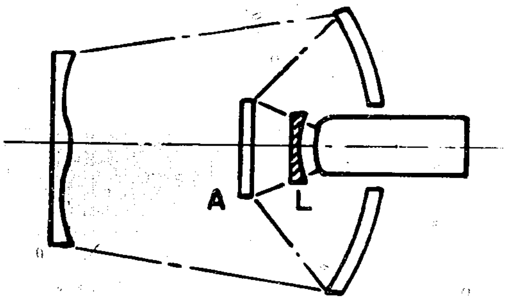


Figure 8(N)
LENS FOR CORRECTING CURVATURE OF IMAGE

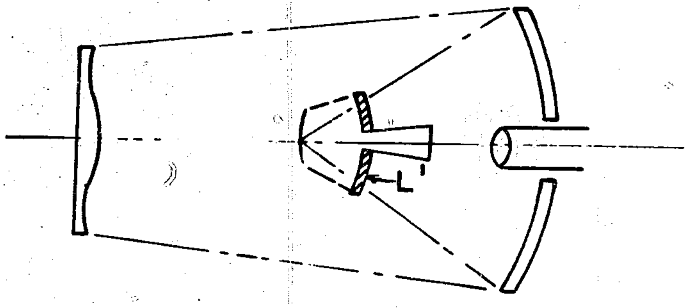


Figure 9(N)
SURFACE OF IMAGE TUBE USED FOR CORRECTING CURVATURE OF IMAGE

ENCLOSURE (N), continued

The non-transparent nocto-tube has a radically different radius of curvature than the Schmidt system. But we may be able to make these two surfaces coincide to some extent by using an optical lens as shown in Figure 9(N). However, in this case the glass surface of the image tube must be precisely polished as is usual for lenses.

b. Polishing the glass surface of image tube. When the glass wall of the photosensitive surface of the image tube is not uniformly thick, it becomes a cause of aberration. For example, the wall of an image tube with 100mm radius of curvature and thickness one mm, to be combined with F = 0.7 Schmidt camera, must be uniformly thick to ±0.1mm. For this purpose, a circular disk is usually cut from a glass sphere with a uniform wall and desired radius of curvature. Sometimes the disk is made by method of glass casting or pressing. The disk is then attached to a glass cylinder to be the base of the photocathode. But it is preferable to polish the surface by usual lens polishing methods for precision.

In the case of the non-transparent image tube, the glass wall to be put in the path of light must be made of the desired curvature by casting or pressing and then must be polished. When the auxiliary lens is to be used, this polishing is indispensable. Our research was not extended to this point.

The accuracy of dimensions of the image tube is much inferior to an optical system such as Schmidt optics, and much care should be taken in manufacturing the image tube. It is preferable to use some adequate guide during glass work to give desired curvature, and also while mounting the electrodes in the tube to make the axis coincide. Further, the axis of Schmidt system and image tube must coincide with each other. For this purpose an accurate socket must be used.

5. How to Prevent Reflection Losses. It is usual to put a thin film of adequate thickness and refractive index on the surface of optical systems to prevent loss of light by reflection. However, in the case of Schmidt system, there was little need of consideration of this point, and we applied this method only on eye pieces.

We think it better to apply this prevention of reflection loss to all the optical parts. To make an adequate film on glass surface, dipping the glass in acid or evaporation of fluorite or cryolite in vacuum is usually used.

6. On infra-Red Transparency of Glass. We did not measure the transparency of glass for infra-red ray, because we thought white glass or BK 7 has almost the same transparency for rays between 800 mu - 1200 mu as that for white light. We used hard glass containing small amount of Pb for image tubes, and on this we also did not measure the transparency, as we thought it unnecessary.

ENCLOSURE (O)

METHOD OF PRODUCING ORGANIC DYE INFRA-RED FILTER

An edited report prepared for the purposes of this investigation by Prof. Y. HOSHINO, of Tokyo University of Engineering. It contains brief details of laboratory method of dyeing PVA sheet filters, also mention of a selectively transmitting ultraviolet filter.

