A POSSIBLE RELATION BETWEEN THE NIGHT AIRGLOW AND THE IONOSPHERE

Thesis by

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In Partial Fulfillment of the Requirements

for the Degree of

Doctor of Philosophy

California Institute of Technology

Pasadena, California

1953

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deleted by the author.

Acknowledgements

A great many people have contributed to the success of this investigation, if success it be. It is with deepest gratitude that I offer my words of appreciation to the following people:

Dr. Franklin E. Roach, head of the Aerophysics Group at the U.S. Naval Ordnance Test Station at China Lake, California. He has made all his facilities available to me, aided and encouraged me and helped the project in every way. D. R. Williams encouraged the ionospheric work and helped in many ways. H. B. Pettit read many of the records and aided in the more onerous portions of the routine work. Dr. D. Locanthi and E. Tonsberg-Hansen scaled some of the night glow records.

The personnel of the ionospheric station at Stanford were very helpful. R. A. Helliwell, A. M. Peterson and L. H. Bixby were helpful during my visit to Stanford.

Acknowledgement of the work of the Optics Branch at China Lake under J. Wallin who designed the photometer optics and to the staff of Penn Optical Company who manufactured them.

Norman Chase of Chase Electronics wired up a great deal of the apparatus and was aided at times by Miss Pettit, Williams, Roach and Perry Ritter.

Special thanks go to Drs. Oliver Wulf, C. H. Dix and C. F. Richter who patiently listened to and advised the writer on many occasions.

Dr. Gennady Potapenko was official advisor on the research and to him I express my respect and gratitude.

We are indebted to Polidore Swings of the University of Liege, Belgium for a critical reading of the manuscript.

To my wife, Marie St. Amand I am most of all indebted. Without her tolerance and encouragement I could never have carried out this work. To put up with the writer under the best of circumstances is an accomplishment, to do so under the circumstances attending the conduct of my scholastic career and the conduct of this research is more than is to be expected of a person. She was also of great help in the routine computations.

ABSTRACT

(1) It has been found that the diurnal variation of the 6300-6364 Angstrom OI radiation is similar to the diurnal variation of the electron density of the F Layer of the ionosphere. It has been suggested that this similarity is not incidental, and the two phenomena are closely related to each other. The factor of proportionality changes with the seasons.

(2) It has been found further that the diurnal variation of the intensity of the 5577 OI radiation is similar to the diurnal variation of the height of the F layer. It is postulated that the 5577 radiation takes place within a region which shares in the vertical movements of the F layer.

(3) It has been found also that the intensity of the 6300-6364 radiation changes when the height of the F region changes.

(4) Heights calculated by the method of Van Rhijn for the 6300-6364 radiation fall within the height range of the F layer. Those calculated by this method for the 5577 radiation fall at the base of the F region. The independent identification of the radiation with the F region lends confidence to height values of the emitting regions calculated by Roach, Barbier and others.

(5) The mechanisms of excitation producing the 5577 and 6300 radiations appear to be different. There is also little evidence for production of the redlines by cascading of electrons from the energy levels producing the green line.

(6) The instrumentation used in measuring the intensity of the nightglow is discussed in detail.

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Introduction

As one stands out of doors on a clear moonless night and gazes about he soon discovers that he can see large objects quite clearly. If he pauses to think about the matter he probably concludes that the stars are responsible for the illumination. The light, however, is brighter toward the horizons and the illumination, equal to that produced by a candle at fifty paces is far too bright to be due to the stars. In fact, it has been shown that only one-fifth of the light on a dark moonless night comes from sources in outer space. The remainder is produced in our own atmosphere and surrounds the dark side of the earth with a feebly glowing cloak.

It has been known for some years that this light comes from heights comparable with the several layers of the ionosphere. It seems reasonable therefore to suspect a connection between the light of the night sky and the ionosphere. This paper deals with an investigation of this problem. It begins with a discussion of the night sky in general, followed by a description of the instrument used to measure night sky illumination and a discussion of the ionosphere and techniques of measuring ionospheric parameters. Data are then presented that show a possible relation between the two phenomena and certain conclusions are drawn concerning the relation.

As in most discussions in the field of the upper atmosphere, many diverse disciplines must be called upon to contribute to the solution of a single problem. For this reason we feel it wise to build up the background material in greater detail than would ordinarily be necessary. We must ask the reader familiar with the more trivial details of the background material to bear with us until he reaches the crux of the argument.

This work was begun while a part time employee of the Aerophysics Branch of the Research Department of the Naval Ordnance Test Station at China Lake, California. The work there was directed by F. E. Roach, head of the Aerophysics branch. The ionospheric investigation was begun with the consent of Dr. Roach and D. R. Williams, Assistant Head of the group. They have kindly made available the data collected by the group at Cactus Peak.

The work was finished by the author at the Department of Geological Sciences of the California Institute of Technology.

PART I

The Nature of the Night Airglow

As was mentioned in the introduction, the light of the night sky comes partly from outer space and partly from the atmosphere of the earth. We are concerned with the telluric portion of the light and will set forth a few of its characteristics. The reader is referred to SWINGS AND HEINEL (1951), MITRA (1947) for excellent review papers in this field.

The telluric portion of the night sky illumination, hereafter called airglow, night airglow or nightglow, comes in the main from the upper reaches of the atmosphere. Heights for various emission lines and bands have been estimated to fall in the region from 70 to 1,000 kilometers. The light itself is composed of a continuous spectrum upon which are superimposed lines and bands of elements and compounds found in our atmosphere. Table I, taken from MITRA (1947) and compiled therein from a great many sources and added to by us from other sources, lists a few of the brighter lines and bands. The relative distribution of energy in the background continuum is shown in Figure 1, adapted from BABCOCK AND JOHNSON (1941), and from PEARSON AND KOOMEN (1950).

The outstanding features of the light are noted at a glance. The continuum rises in intensity from the violet to the infra red. The principal line radiations are those

TABLE I

LINE AND BAND SPECTRA IN THE NIGHT AIRGLOW

Wave Length Å	Origin	Intensity Quantal Cm²/sec. col.	Excitation Potential e.v.	Remarks
5577	O atom Metastable	$3\text{-}6 \times 10^8$	4	Green Auroral line most prominent feature spectrum
6300 6364 6392	O atom Metastable	$1\text{-}4 \times 10^8$	2	Only 6300-6364 observed
5894	N_a atom "D lines"	$1\text{-}4 \times 10^8$	1.8	Always present (Doublet)
7000 to 9000	OH molecule	$10^{10} \pm$		Meinel bonds
10,440	OH Molecule			Meinel Bonds
3084 to 3082	O_2	?	4.5	Herzberg Bond system
3100 to 6125	N_2	?	6.14	Vegard-Kaplan ~~ion~~ system

* See G. Dejardin Rept. to Gassiot Comm., Roy Soc., (1946).

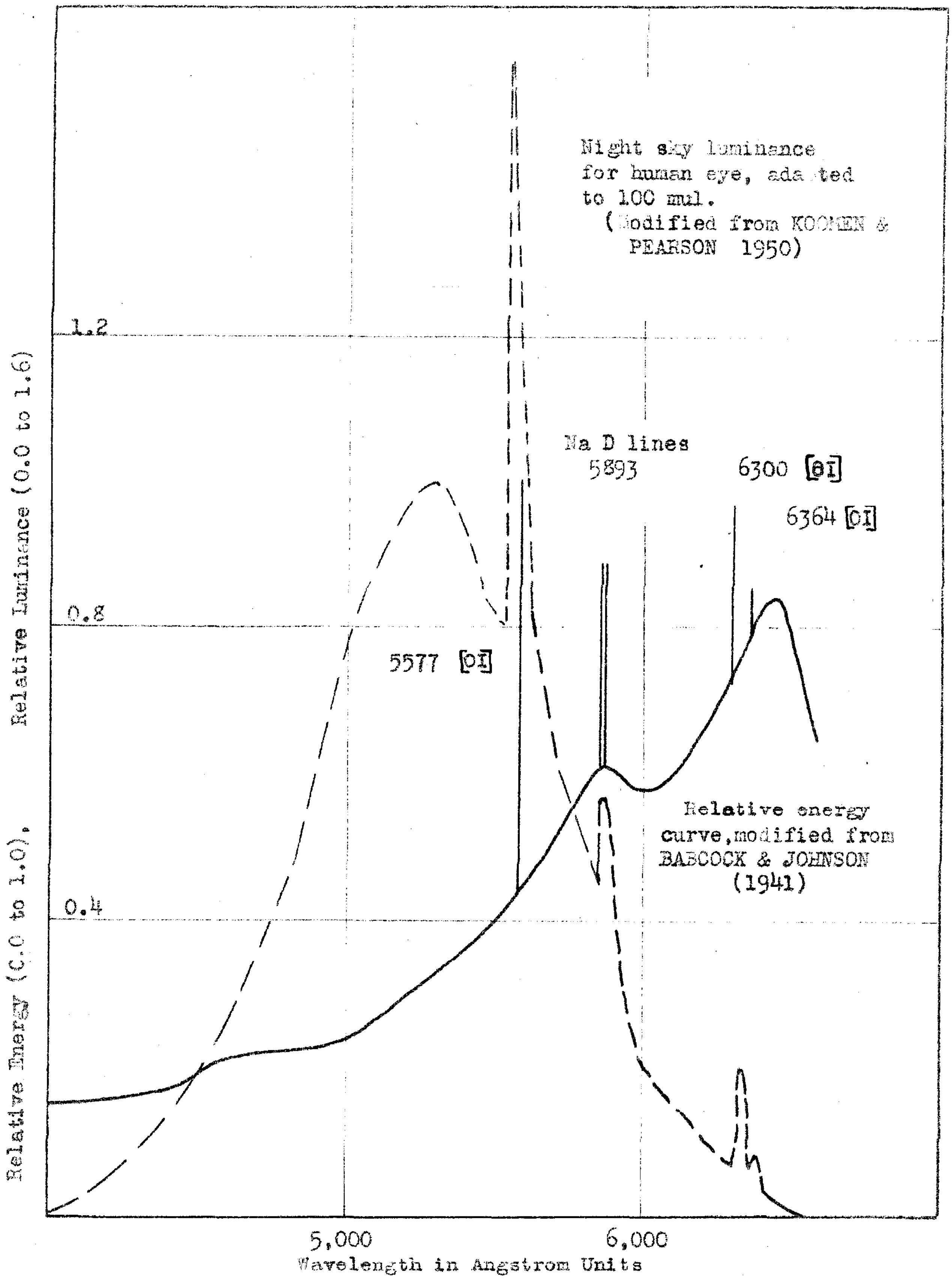


Figure 1. Distribution of energy in night sky spectrum, with additional curve showing response of human eye to night sky light.

of atomic oxygen at 5577 Å and 6300-6364 Å. The sodium D lines also form a prominent part of the spectrum. The chief band spectrum is that of the OH molecule. The highest excitation potential is about 6 volts.

The spectrum of the night sky differs from that of the polar aurora in that the excitation potentials are much lower. The nightglow does not appear to be directly related to the aurora, but a connection, or lack of one has not definitely been shown. The difference appears to be in degree of excitation and in the widespread character of the airglow as contrasted to the localized occurrence of the aurora polaris. It is usually assumed by night sky spectroscopists that the presence of an auroral display is announced by the appearance of the first negative bands of N_2^+.

Heights have been reported for a number of the emissions in the night glow. Table II contains a list of the heights together with the reference to the persons reporting the heights. The heights listed vary widely and it should be remembered that the calculation of heights to something as feeble and tenuous as the nightglow is very difficult and the values presented herein should be taken as order of magnitude estimates only. A discussion of the technique of height calculation will appear later in the paper.

The various atomic lines have been studied in some detail, but only the brighter lines are easily observed, and even with the best photoelectric equipment available today, the work is still in a rudimentary state. The 5577

TABLE II

HEIGHTS REPORTED FOR VARIOUS COMPONENTS OF THE NIGHT AIR GLOW

Most reliable heights are starred.

Radiation	Source	Height Kms.	Investigators
5893	Na	50	Garrigue by Barbier, 1936
		80	Dufay and Cheng Mao-Lin, 1947
		250	Roach and Pettit, 1951
		250	Barbier and Roach, 1950
		310	Barbier, 1950
6560	OH	500	Elvey and Farnsworth, 1942
Infra red	"	125	Elvery, 1942
"	"	70*	Roach, Williams and Pettit, 1950
"	"	300	Masaaki Huruhata, 1950
5577	O1	200	Garrigue, 1936
		500	Elvery and Farnsworth, 1942
		103	Dufay and Cheng Mao-Lin, 1947
		260	Karimov, 1947
		900 75	Abadie, A. Vassy and E. Vassy, 1945
		1000 to 400	Abadie, A. Vassy and E. Vassy, 1949
		110	Roach and Barbier, 1950
		215*	Barbier, Dufay and Williams, 1951
		250*	Roach and Pettit, 1951
6300	O1	500	Elvery and Farnsworth, 1942
		180	Dufay and Cheng Mao-Lin, 1947
		1000-65	Abadie, A. Vassy, E. Vassy, 1945
		1000-400	Abadie, A. Vassy, E. Vassy, 1949
		350*	St. Amand, 1952
		In general $>$ H5577*	St. Amand, 1952, Roach and Pettit, 1951

line reaches a maximum intensity sometime during the night, usually within 3 hours of local midnight, while the sodium D line shows a rather indefinite nocturnal variation, ROACH AND PETTIT (1951A). The 6300-6364 lines are brightest after sunset and decrease in intensity throughout the night. The other lines have not been studied in sufficient detail to report on the diurnal variations here.

There appears to be a marked annual variation in the intensity of the sodium D lines, ROACH AND PETTIT (1951B), and a less marked annual variation in the cases of the two atomic oxygen lines although there have not been enough carefully standardized measurements taken yet to really establish this.

Attempts have been made to correlate the variations of the light from the night sky with all manner of terrestrial and cosmic phenomena, but so far nothing convincing has been demonstrated.

The night glow is in general of uneven and patchy distribution and shows large patches or clouds of brighter radiation which appear to move across the sky. ROACH AND PETTIT (1951A) contend that the patches move primarily from east to west. This is to be expected in consequence of the diurnal variation noted by a large number of observers, which places the maximum intensity of the 5577 radiation within a few hours of the same local time. HURUHATA (1950) contends that the patches move north and south as well as east and west.

We will now move on to a description of the instrumentation with which the work described herein was carried out.

PART II

Instrumentation

The instrument used in this work was designed at the Naval Ordnance Test Station at China Lake and Pasadena, California. It is used in the work of the Aerophysics Branch there. The Optical design work was done by W. Wallin of Michelson Laboratory, the mechanical work by D. R. Williams and J. C. Pemberton, the electrical and electronic portions of the design by the present author. The machine was later partly redesigned to correct certain mechanical and electrical difficulties. D. R. Williams was in charge of the developmental work.