1. Requirements Stated by Military

a. Transmission as high as possible.
b. Visibility threshold to dark-adapted eye not over 300 meters, when used with a 1 kw tungsten lamp and 30cm mirror.
c. Water resistant.

2. Test Equipment

Caesium photocell, maximum sensitivity 8500 A°, long-wave cut-off 15,000 A°.

3. Materials

Base - polyvinal alcohol.

Dye - Napthaline Fast Black, supplied by Kalle Co. (Germany and U.S.). Three kinds were used KS, KSG, and RS. KSG was the most suitable. The chemical structures were not published for KSG and RS; the structure of KS is shown in Figure 1(0).

4. Method of Manufacture. The "Absorption Method" was developed by the author to eliminate impurities in the dye. A lump of polyvinal alcohol "the size of your thumb" in a viscous state is immersed in a solution of napthline fast black dye for one hour. The pure dye is absorbed, but the impurities are not. The lump is then washed in cold water for one hour, during which time the impurities are washed away. The PVA is then dissolved in hot water and spread in solution on a glass plate. It is then dried in a drying oven at 60° - 70°C. The resulting film is treated with formic and sulfuric acids to make it waterproof.

5. Characteristics of Filter Film

a. The spectral transmission curve is shown in Figure 2(0), in comparison with an ideal filter and the standard IRD-1. The transmission relative to the sensitivity of a caesium-silver photocathode is 1.7 times that of the IRD-1.

b. Thickness is 0.5 to 1.0mm.

c. Moisture resistance is good.

d. Heat resistance is fair. Must be protected by forced air cooling to prevent destruction of dye.

6. Samples. To be prepared by Mr. HOSHINO if possible.

7. Military Security. HOSHINO recommended that Mr. E. H. Land of the Polaroid Corporation be consulted if we wish to duplicate these filters, as he is a "respect-worthy" man. Apparently there has been no breach of security here, as HOSHINO stated that he had only followed Land's techniques in the preparation of polaroid filters.

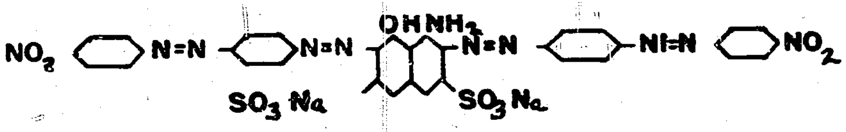


Figure 1(O)