The instrument is an outgrowth of and an improvement on an earlier model described by MARLOW AND PEMBERTON (1949). The new instrument departs radically from the older version and a great improvement was made in overall operation.

The device is entirely automatic; intensity of light can be recorded in as many as four different wavelength regions while the instrument surveys the entire sky every 32 minutes. There are two separate functions performed by the machine. The first is that of measuring the intensity of light, this is done by the telescopes, photomultiplier tubes, amplifiers and recorders. The second is that of surveying the heavens, done by a mechanical system that orients the telescopes according to a preselected program. All operations are performed automatically and the actual photometer unit is operated remotely through a control panel situated at some distance from the photometer itself. The photometer is shown in Figure 2, and the control and amplifier panel in Figure 3. The optical and electronic portions of the apparatus will be described first.

Optical Design

Telescope: The telescope optics are shown in Figure 4. The tubes and fittings are of brass. The field of view, a circle nominally 5^{o} in diameter, is determined by the focal length of the objective lense and the diameter of the field lens. Figure 5 shows a schematic representation of the arrangement and will aid in understanding the operation. The focal length of the objective is so chosen that the focal plane falls within the field lens. Now, any light from an infinitely distant source falling upon the objective from an angle such that it can be focused upon the field lens will enter that field lens and light from angles greater than that will fall upon the lens housing and be rejected. The field lens is chosen so that it will bring to a focus upon the cathode of a photomultiplier tube, an image of the objective lens, or of a mask placed just before it. This means that all light coming from within the field of view of the apparatus will fall upon the photocathode and be detected, but that no image of the original light source will be formed. The advantage of this is that the illuminated area is held stationary on the photocathode and the sensitivity over the field of view is supposedly held constant.

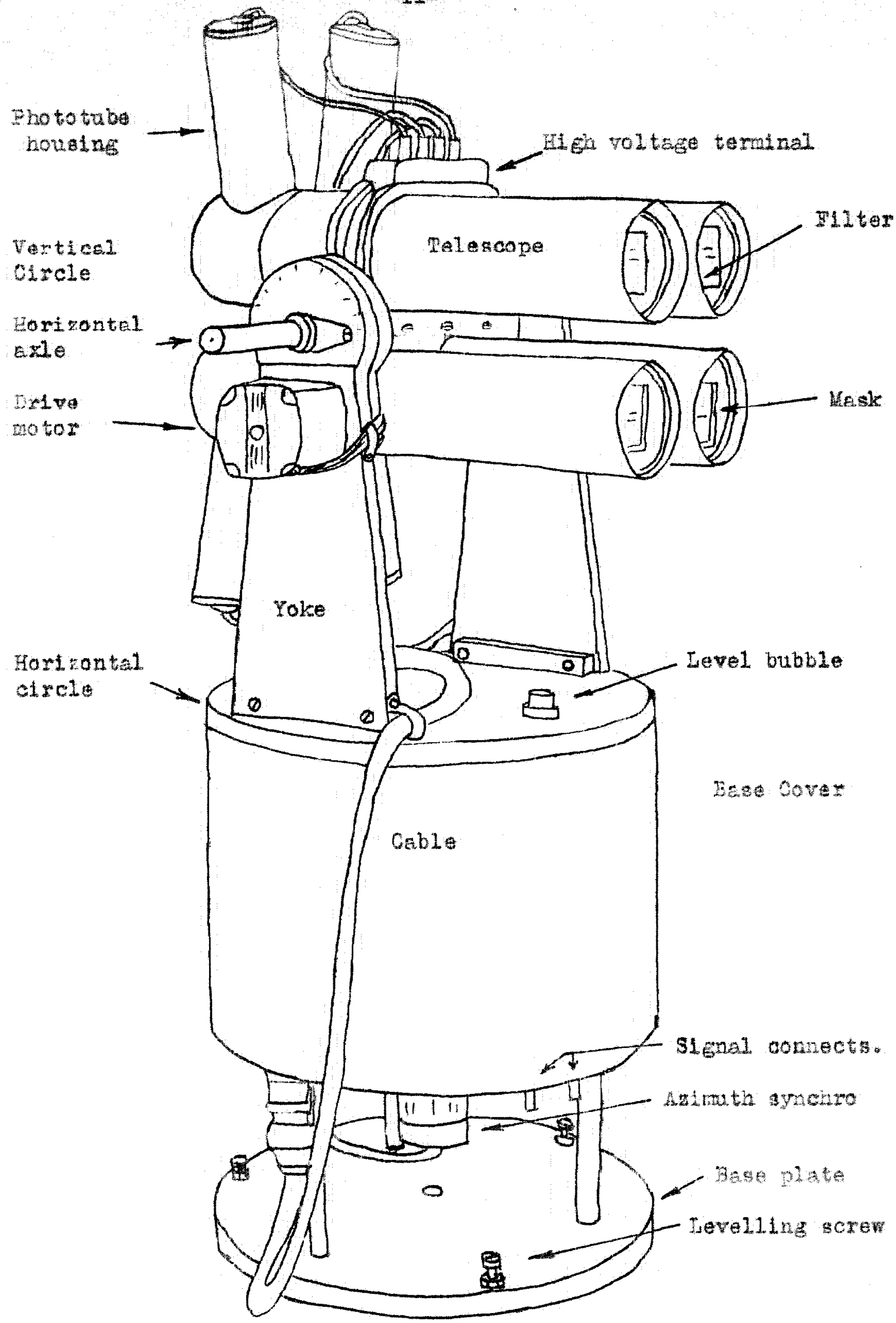
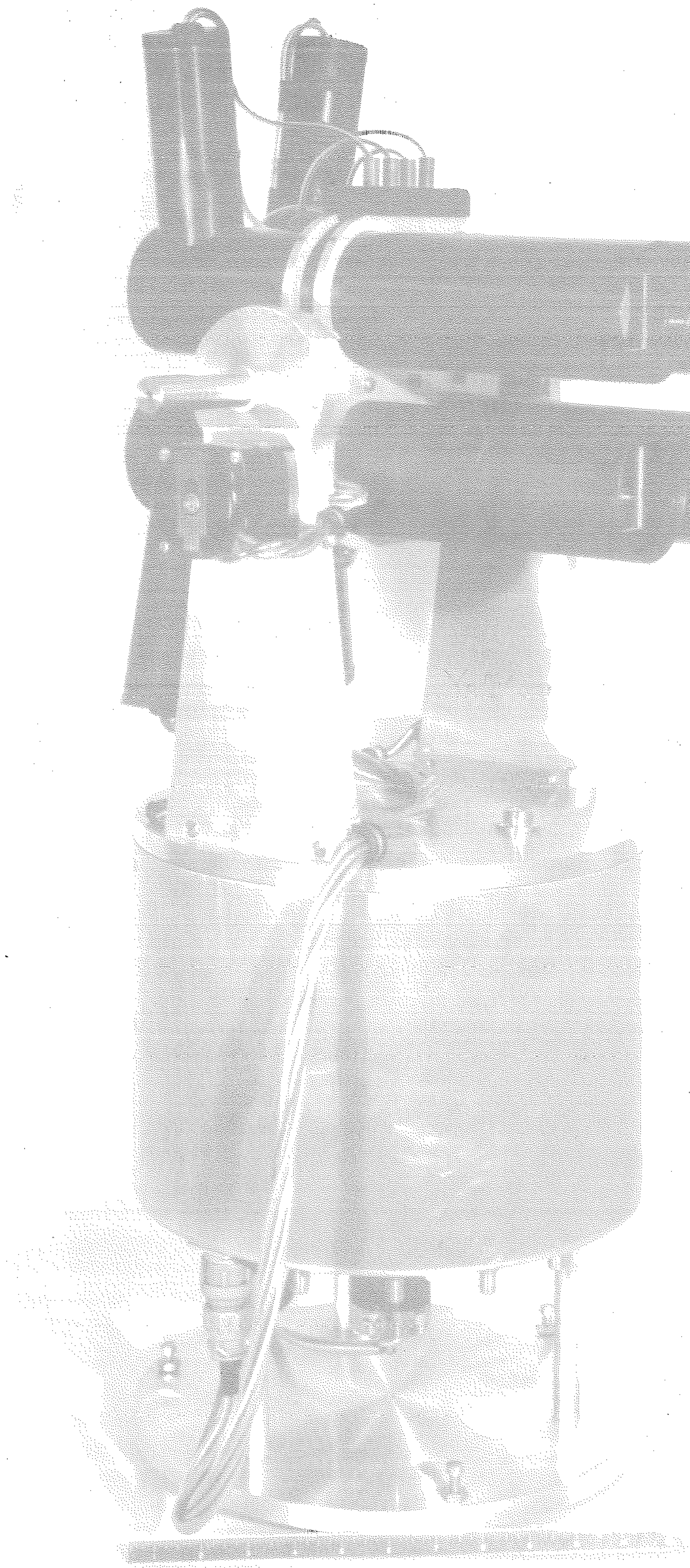


Figure 2. Photometer Unit. This unit is mounted out of doors.



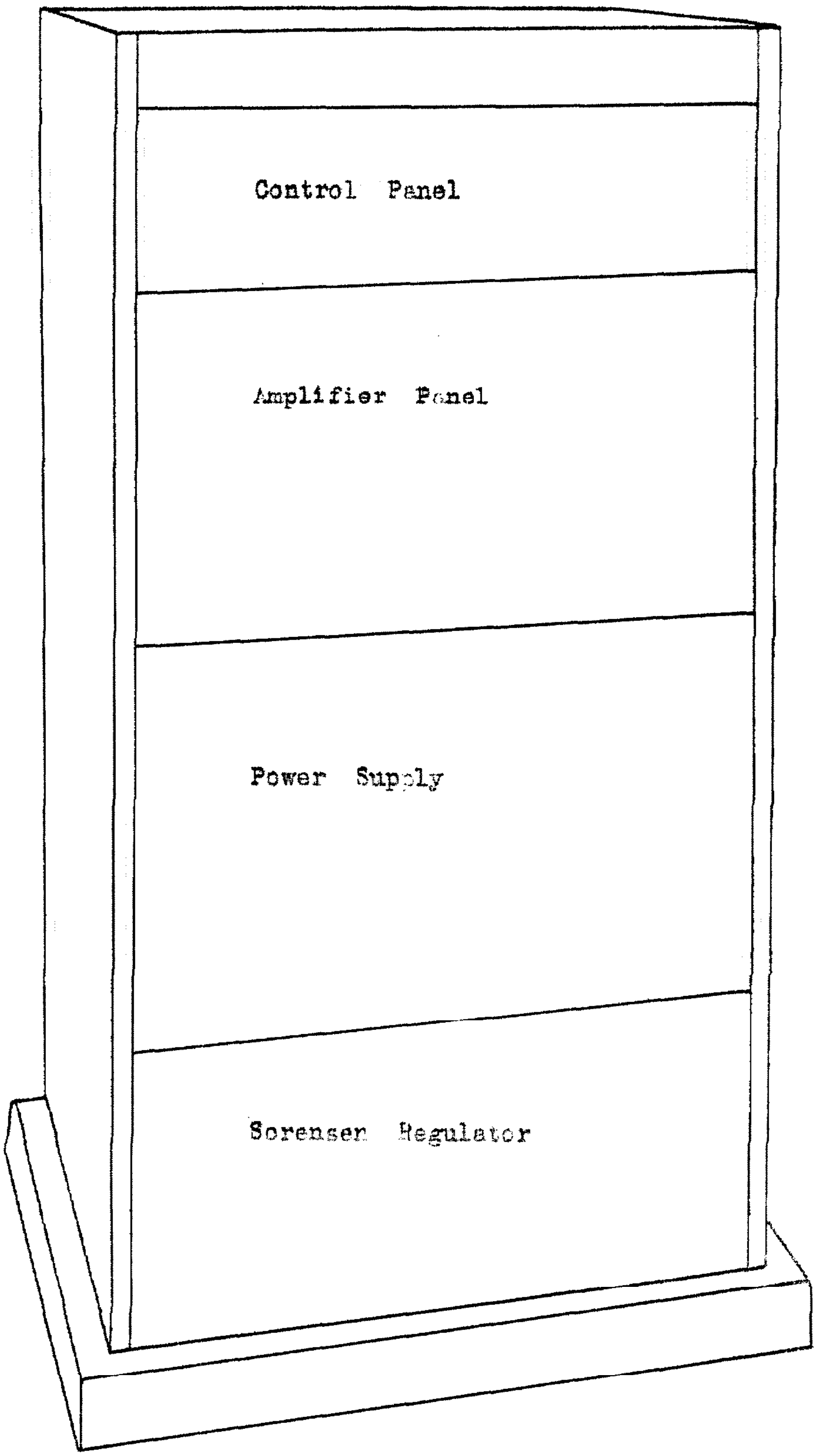
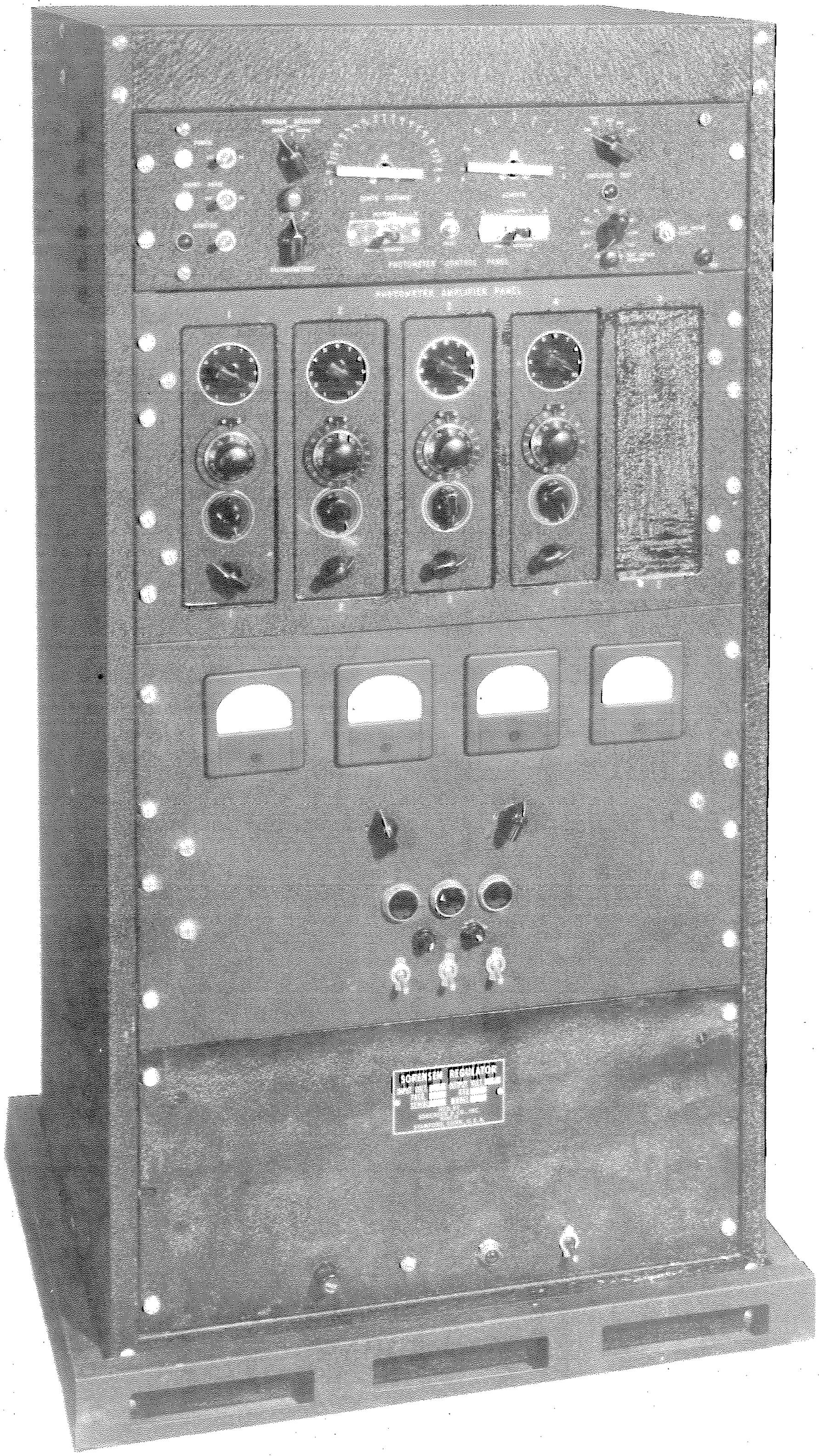
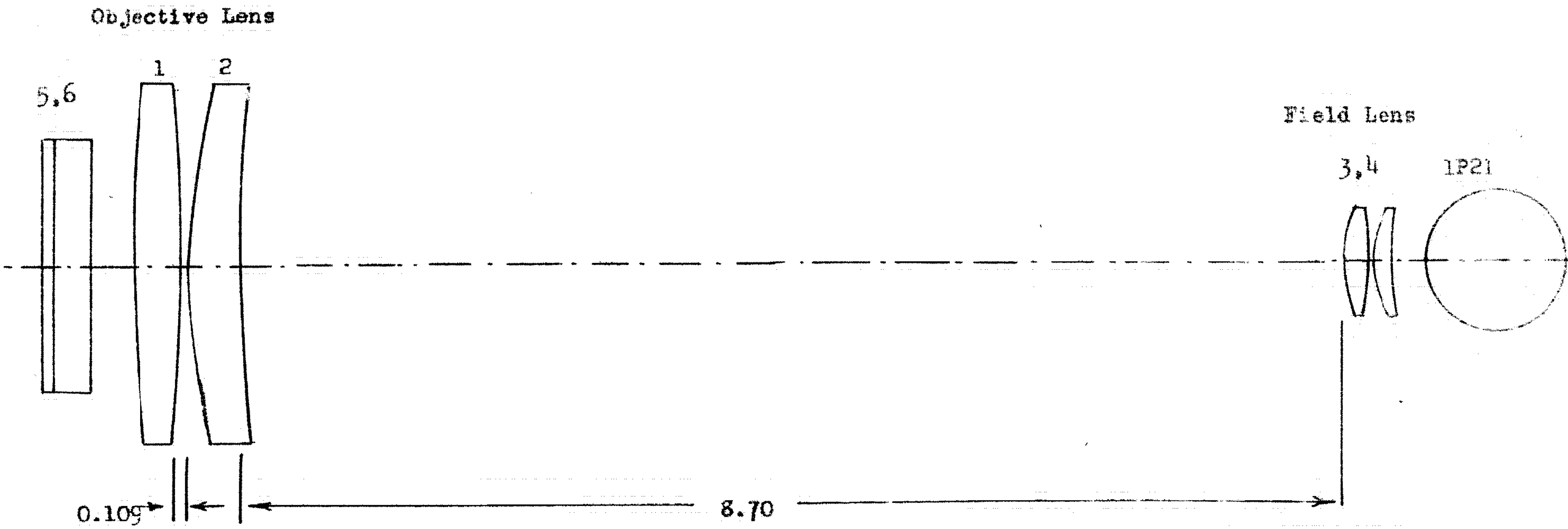


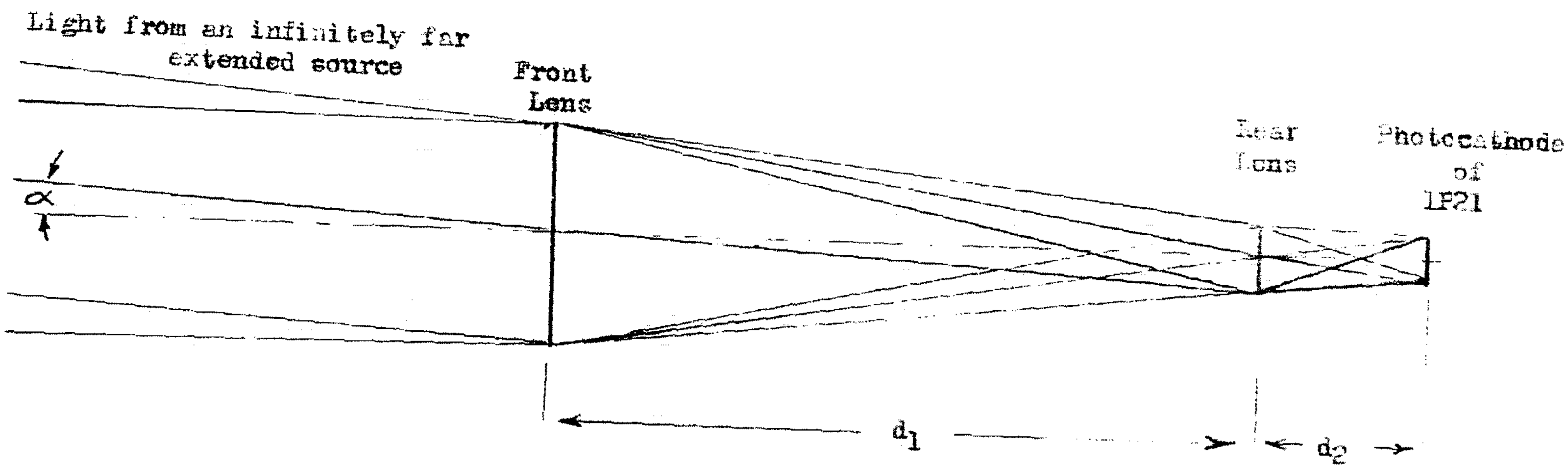
Figure 3. Control and Amplifier Rack. This portion of the apparatus is located in the observing hut.





Element Number	Diam. In.	Radii		Center Thickness	Index of Refr. N_D	Eff. Focal L. In.	Material
		Front	Rear				
1	2.85	10.96	-73.43	0.35	1.523	9.73	Water white Plate glass
2	2.85	5.77	14.43	0.41	1.523		
3	0.90	1.26	- 2.85	0.18	1.611	0.73	Dense barium Crown, 3
4	0.90	0.64	2.22	0.18	1.611		
5	2 X 2	Colored glass transmission filter					
6	2 X 2	Interference filter					

Figure 4 . Telescope Optics.



tan = (Radius of Rear Lens)/ (Focal Length Front Lens)

Figure 5. Ray Tracing Through Photometer Telescope. To illustrate use of field lens.

Although a field lens is not really needed, the use of one results in a marked improvement in ease of calibration and accuracy of height determination. The images of stars falling within the field of view are not occulted by the grid wires in front of the photocathode, thus making the instrument useful for photometry of both point and extended sources and ensuring that the average sensitivity of the apparatus is not dependent upon the location of bright sources within the field of view. The photocathode of the 1P21 is not uniformly sensitive over its surface as may be seen from Figure 6 adapted from KESSLER AND WOLFE (1947). Since the image formed on the photocathode does not move about the surface the average sensitivity is held constant.

This is the intent of the design; it is impossible, however, to design a symmetrical lens system that will assure uniform sensitivity over the entire field of view of the instrument because the photocathode of the 1P21 is curved. This leads to some difficulties which will be discussed in the section on calibration. In any future instruments the 1P21 should be replaced with an "end-on" type photomultiplier so that the cathode will be as nearly plane as possible.

It is interesting to notice that as long as the front lens is sufficiently large to gather light that the F ratio of the lenses is not too important since the response of a phototube is to all the light falling upon it and so long as

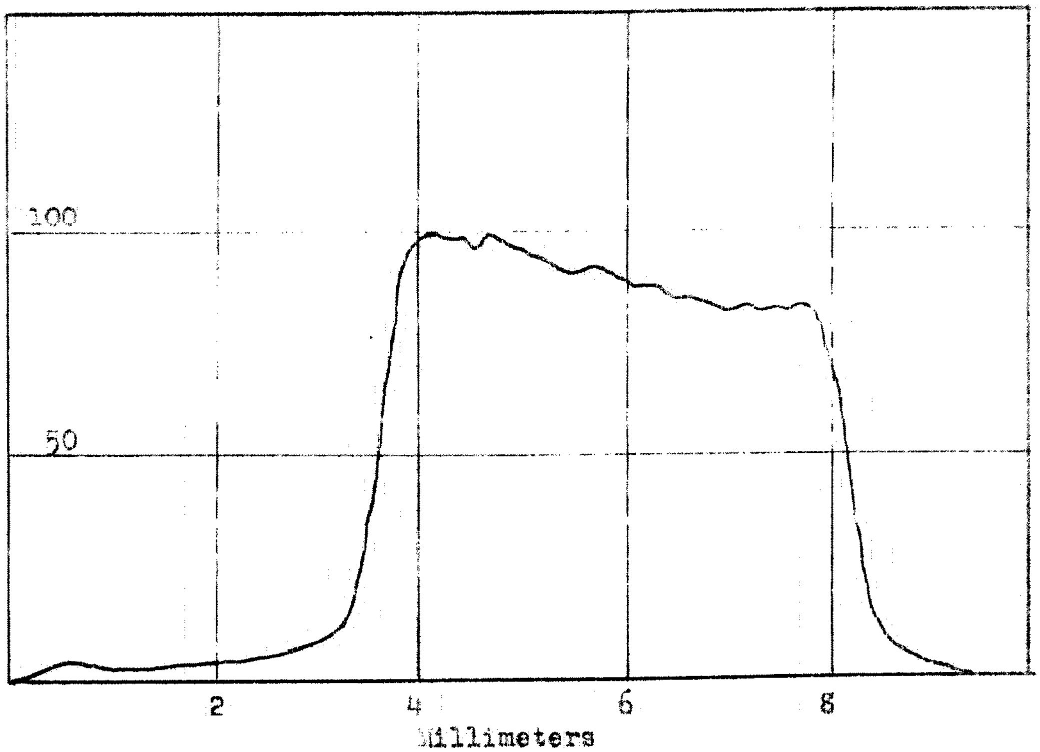


Figure 6A. Change in sensitivity from left to right across photocathode of 931A, physically identical to 1P21

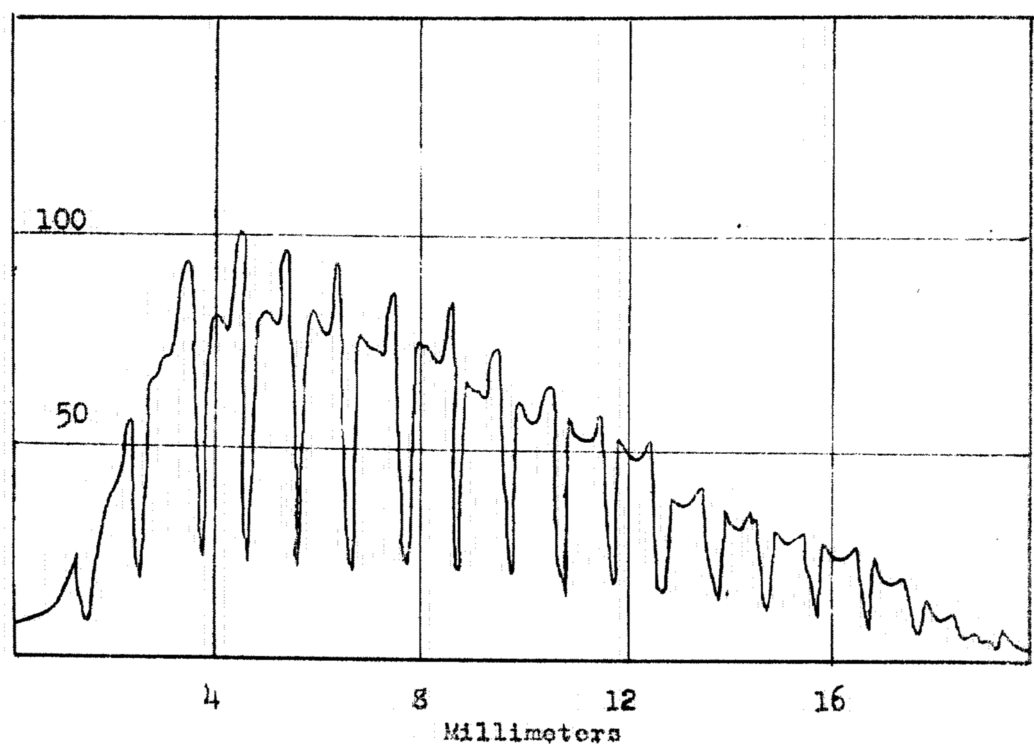


Figure 6B. Change in sensitivity from bottom to top of cathode of 931A. The sawtooth character is due to wires of the focussing grill.

the size of the image does not exceed that of the cathode, the total light coming through the system will produce the response, rather than the brightness of any particular part of the image.

Photomultiplier Housing

The light sensitive tube, a 1P21 type photomultiplier, is held in a specially designed mount at the rear of the telescope and protected by a light tight housing. The position of the tube may be adjusted in horizontal translation, rotation and by vertical translation. Focussing is accomplished by removal of the back of the housing and forming the desired image on a translucent screen of the same shape and in the same position relative to the tube base as the photocathode. This is done with a distant point source of light. When perfectly focussed the image of the point source is spread uniformly over the square image of the filter mask.

The tube is then inserted and the holder adjusted vertically for maximum response. The details of the phototube holder may be seen in Figure 7. The voltage divider resistors are located in the cylindrical tube at the bottom of the tube socket, permitting the use of a three conductor cable to bring the high voltage to the tube and take the signal from it. Connection is made to the tube base through a shielded, amphenol, microphone plug.