CHEMICAL STRUCTURE OF NAPTHALINE FAST BLACK DYE, TYPE KS

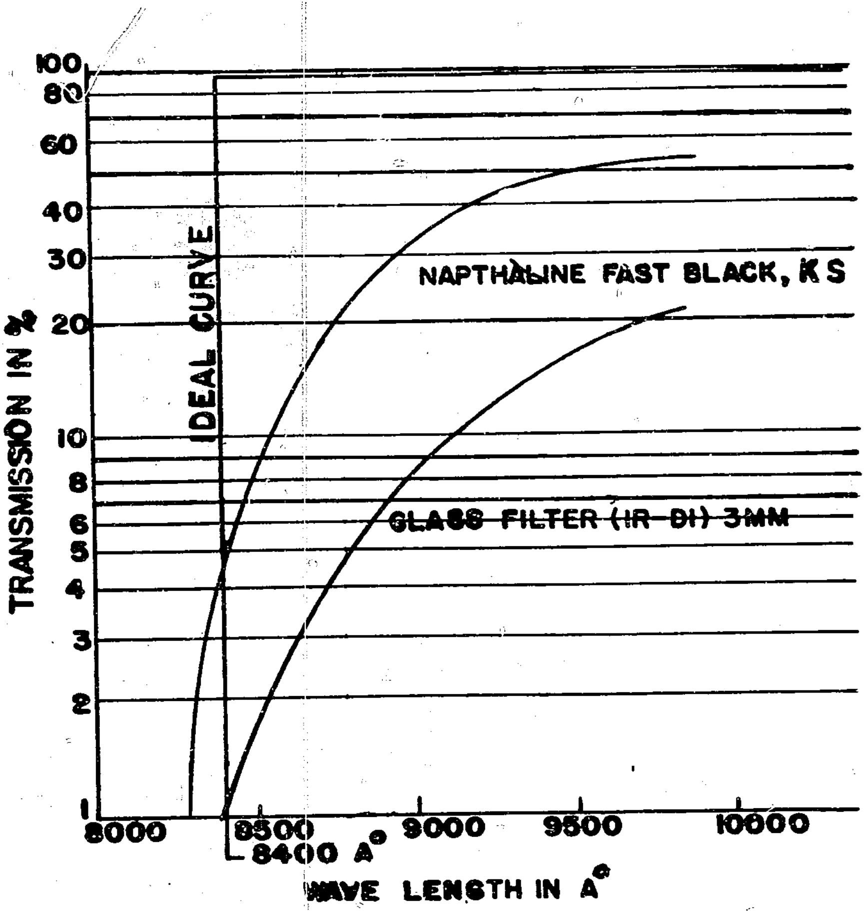


Figure 2(O)

TRANSMISSION CURVES OF PVA FILTERS

ENCLOSURE (O), continued

8. Selectively Transmitting Ultraviolet Filter. HOSHINO had also developed a selectively transmitting ultraviolet filter, called DU-1, which would transmit only the 2537 Å line of mercury. It is about 0.2mm thick. In manufacture, PVA film is immersed in an aqueous solution of I_2 and KI for a few seconds and quickly wiped with filter paper, or the PVA solution may be spread on a glass plate and dried. It is treated with Formalin and sulfuric acid for strength and waterproofing. It is possible that this filter may provide a truly invisible ultraviolet system, in connection with a detector of $ZnO \cdot SiO_2$. It may also be valuable in distinguishing between SiO_2 and $CaWO_4$ (Scherrite ore) through fluorescence of the latter, or in detection of rare earths in Monazite sand. Samples of this filter have also been requested.

ENCLOSURE (P)

INFRA-RED LIMIT OF HUMAN VISION

A brief report on experiments conducted in 1944 to determine the limit of human vision in the near infra-red, in order to set limits for filters.

By

Dr. Toshio TAKAMINE and Miss Hisa NAKAYAMA
Institute of Phys. & Chem. Research, TOKYO

1. Introduction

The question of how far the human eye can perceive the infra-red part of the spectrum is of no small importance. In order to test this, the authors have carried out a simple experiment in 1944 which will be described in the following. The farthest line we could see in the red end was the caesium line at 8520 A.

2. Experiments

As the source of light we employed an ordinary carbon arc (100V, 10A, DC) with cored carbon in the anode. The core was fed with the salts of various elements such as Ba, Cs, Li, K, and Rb from time to time so that the spectrum lines due to these elements appeared constantly during the observations. For the spectroscope, we used a simple one constructed in our laboratory consisting of a collimator, a single 60° Flint prism (n_d=1.57, 7cm base), and an objective of Zeiss Tessar F/4.5 f = 18cm. The image of the arc was projected on the slit of the spectroscope by an achromatic lens F/3, f = 10cm.

The method of observation was quite simple. The observer was dark-adapted for five to ten minutes and viewed the spectrum with a Zeiss ocular F/3.5 f = 5cm, under cover of a black cloth. The operator looked after the proper feeding of the salts to the arc as well as keeping its image on the slit.

Beginning with the very bright doublet $\lambda = 7665$A and $\lambda = 7699$A due to K, which is easy to recognize, the observer surveyed the red end of the spectrum along its focal plane toward the longer wave length region. The lines chosen as the convenient landmarks, so to speak, were the following:

K	7665	Li	8126
	99	Na	8195
Rb	7800	Ba	8210
	7948	Cs	8520

As regards the identification of these lines, we have taken the spectogram obtained by using the same instrument on the plates specially sensitized for the near infra-red region. On comparing the map of the portion of spectrum which was prepared by each observer with the spectrogram above mentioned, we could ascertain the correctness of his identification in each case.