Because the sensitivity of the 1P21 and similar photomultiplier tubes is affected by the magnetic field in

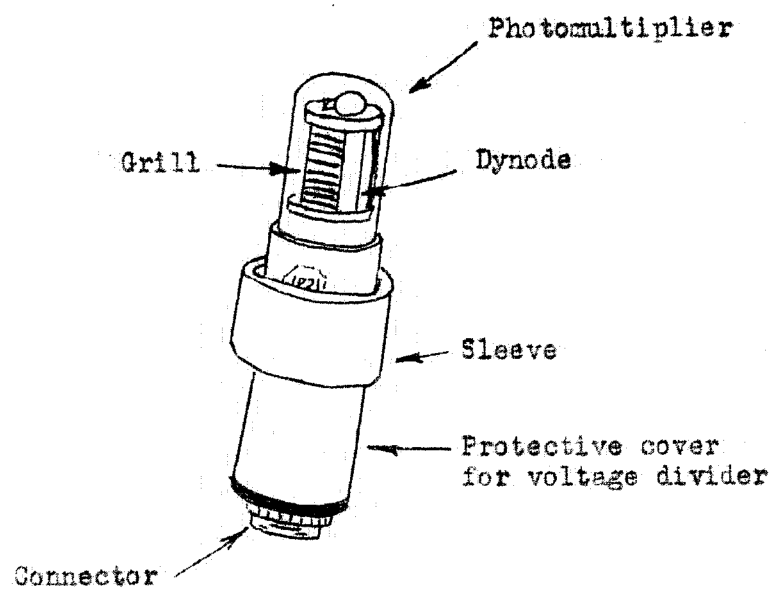
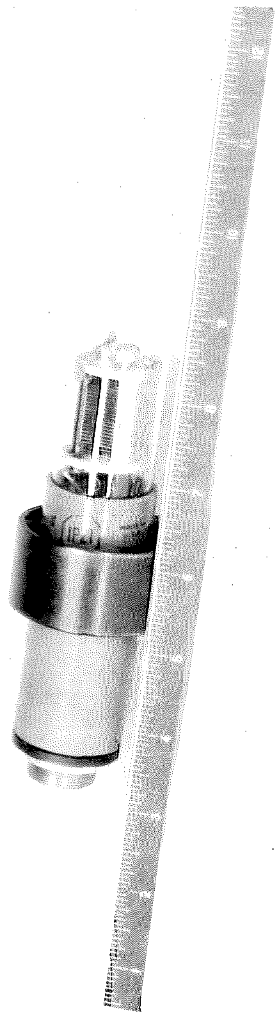


Figure 7. Photomultiplier tube in Holder. The resistors for the voltage divider are in the bottom of the holder.



which they operate, and reversal of the tube position in the earths magnetic field can cause changes of up to 15 percent, the tubes are shielded with caps of mu metal. This precaution reduces the magnetic effect, as it is called, to less than one percent.

All metallic portions of the telescope are blackened to reduce light reflections and a baffle system is included in the telescope tubes to prevent light reflected from the sides of the tubes from entering the field lens.

Filters

The spectral range over which the instrument is sensitive is determined by the spectral range of the photomultiplier used. The 1P21 has an S-4 surface, the relative response of which is shown in Figure 8 along with the photoptic curve and the response curve of a typical filter. The range of the unfiltered 1P21 is too great and for this reason interference filters of the Fabry-Perot type are used in conjunction with a transmission filter. The combination passes a very narrow bandwidth, the half sensitivity points being about 30 Angstrom units on either side of the central wavelength. The equivalent width is of the order of 60 Angstrom units. The function of the transmission filter is to cut down response in the wings of the interference filter and to eliminate unwanted transmission maxima of the interference filters.

The filters are held in front of the objective by a frame secured by a retainer ring. The filter is masked by

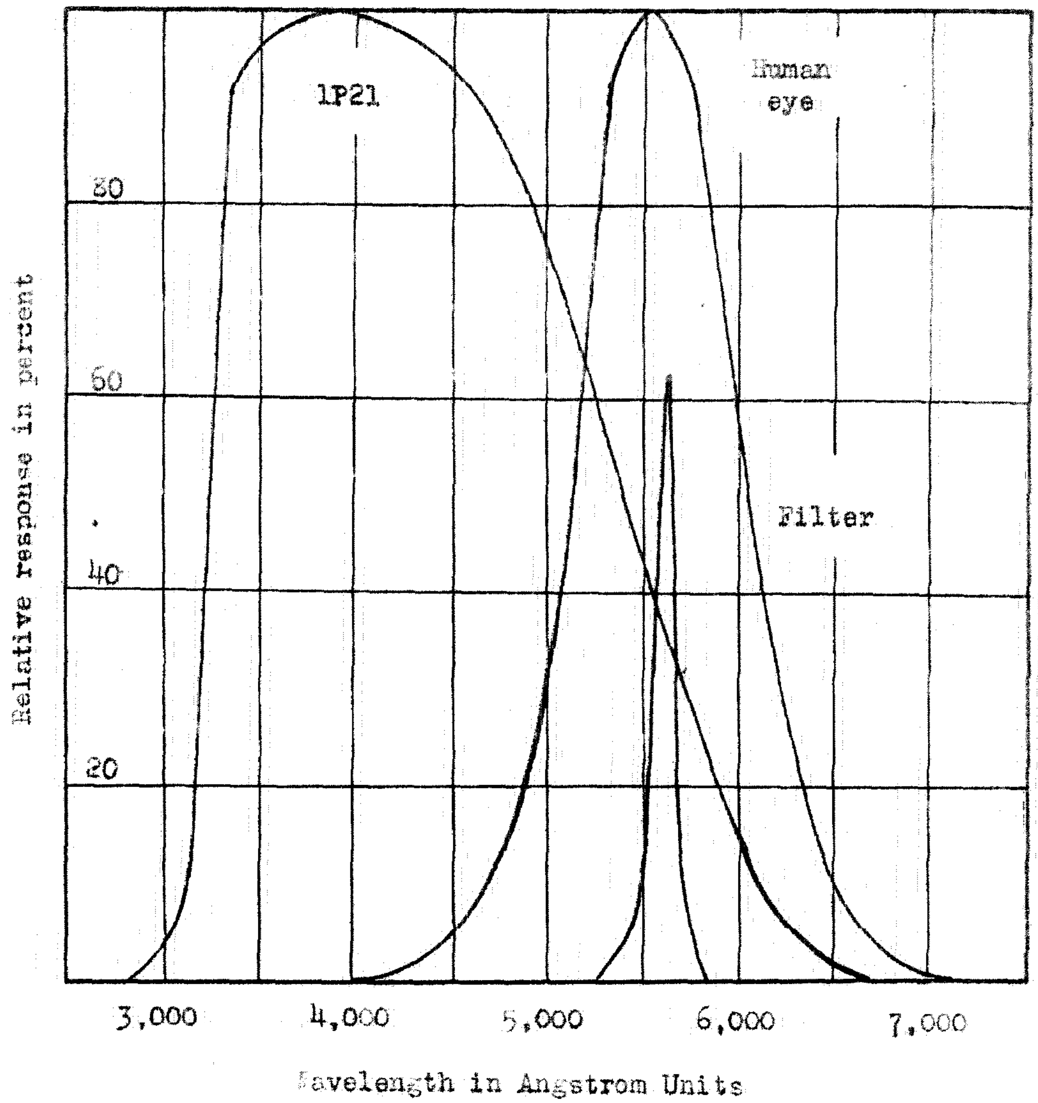


Figure 8. Spectral response of 1P21, human eye and typical interference filter.

the frame and the exposed portion of the optical system is actually a square, two inches on a side. Neutral filters may be placed in the holder with the interference filter, permitting use of the instrument in bright light.

Shutters

As originally developed, the instrument used a hinged flap type shutter, actuated by a solenoid. The shutter was placed just in front of the field lens. Compur type shutters with adjustable iris diaphragms will replace these so that the field of view of the instrument will be controllable, permitting use in extinction measurements and stellar photometry.

Electronic Design

Photomultiplier: The 1P21 photomultiplier used as a radiation detector in this apparatus is described in literature furnished by the Radio Corporation of America and discussed in detail by a number of authors. Special reference is made to ENGSTROM (1947), KRON (1948, 1946), DEWITT AND SEYFERT (1950) and ZWORYKIN AND RAMBERG (1949). A short discussion will be given here to facilitate explanation of the apparatus.

The photomultiplier tubes consist of a cathode, and a series of nine dynodes, all coated with the same photosensitive material. The dynodes are placed at increasingly positive voltages with respect to the cathode. Figure 9 will aid in understanding the arrangement. Light striking

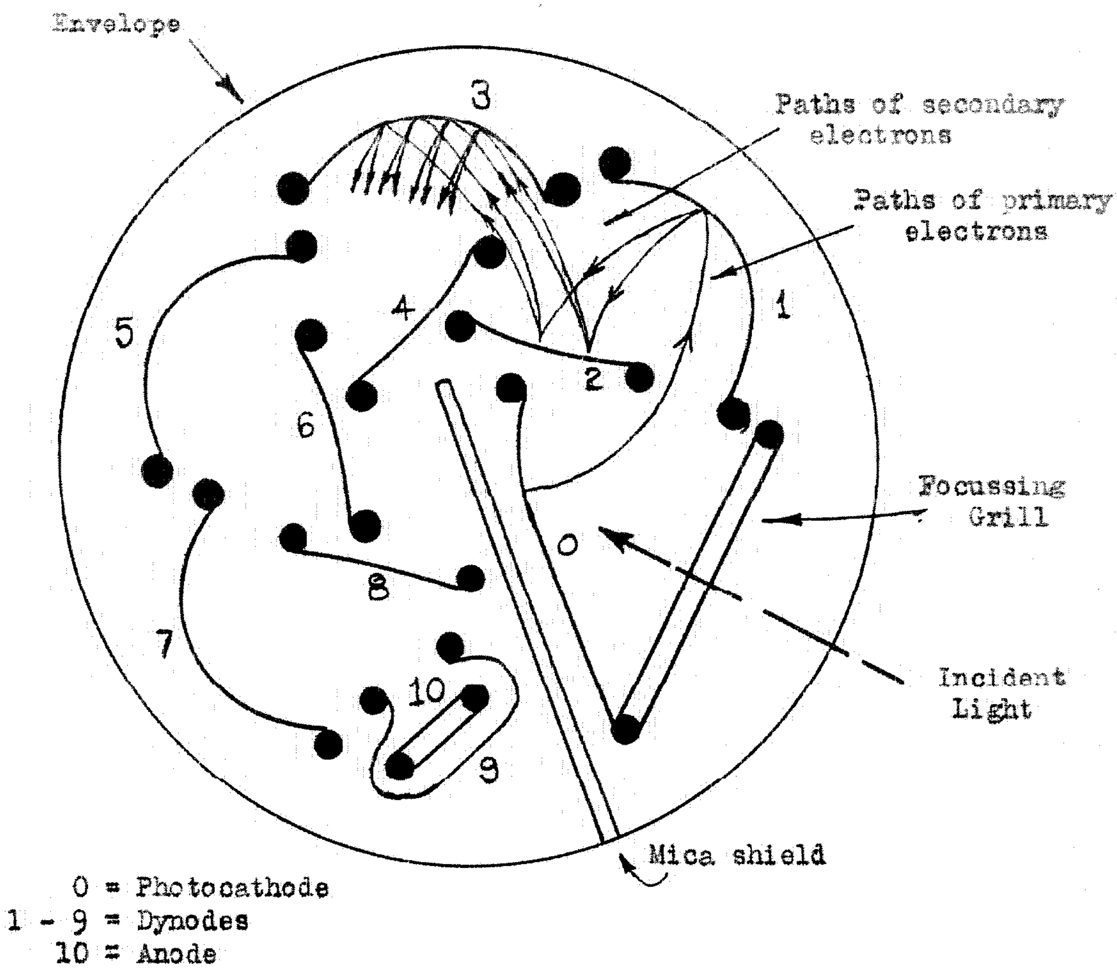


Figure 9. Schematic representation of electrodes in a 1P21 type photomultiplier.

the photocathode ejects photoelectrons from the sensitive surface. These primary electrons are then directed to the first dynode where the electrons each eject a number of secondary electrons. These are attracted to the second dynode where the process is repeated. This results in current amplifications of the order of 2,000,000 for a good tube.

The anode (number 10) is a wire grid through which the electrons can pass freely to dynode 9 which partially surrounds the anode and acts as a shield. The spacing is such that all electrons leaving 9 are collected by the anode. This arrangement makes the sensitivity independent of the voltage between the anode and the ninth dynode, over a very wide range. This brings about two important consequences, the first is that the noise output and stability can be improved by operating dynode 9 at a lower voltage without loss of sensitivity and secondly the output current is essentially independent of output impedance for all reasonable values of impedance. This permits changing the sensitivity of the photometer by changing the value of the output impedance. In this way the voltage output of the photomultiplier can be held within a certain range, and the amplifier used with the tube, designed to cover this range for all values of incident flux within the range of safe response of the tube.

The overall sensitivity of the photomultiplier is a function of the overall supply voltage and for this reason the dynode potentials must be very stable. Figure 10 shows the sensitivity and dark current as functions of voltage. Although the dark current of the 1P21 is comparatively low, of the order of 10^{-7} amperes, it is occasionally greater than the signal current and hence must be made as stable as possible. The dark current is a function of temperature and voltage. At lower voltages the dark current is mainly leakage about the base of the tube and through the circuit components. This portion of the dark current can be minimized by clean design and careful selection of insulating material for the tube socket and leads. At higher voltages, ion bombardment predominates. Therefore in selecting an operating voltage a compromise must be made between achieving a high tube gain and a useful signal to noise ratio. It has been found that 900 volts is an optimum working value under the temperature conditions prevailing at the Cactus Peak Observatory, where the apparatus is used. This corresponds to 95 volts between successive dynodes except between dynode 9 and the anode, where a potential of 45 volts is used.

It is interesting to note that the sensitivity of the 1P21 can be controlled by controlling the voltage on any dynode, or on all of them, or on any combination of dynodes. This will certainly have many applications in the construction of photoelectric devices for special purposes. It would also furnish an excellent means for delivering inverse feedback to the photomultiplier itself to increase the stability of the device.