It was naturally desirable to get the statistical mean value of the results obtained by a large number of observers. In the present experiment, which was only preliminary in nature, the number of observers were five, all being members of our laboratory. In included both male and female, the age ranging from 60 to 19 years old.

ENCLOSURE (P), continued

3. Results

The farthest infra-red line we could see was the caesium line $\lambda = 8520A$. This result was somewhat surprising, in as much as the values hitherto given in most of the text books range from 7500A up to 8000A. It must be admitted that our experiment is only a very crude one and we are intending to re-examine the limit more carefully in the near future.

In the experiment of this kind there are certain factors that must be taken into consideration, and these will be discussed in the following paragraphs:

a. Intensity of the source. The limit mentioned above would depend to a certain extent on the intensity of the source of light. On the other hand, it may be stated that this shift of the limit due to the variation of intensity would be rather trivial, provided that the source is fairly strong. It must be admitted that the present experiment is a qualitative nature. The arc flickered so that the intensity was fluctuating, and moreover, even when the arc was burning steadily, the intensity of a certain line could not be kept constant.

b. Individual difference. It is hardly necessary to say that the limit set above differs according to the individuality of the observer, so that the generality of the results requires tests on large numbers of observers. Color blindness and other abnormal vision must also be considered; besides, the age and perhaps sex difference of the observer would come into the problem. As regards the former, it seems that the greater the age, the less we see in the infra-red. Health conditions of the observer would also come into play. It has been known that certain kinds of food rich in nourishment increase the eyesight at least for a certain time.

As regards the color of the line Cs λ8520, many of the observers noticed that it appeared whitish instead of reddish. A similar phenomenon is met when one tries to see the ultra-violet end of the spectrum. However, in this case, the UV rays excite the fluorescence in the eye-media. Whether the near infra-red rays should produce any phosphorescence in different media of the eye seems to remain an open question.

Finally, it may be remarked that in the experiment of this kind, a phychological effect often comes in; each observer should carry out his own experiment, not being affected by any preconceived notions in expecting the position of the line. These problems which are more physiological than physical may better be left for a future study with the cooperation of the experts in the medical line.

ENCLOSURE (Q)

HEAT TRANSPARENT WINDOW MATERIALS

An edited translation of a report prepared for the purposes of this investigation by Prof. S. KATO, of Kyoto Imperial University. It contains transparency curves of various window materials, and chemistry of protective coatings for rock salt.

December 1945

1. Chloride of Rubber. We measured the transparency of chloride of rubber, both pure and mixed with "synparin" as softener and "guanigin" as stabilizer. Samples treated by sulphur were also measured. We found there is no distinct difference of transparency between them. (See Figures 1(Q) and 2(Q).) It is better to adopt chloride of rubber treated by sulphur. We changed the amount of HCl and found that about 27% HCl was the best. Following are the measured results:

Thickness (mm)	Coefficient of transmission (%)
0.15	28
0.10	40
0.05	54
0.02	66
0.01	68

But chloride of rubber suffers influence by temperature, becoming brittle at low temperatures, and losing its transparency at high temperatures. These changes are reversible, and it reassumes its original character when brought to room temperature again. It is apt to disintegrate when heated more than 100°C.

Transmission curves for fluorite, KCl, and NaCl are shown in Figures 3(Q), 4(Q), and 5(Q).

2. Protection of Rock Salt From Humidity

a. By means of a simple paint. Ethyl fibrin with 10% of castor oil solidified at low temperature or 10% of paraffin. Samples with paraffin gradually absorb humidity and lose transparency, and so are not practical.

b. By means of more than two paints. From the point of protecting from humidity, non-polar compounds, especially multimolecular hydrocarbon, are the best materials. But these non-polar compounds have little adhering power to crystals, so it is best to paint polar paints on first and cover them with non-polar compounds. We used the following materials and compered them.