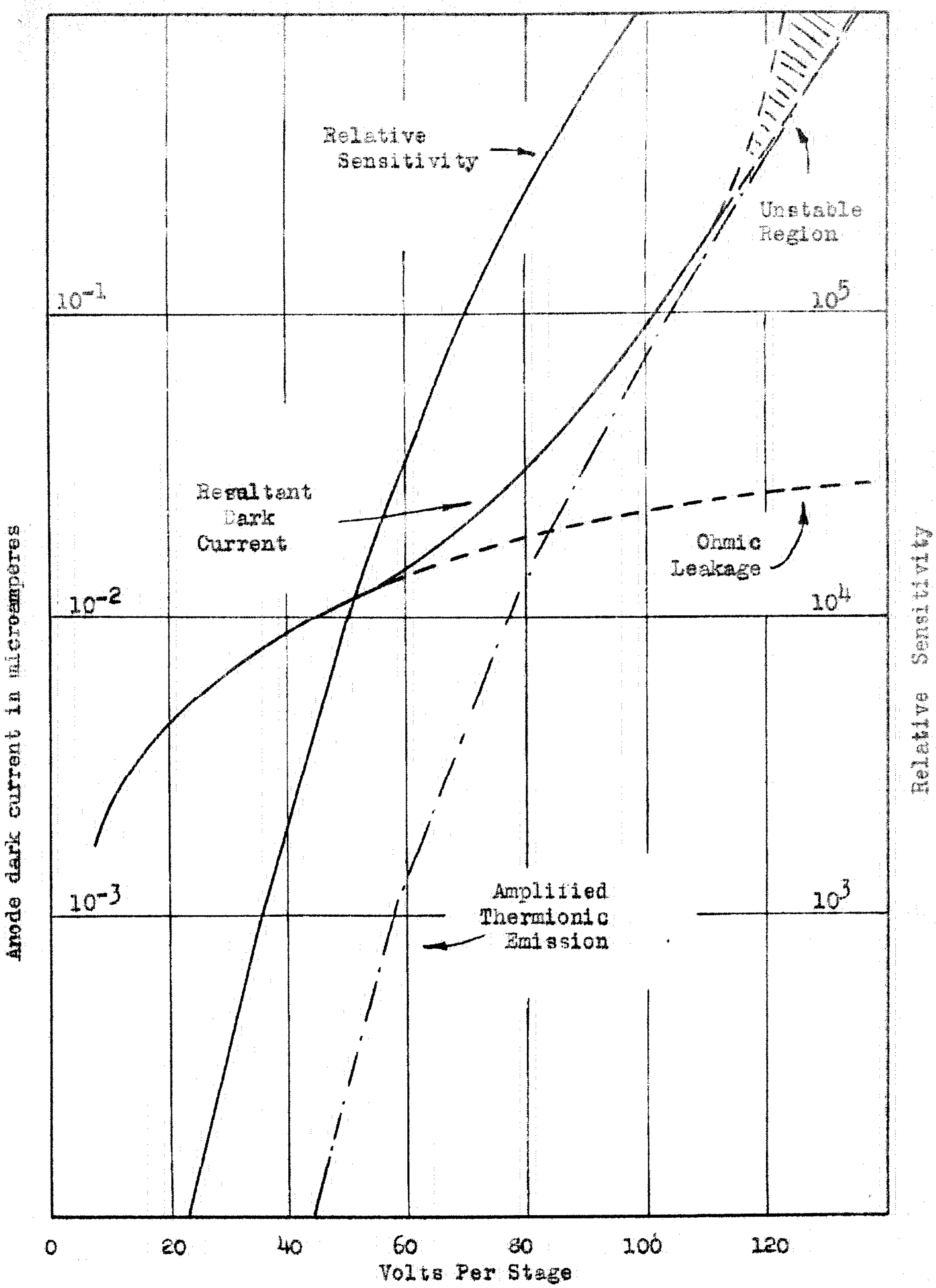


Figure 10. Dark Current and relative sensitivity of photomultiplier tube as functions of voltage. Dark currents in selected tubes are actually much lower than these.

Various investigators have reported that the photocathode of the 1P21 behaves as if it were optically polarized. Tests performed with the apparatus described here revealed no effects attributable to polarization. It is possible that the apparent polarization was due to a shift of the image on the photocathode as the tube or the light source was rotated. It is also possible that light reflected from the sides of the apparatus may have brought about this condition.

ENGSTROM (1947) reports that the current output is a linear function of the illumination over the range from 10^{-3} to 10^{-9} amperes and even to values as low as 10^{-12} amperes if photon counting techniques are employed. The range of operation in night sky work is much less than this.

As mentioned before, magnetic defocussing of the electron beam by the magnetic field of the earth is a troublesome feature of this type of tube, but can be corrected for in analysis of the data or eliminated by soft iron or mu-metal shields. Measurements made with a radium light source indicate that the magnitude of the effect is different for each tube and that the variation of sensitivity is in the region of 5 to 15 percent, plus or minus, of the mean zenith sensitivity, depending upon the orientation of the tube. A recent discussion of this effect by EGGEN (1951) is in accord with these findings. Figure 11 shows the variation

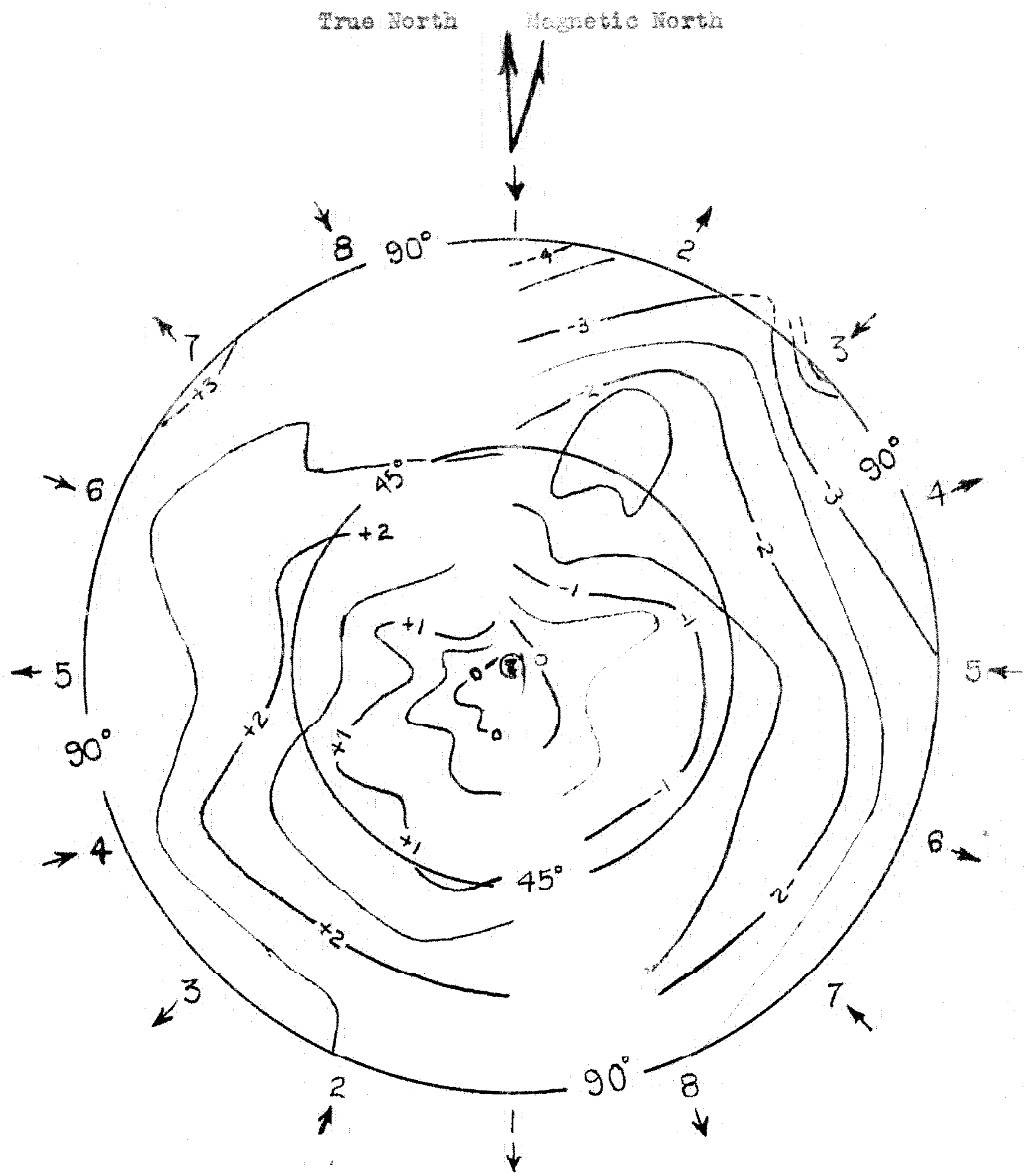


Figure 11. Error due to the effect of the earth's magnetic field upon the 1P21 used to record 5577 in February 1952. Expressed as percentage of mean zenith sensitivity. Values shown are means of seven surveys.

of sensitivity with orientation for a typical photometer. DE WITT AND SEYFERT (1950) have put this phenomenon to good use by defocussing the electron beams with a horseshoe magnet in order to eliminate the component of dark current arising from ion bombardment and thermionic emission so that they could determine the leakage current in their apparatus. The author would like to suggest here that the magnetic effect might be put to practical use in the construction of a sensitive, light weight magnetometer which would be relatively insensitive to accelerations, and perhaps useful for orientation of guided missiles, oil well logging, etc..

Photomultipliers become rapidly fatigued at light levels high enough to give output currents in excess of one milliampere. The output currents encountered in night sky work is many times lower than this; and the change of sensitivity from fatigue may be eliminated by operating the tube with the voltage on for some time before observing with it.

Amplifiers

The amplifiers are an adaptation of a vacuum tube voltmeter circuit described by GRAY (1948). The constructional details are shown in Figure 12, a schematic diagram in Figure 13.

The input resistances used to control gain are Nobeloy low drift metallized film resistors selected for temperature stability and low noise output. The input tube is the red

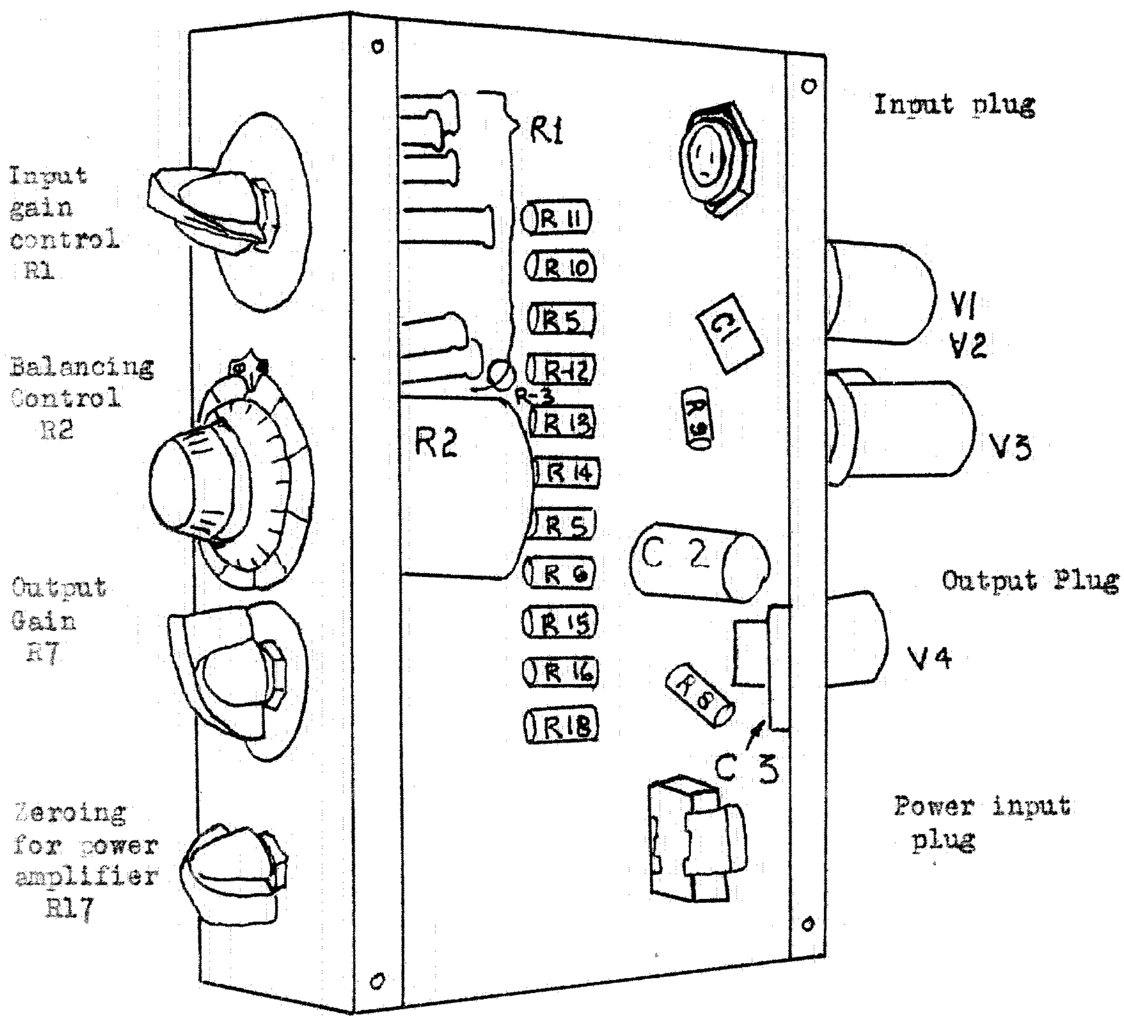
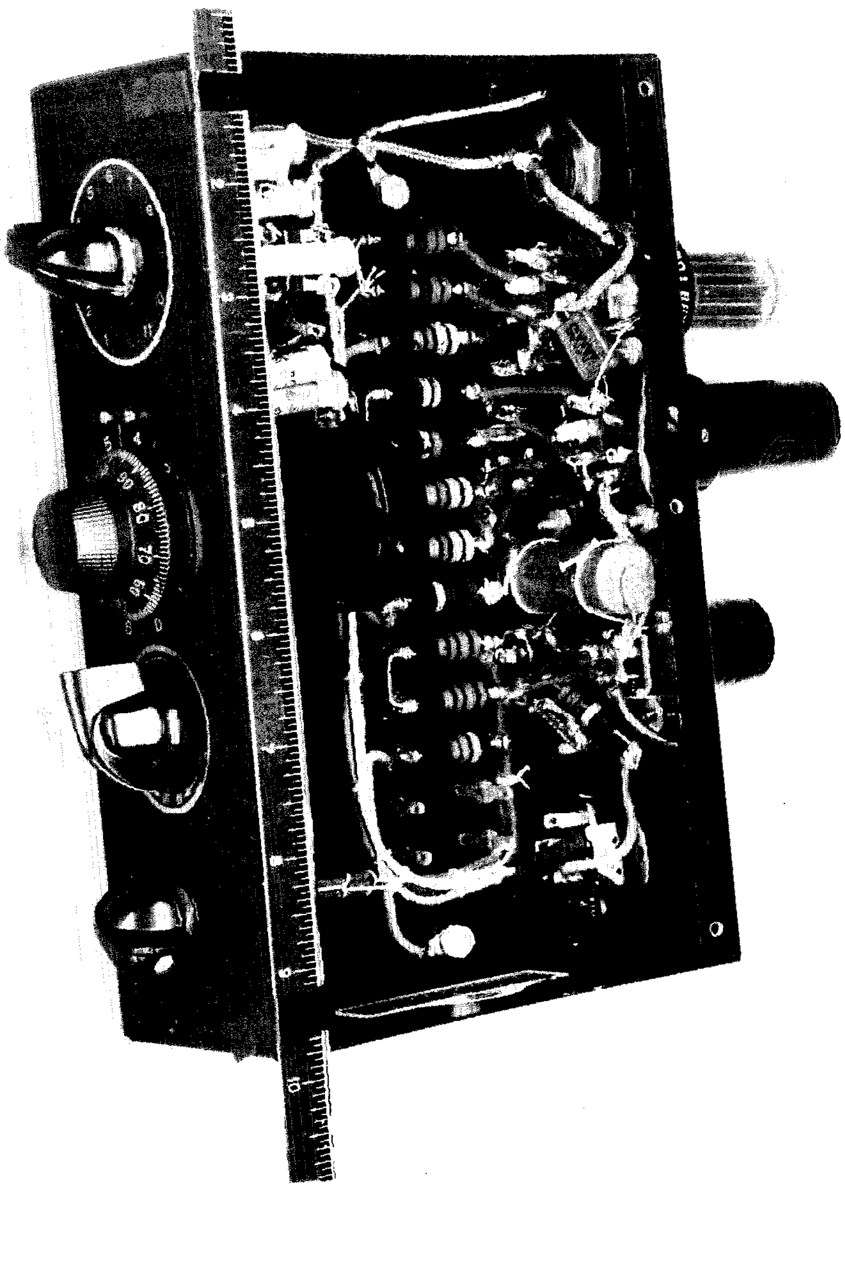