Ethyl fibrin (EC), benzyl fibrin (containing bakelite) (BB), butylol (Bu) for over paints and opanol (OP), polystyrole (PS), polychrolovinyl (PVC) for under paints. For the former, EC, BB, Bu were the better ones, and for the latter, OP was the best and PS, PVC could be used by adding adequate material easy to mould.

The following combinations of 10 - 20μ thick were found good paints.

EC - OP - PS
BB - OP - PS
Bu - OP - PS
EC - PS
BB - PS

For example we used:

No. 1 PS twice and EC twice.
No. 2 PS once, OP once and BB twice.

Compositions of main paints are as follows:

EC

Xyrol	25 cc
Toluene	50 cc
Butanol	15 cc
Amyl Alcohol	10 cc
Ethyl Fibrin	5 gr
Castor Oil	0.5 gr

(Solidified at low temperature)

BB

Toluene	30 cc
Benzol	30 cc
Alcohol	10 cc
Butanol	10 cc
Butyl-Acetate	20 cc
Benzyl Alcohol	1 cc
Benzyl Fibrin	6 gr
Bakelite	4 gr

O

Toluene	40 cc
Benzin	60 cc
Opanol	2 gr

PS

Toluene	60 cc
Benzol	40 cc
Polystirol	8 gr
Napthaline	16 gr
Tetraline	0.8 gr

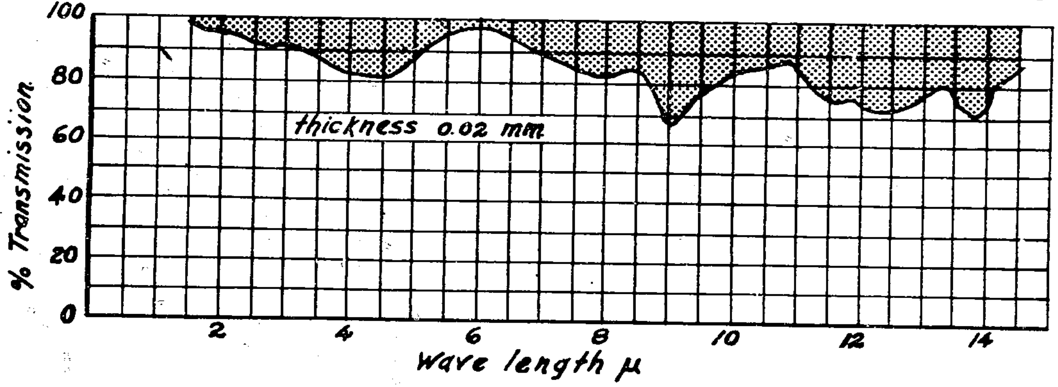


Figure 1(Q)

TRANSMISSION CURVE OF CHLORIDE OF RUBBER (THICKNESS 0.02mm)

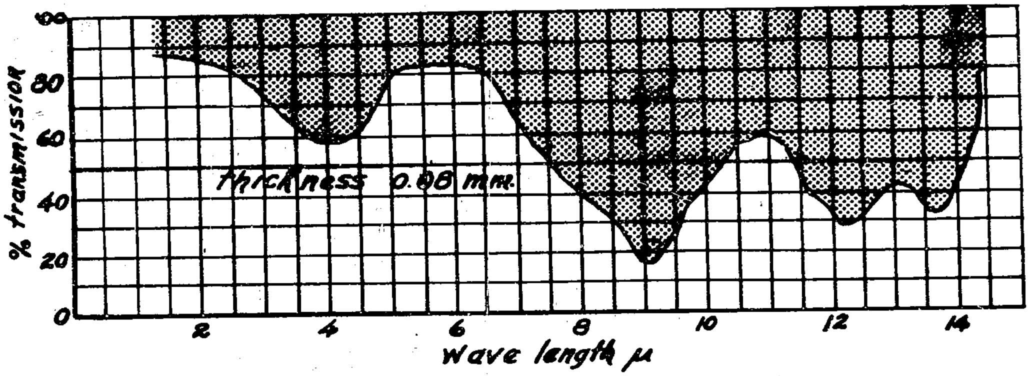


Figure 2(Q)
TRANSMISSION CURVE OF CHLORIDE OF RUBBER (THICKNESS 0.08mm)