Figure 12. Direct Current Amplifier. This is a photograph of the earliest model, the later ones use "turret" sockets and both sides of the chassis are removable.



LIST OF COMPONENTS FOR D.C. AMPLIFIER

Vacuum Tubes

V 1	5691
V 2	6SJ7
V 3	6SN7
V 4	6AC7

Resistors

R 1	Input gain control, in steps, 40M,20M, 10M etc.	
R 2	50 K	
R 3	1 M	
R 4	47K	(K means thousand ohms, M means million ohms)
R 5	47K	
R 6	1 M	
R 7	50K Potentiometer	
R 9	2.7M(nominal)	
R 10	3.3M	
R 11	3.3M	All fixed resistors are two watt resistors
R 12	220K	
R 13	22K	
R 14	47K	
R 15	17.5K (nominal)	
R 16	33K	
R 17	10K	
R 18	18K	

Condensers

C 1	100 micro-micro-farad.
C 2	0.25 micro-farad, 250 volts.
C 3	0.05 micro-farad, 250 volts.

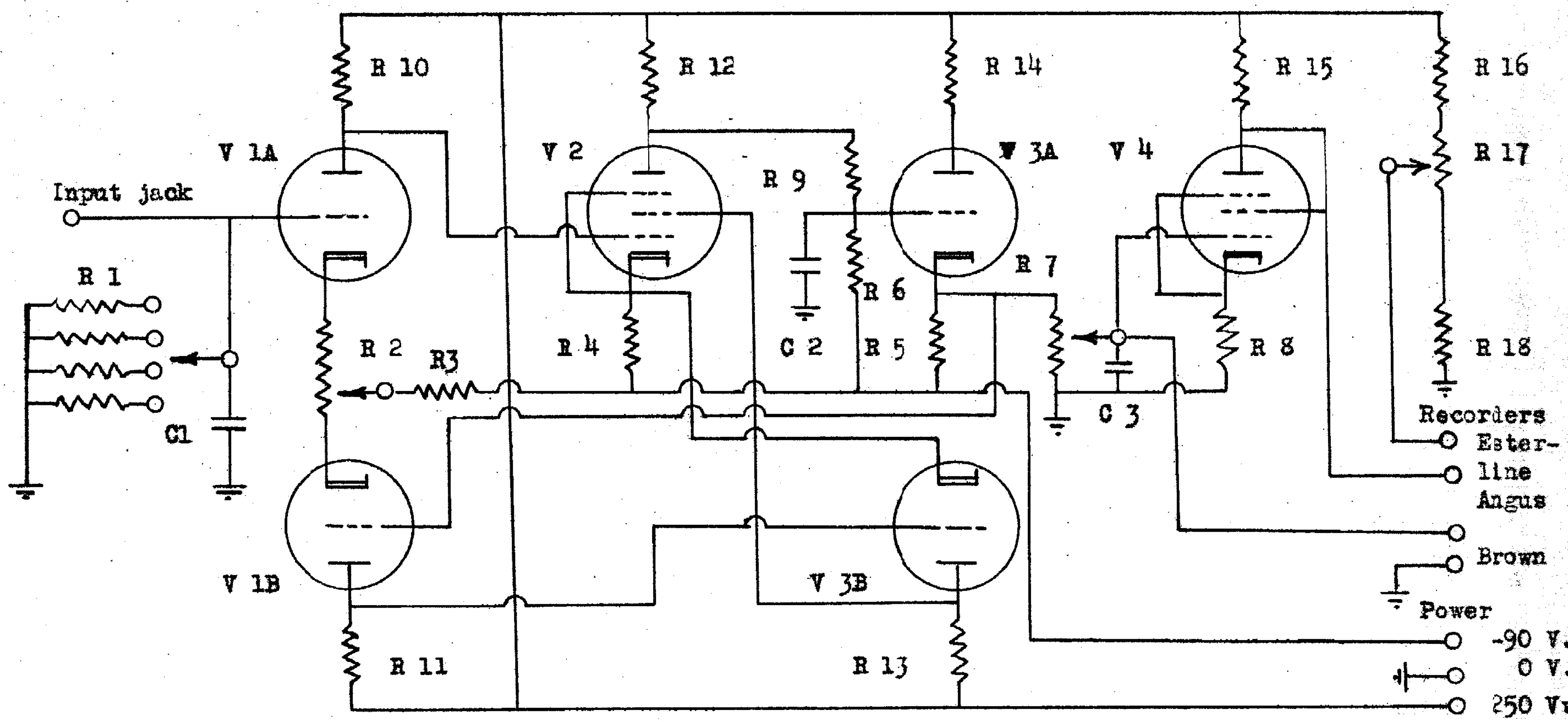


Figure 13. Direct current Amplifier used in the night sky photometer.

based "ruggedized" 5691. Degenerative current feedback is delivered to the second half of the input tube which acts as a differential amplifier. The second stage is a high gain pentode. The output stage is a cathode follower and hence has a low output impedance. This is well suited to use with a Brown "Electronik" recorder, but when used with an Esterline-Angus recorder results in considerable over-damping of the galvanometer. In order to use the latter type recorder, an additional stage was added to the amplifier with an output impedance tailored to produce critical damping of the zero to one milliampere movement of the Esterline-Angus recorder. The time constant of the amplifier has been set at 1/25 second in order to decrease a tendency to oscillate at high gains. Since the time constant of the Esterline-Angus recorder is 1/2 second, the frequency response of the amplifier is abundant for the use for which it was intended. The time constant can be changed by changing the condensers C-1 and C-2. Without the time constant condensers, the circuit has a flat response from direct current to frequencies in excess of 50,000 cycles per second. The frequency range could be extended if the helipot used for balancing the amplifier were replaced by a carbon potentiometer.

The helipot, R-2, is adequate for balancing the primary amplifier in most cases, but occasionally it is necessary to alter the zero point of an amplifier by changing values of R-6 and R-9.

The overall gain of the amplifier in normal operating circumstances is of the order of 10^4 but may be increased by reducing the current fed back to the second grid of the input tube. This feedback is normally fixed at maximum to insure the highest possible stability. Theamplifier is very stable. Operating with an input resistance of 40 megohms and with the photomultiplier disconnected, a drift as great as 10^{-5} amperes in output current over a period of several hours is uncommon. Even with the photomultiplier connected, the drift is verysmall, what there is being due to instability in the 1P21 dark current. The output current is a linear function of input voltage over the normal operating range. The departure from linearity over this range is less than one percent. At output currents greater than one milliampere, the output becomes a non-linear function of input and damage to the Esterline-Angus recorders is prevented by limiting of the output current to several milliamperes.

Typical values of signal current and dark current are in the vicinity of 2×10^{-9} amperes.

The parts of the amplifiers are mounted in individual cells in the control panel. Connections are made through plugs at the rear. The individual amplifiers may be removed separately without disturbing the others. All controls are located on the front of the chassis and include an input resistance tap switch by which the gain is controlled, a helipot for balancing the primary amplifier and for subtracting the response due to dark current, the output gain control and the balancing potentiometers for the impedance matching stage.

Power Supply:

The power supply consists of three parts, the high voltage supply for the photomultipliers, a low voltage for the amplifiers and a filament supply; all are adjustable and regulated. The details are shown in Figure 14, the schematic diagram in Figure 15.

The high voltage supply is adjustable from 600 to 1500 volts. The amplifier power supply delivers 250 volts positive and 90 volts negative. There is a separate 90 volt regulator tube for each amplifier.

A sola regulating transformer was used as a filament regulating device while the unit was being developed in Pasadena. At Cactus Peak, where there was very poor frequency stability in the A.C. supply, because of the use of a gasoline powered generator, it became necessary to use a Nobatron regulator. Regulation of the filament supply is necessary with the amplifiers employed.

The output of the regulated supplies are stable over an input range of 85 to 150 volts. Changing the input voltage by this amount does not produce a noticeable change on the record made by the instrument even with the photomultipliers connected. The high voltage increases about one volt an hour upon first turning it on. This can be

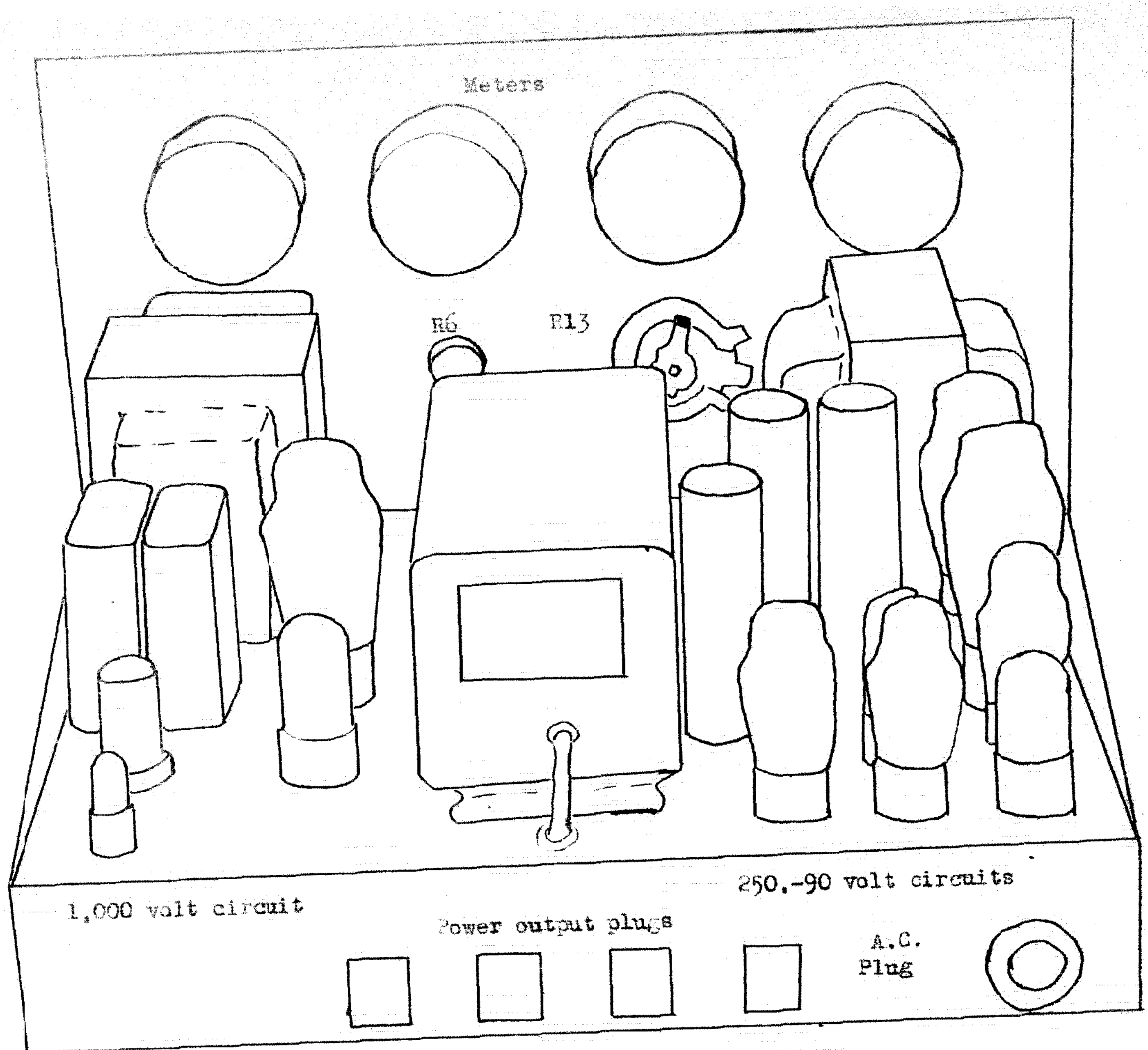
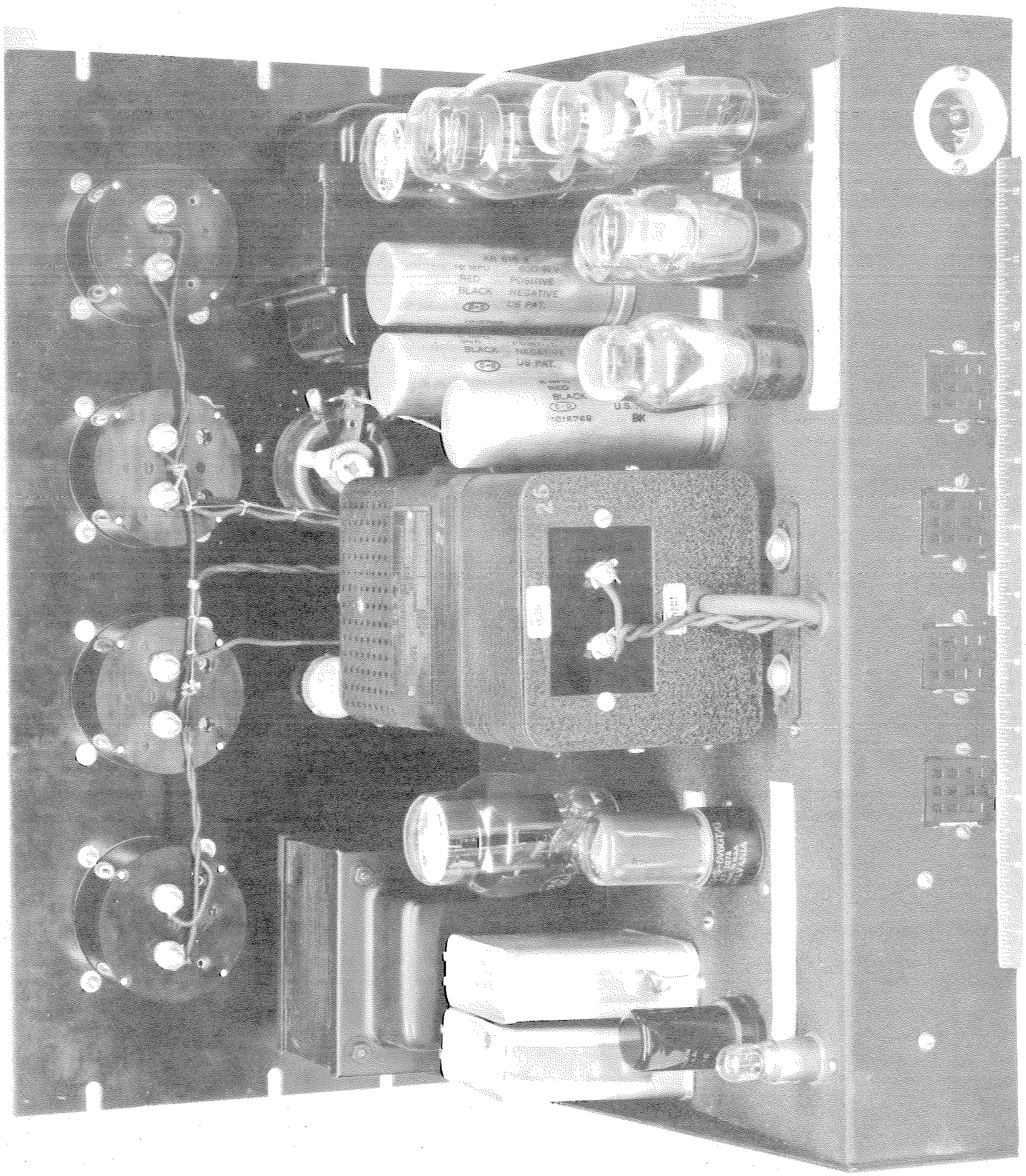