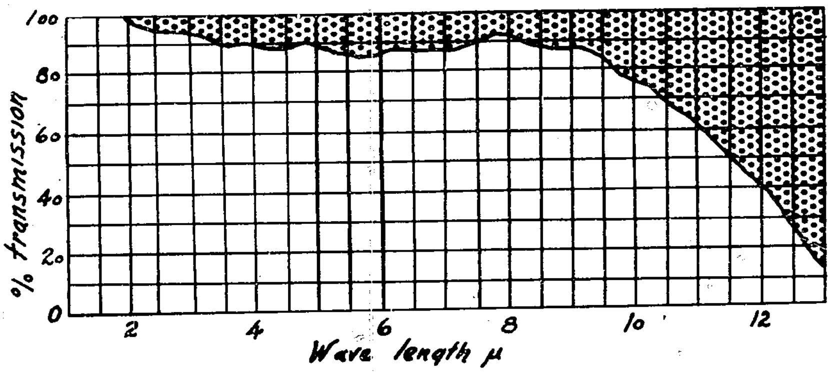


Figure 3(Q)
TRANSMISSION CURVE OF FLUORITE (THICKNESS 0.93mm)

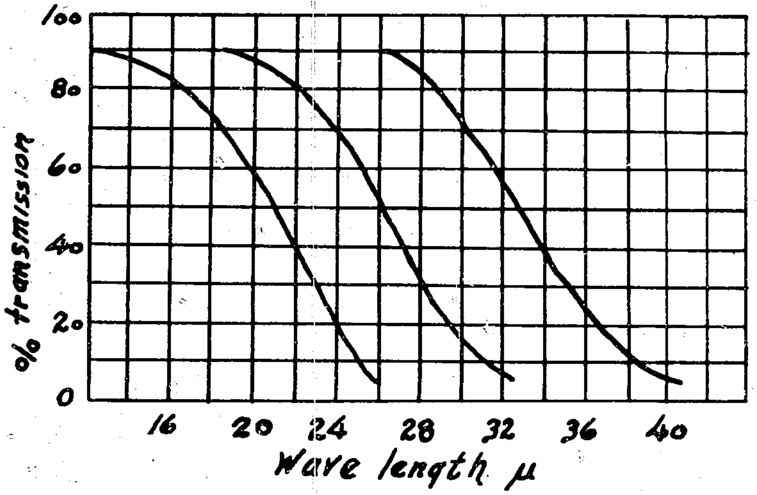


Figure 4(Q)
TRANSMISSION CURVE OF KCl

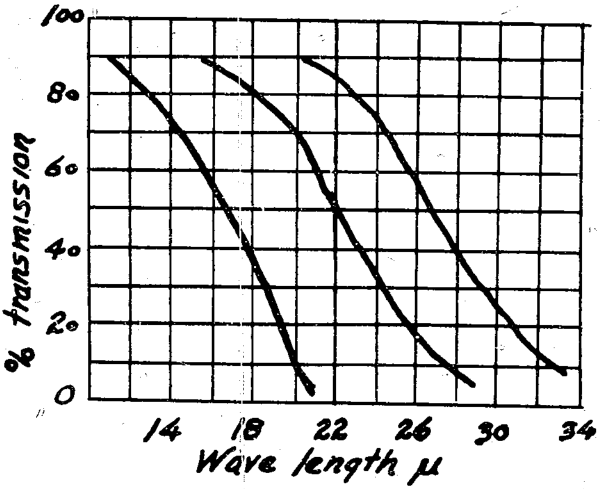


Figure 5(Q)
TRANSMISSION CURVE OF NaCl