Figure 14. Rear view of Power Supply. All output voltages are regulated


RED POSITIVE
BLACK NEGATIVE
US PAT.

LIST OF COMPONENTS FOR REGULATED POWER SUPPLY

F 5AG3 Fuse

C1,2	1 uf, 2000 v.	C6	20 uf, 450 v.
C3	100 uf, 2000 v.	C7	0.1 uf, 400 v.
C4,5	0.5 uf, 1000 v.	C8	20 uf, 250 v.

All resistors are two watt unless otherwise specified.

R1,2	1 M	R12	1 M
R3	100 K	R13	12 K
R4	560 K	R14	12 K
R5	50 K	R15	15 K
R6	50 K Potentiometer	R16	10 K 15 watt
R7	47 K	R17	68 K
R8	2.2 M	R18	10 K (nominal, adjusted to light V9.)
R9	Adjusted to give correct meter deflection		
R10,11	470 K	R19	1 K
		R20	8.7 K ea.

T1	6.3 v,	5a.
T2	5 v,	5a.
T3	1500 v,	0.15 a. or less
T4	6.3 v,	5a, 400 vct 400 ma, 5v, 5a.
T5	6.3 v,	Sola regulating transformer
T6		110-110 volt isolation transformer

L1,2 10 Henry, 150 ma

SR1 Selenium rectifier, 5P1, 150 ma.

S 1,2,3 d.p.s.t. toggle switches, 250 v, 10 a.

V1, 5	5R4
V2	6V6
V3	6SJ7
V4	Ne 17, Neon glow lamp
V6	6AS7
V7	6SL7
V8	5651
V9	VR 150
V 10	VR 90

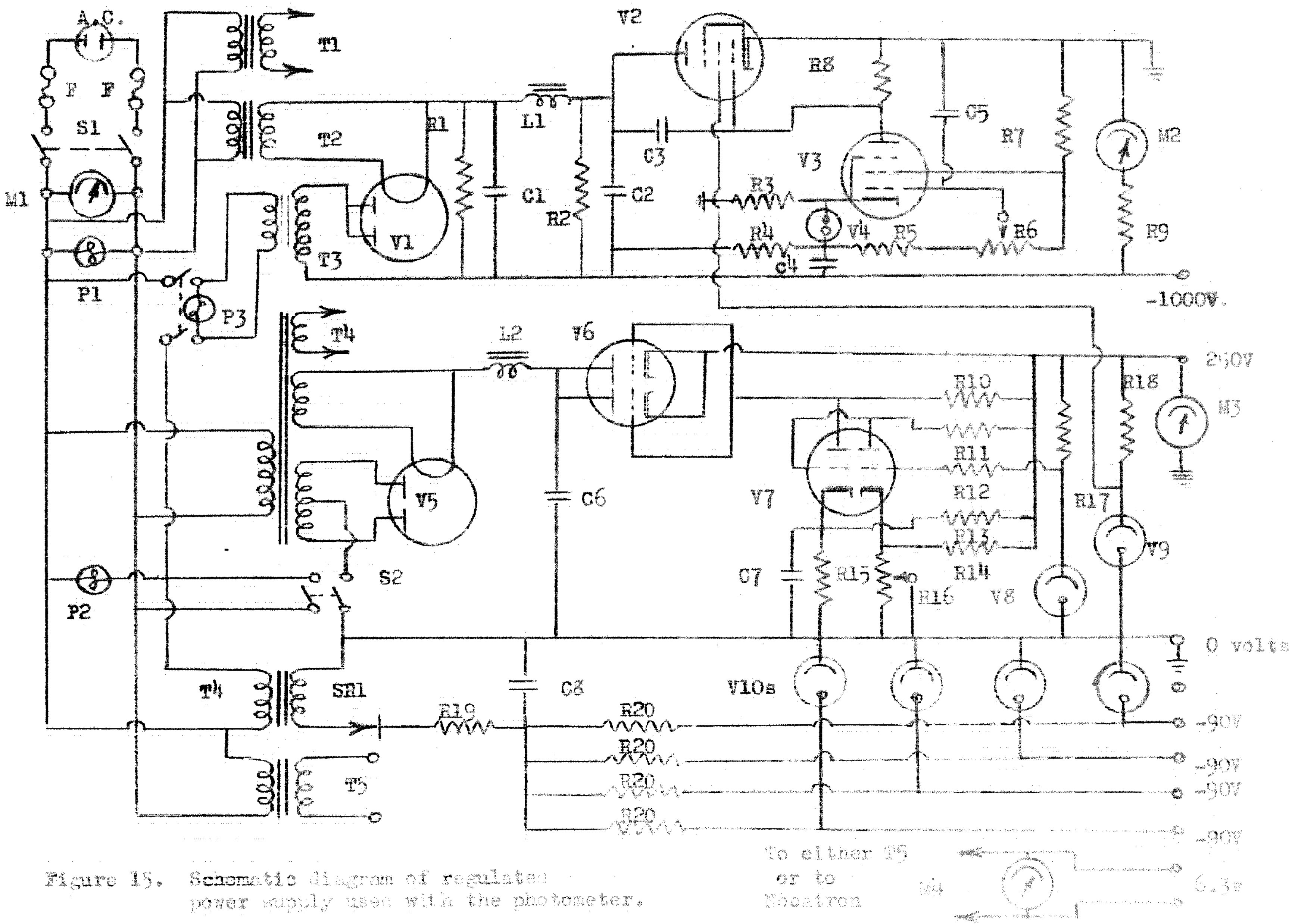


Figure 15. Schematic diagram of regulated power supply used with the photometer.

obviated by operating it with the voltages on for several hours before using it for observation. The overall stability increases with increasing tube age, since the amplifiers and photomultipliers all become more stable with continued use.

The power supply is mounted in the main instrument rack and is so arranged that the filaments must be lighted before the 250 volt supply is turned on and the 250 volts must be turned on before the 1000 volt supply is actuated.

Mechanical Design

Photometer Unit: The device that orients the telescopes is mounted out of doors in a weatherproof shelter on a rigid pier. The telescopes are mounted upon a shaft rotated about a horizontal axis by a Bodine motor. The shaft is supported by two yokes mounted on a plate which is in turn rotated by a Barber-Coleman, shaded pole, reversible motor. The position of the telescopes both in altitude and azimuth is relayed to the control panel by two synchros. The exact details of the switching arrangement are complicated, but no abstruse principles are involved and so an elaborate discussion will not be given here.

The parts are made of aluminum with the exception of the telescope tubes, optics and electrical components. The unit was, except for changes in the telescope mounting scaled up from that of the old instrument.

The signal leads are of low loss concentric line and are brought into the base through screw connected brass fittings. The high voltage leads to the phototubes are brought to a bakelite terminal block so that each tube can be disconnected separately for testing purposes.

Adjustments are provided for limiting the motion of the telescopes and for levelling the apparatus. A "bull's eye" level is mounted on the horizontal circle. Unfortunately, there is no easy way to make small changes in the orientation of the individual telescopes with respect to the trunion, but such an adjustment is currently being prepared.

Control Panel

The whole instrument is remotely controlled. The control panel, shown in Figure 16 is located in a comfortable, heated observing house about 50 feet from the photometer proper. Off-on switches, chart drive switches, recorder selection switches and all other controls for the moving system are located on this panel. The galvanometer switch permits choice of Brown or Esterline-Angus recorders or disconnects the amplifiers from the recorders. The shutter switch permits closing the shutters while the instrument is in operation. Two switch board type keys permit manual change of both altitude and azimuth. Time marks may be placed on the traces by depressing a pushbutton.

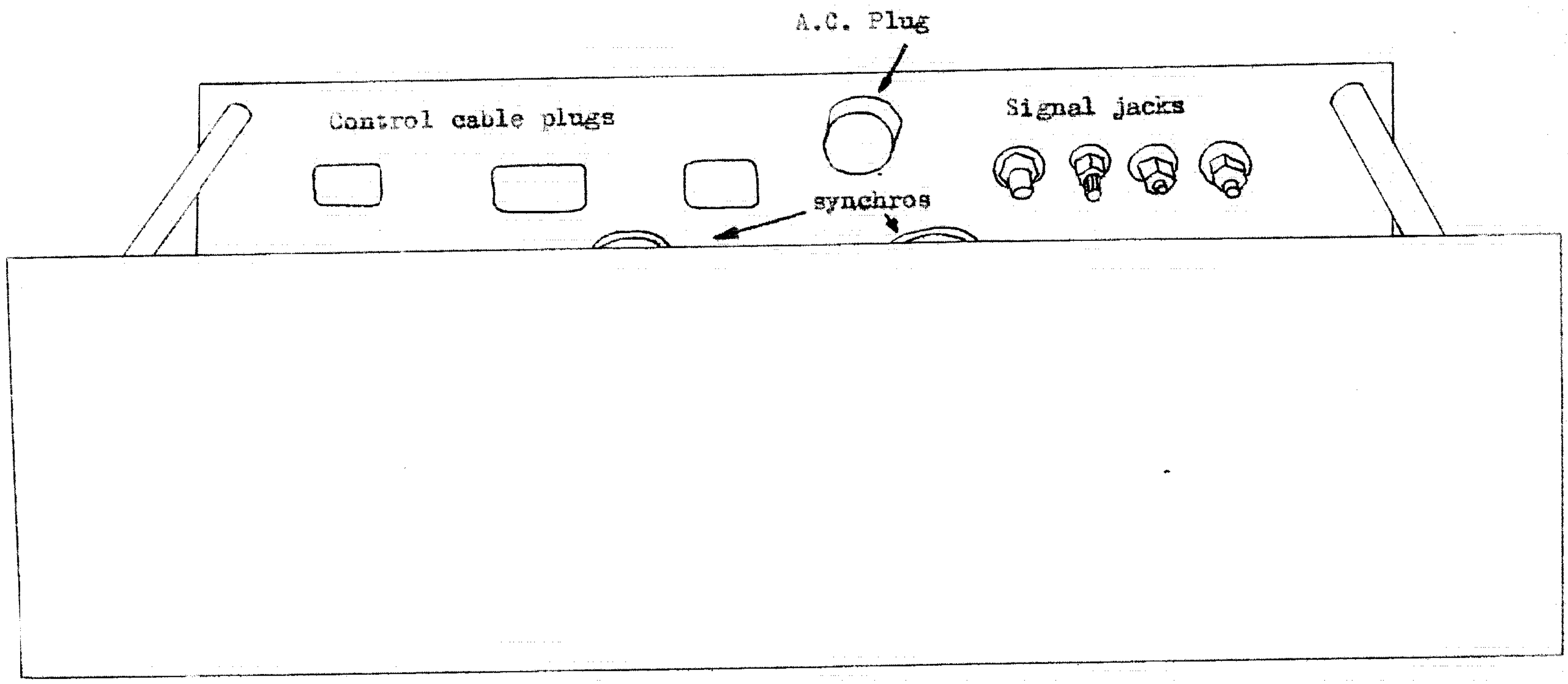
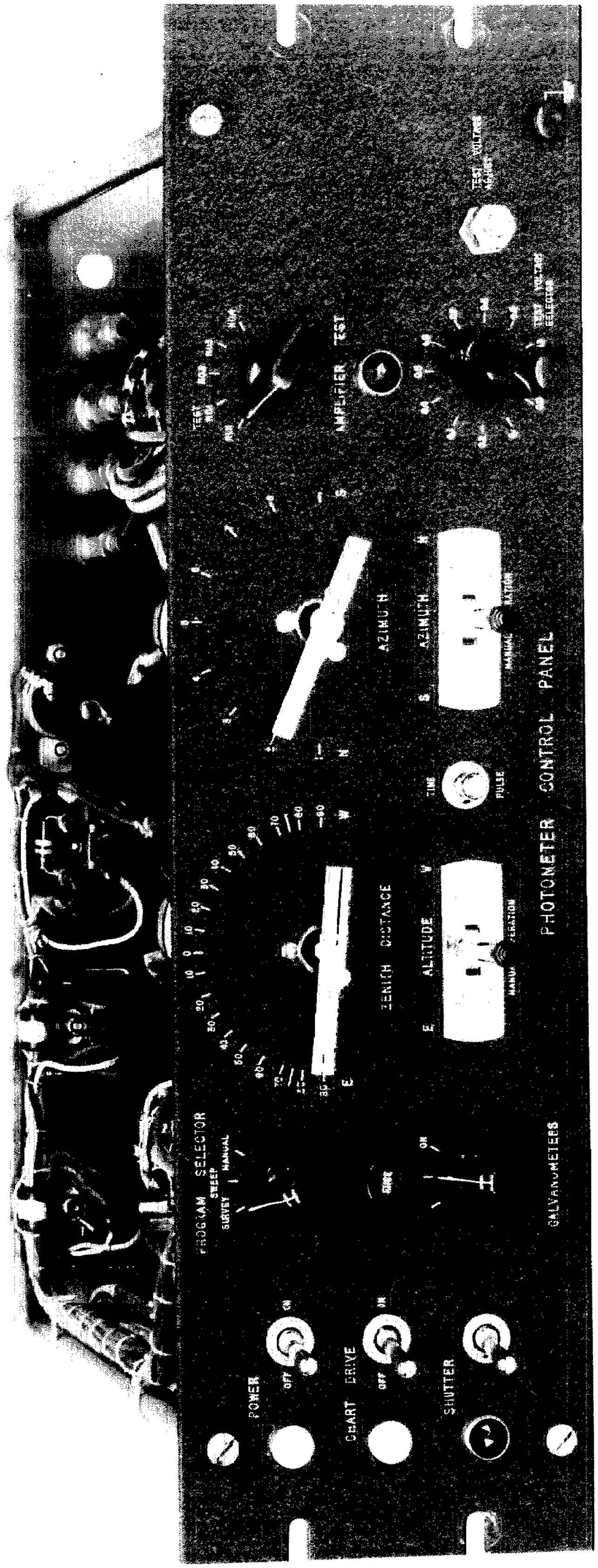


Figure 16. Control Panel. This unit is used to manipulate the photometer unit by remote control.


PHOTOMETER CONTROL PANEL
ZENITH DISTANCE
ALTITUDE
AZIMUTH
AMPLIFIER TEST
TEST VOLTAGE SELECTOR
PROGRAM SELECTOR
POWER
CHART DRIVE
SHUTTER
GALVANOMETERS

A special circuit permits each amplifier to be separately switched from its circuit for testing purposes. By use of the test voltage switch, voltage may be applied in steps of 0.1 volt up to 1.0 volts to test the sensitivity and linearity of the amplifiers. Any one amplifier may be tested without disturbing the others. Means are provided for adjustment of the test voltage.

Programming of the instrument is controlled by the "program selection switch". This permits choice of the manner in which the heavens are scanned. The attitude of the telescopes is indicated by two synchro receivers, driven by the units on the photometer head. Programming: A brief review of the manner in which the heavens may be scanned is given here, although it is the same as in the earlier instrument. "Monitoring" consists of manually directing the telescopes to any desired altitude and azimuth and observing at that position; the shutters may be opened or closed at will. "Sweeping" is the operation of letting the instrument remain fixed at any desired azimuth and rotating the telescopes in altitude from any one horizon to the opposite one. "Surveying" consists of making a systematic survey of the heavens automatically. In this maneuver, the telescopes begin while pointed at the north horizon, rotate through the zenith and down to the southern horizon. At this juncture, the base rotates $22\frac{1}{2}^{o}$ so that the telescopes are pointed south-south west, whereupon the telescopes again make a horizon to horizon scan and upon reaching the north-north east horizon the horizontal circle again rotates so that the axis of the telescope is pointed north east. This process continues until eight sweeps have been completed at which time the telescope axis is returned to the north horizon and the process is repeated. The shutter closes each time the horizon is reached so that the zero for the instrument can be checked. The sequence of operation is shown in Figure 17.

Recording

Although the apparatus may be used with the Brown or with the Esterline Angus recorder, it is ordinarily used with the latter because of its more rapid response to variations in current. Four are used under normal operating conditions. One master recorder has the chart drive motor fastened to its case, along with a clockwork mechanism and several switches for opening and closing shutters and relaying instructions to the photometer unit. The other recorders are coupled by detents to the drive shaft of the master recorder. It would be preferable to use independent synchronous motors on each recorder, however, as considerable trouble is occasioned with the drive coupling when the paper in one recorder jams or one is moved.

The switching apparatus on the master recorder determines the sequence of operations and closes the shutter at the end of each sweep. Because the switches are on the same shaft with the paper drive the same length of paper is assured between successive horizons and it is difficult for the apparatus to get out of step with the recorders.

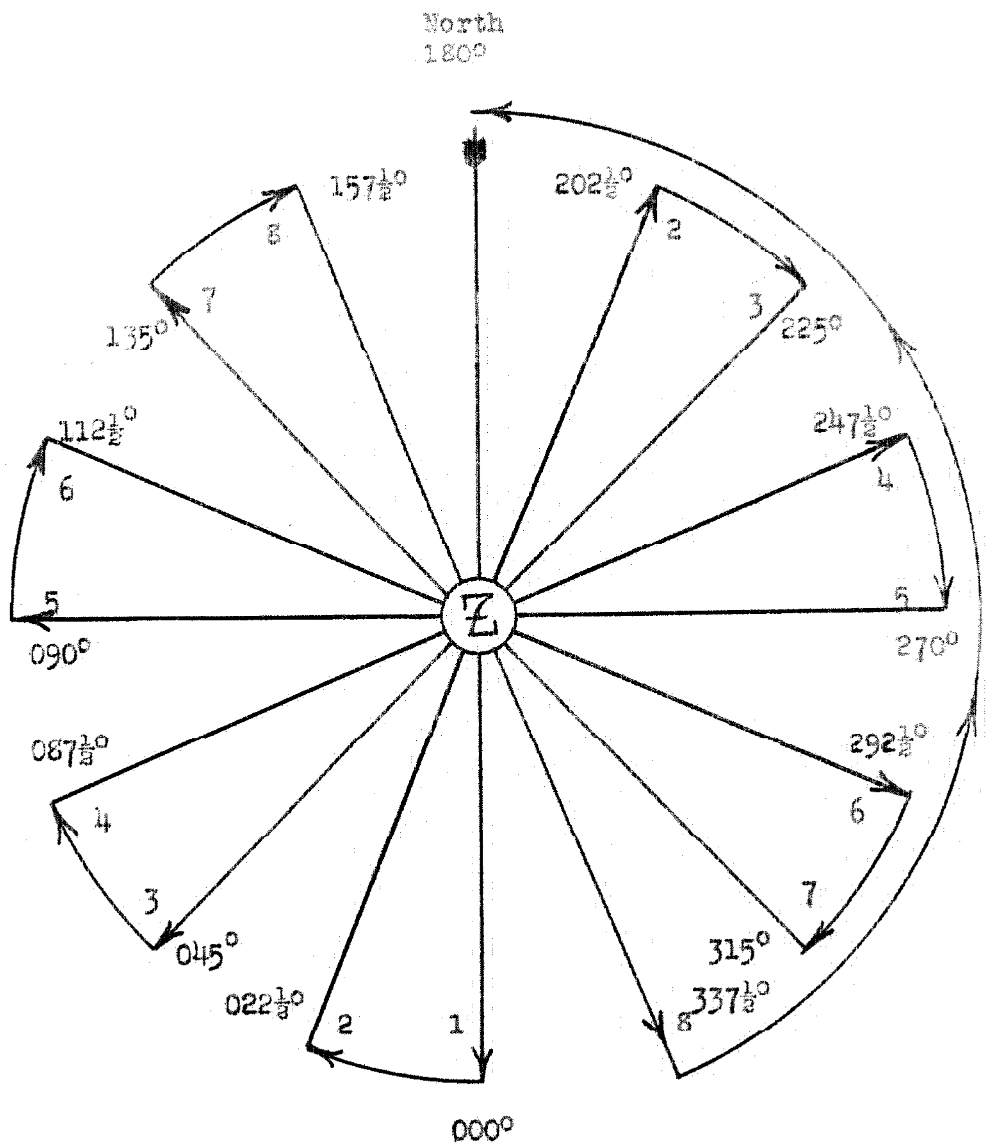


Figure 17. Scanning pattern of night sky photometer.

Time marking pens and horizon marking pens may be used on all the recorders, although they are only mounted in the master recorder.

Standardization Sources

A combination protective cap and standard radiation source is supplied for each telescope. The details are shown in Figure 18. The caps are made of brass and fit over the ends of the telescopes. Non-phosphorescent radium paint is painted between two pieces of glass fastened in by a retainer ring. The radium paint has a continuous spectrum and is very handy for checking the calibration of the apparatus. The changes in intensity due to radio-active destruction of the radium are negligibly small for the duration of one person's life time. There are however small changes with time due to deterioration of the phosphor under continual radioactive bombardment. It would be preferable therefore to construct a radiant standard using a device of the sort described by BLAU AND FEUER (1946). In this device, the radioactive material and the phosphor are separated so that only the gamma rays are active in production of the light. Such a device would be extremely stable.

An important advantage of using radioactive standard sources is that the sensitivity of the apparatus from one night to another may be checked very accurately. The standard sources may be sent to laboratories where they can be accurately calibrated, a difficult field operation. The portability of the devices and the lack of dependence upon

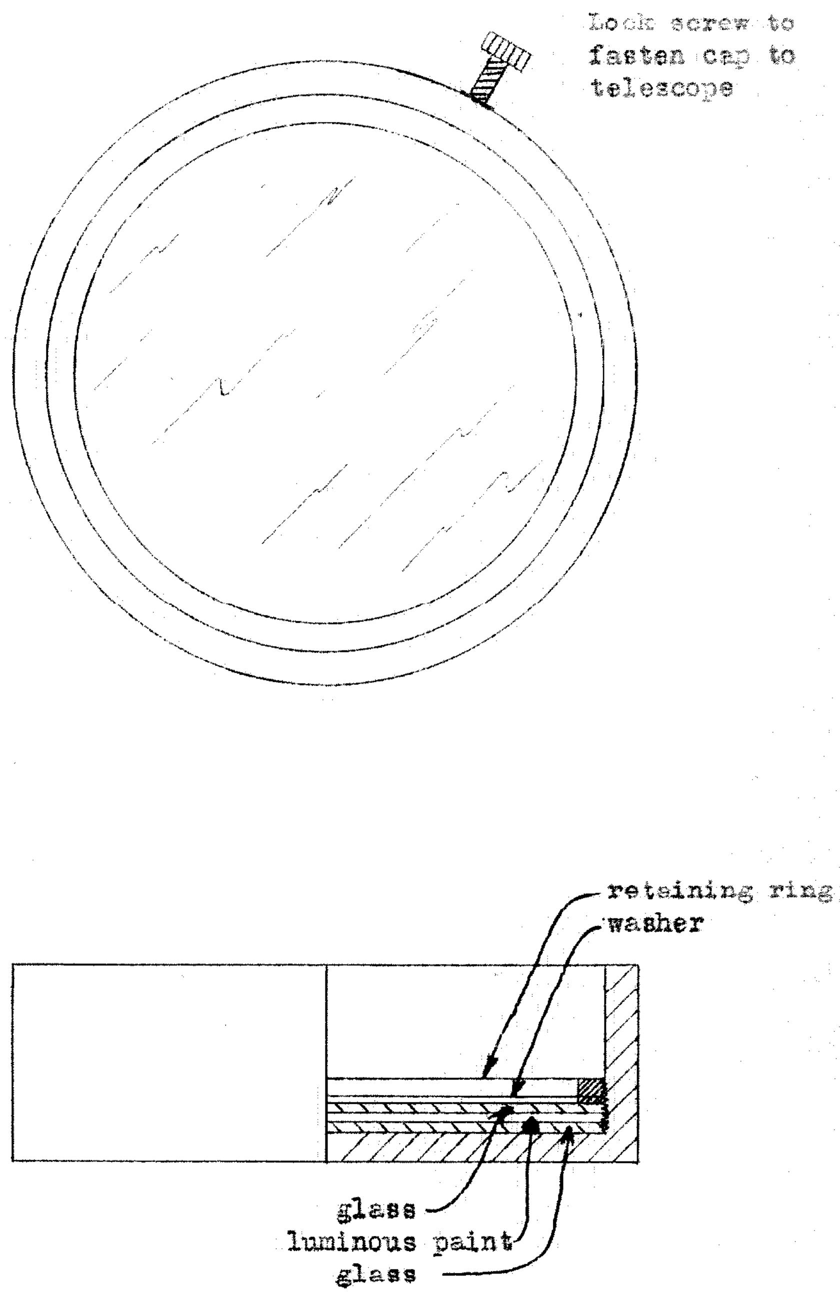


Figure 18. Radioactive energy source for standardization of photometer sensitivity.

temperature or other atmospheric conditions makes it possible for different workers in the field of night sky photometery to ship standard lights from one to the other so that they can obtain direct comparisons of each others work and thus interrelate studies of the distribution of the night glow with geographic position.

Operation

Warm up: Several hours before sunset, the observer turns on the filaments and all the voltages. The shutters are left closed and the protective covers left on the instruments. The warm up period is necessary to minimize drift during operating hours. Care is taken never to allow direct sunlight to strike the photocathode of the 1P21 tubes as this will result in increased dark current and noise for a period of hours after the incident, even if no voltages are applied to the tube at the time it was illuminated. The cause of this is probably phosphorescence induced in the glass by the bright sunlight. On the other hand an extremely noisy, unstable tube can sometimes be improved by exposing it to light with the voltage on. This results in a high output current and the ensuing fatigue may decrease the sensitivity enough to permit the tube to be used. After sunset and just before the end of astronomical twilight, the covers are removed and the sensitivity checked by noting the readings produced by the radium sources. The amplifier linearity and sensitivity are checked during this period.

Observing

Observations are made only on clear nights when the moon is down. Actually, the period of observation could, and should, be extended to other periods of the month when the moon is not in the sky.

At the end of astronomical twilight the radium sources are removed and the night sky observing begun. Usually this consists of conducting surveys. The instrument is set on survey and the ensuing operating is entirely automatic. All that remains for the observer is to mark and fold the traces, record the voltages, observe the sky at frequent intervals to detect clouds and unusual phenomena and to replace the paper rolls as they expire.

At the beginning of astronomical twilight the radium caps are again employed, the amplifiers checked and the apparatus shut down and covered.

Traces

Typical traces are shown in Figure 19. The brightening near the horizons is due to the inclusion of more of the radiating layers in the line of sight. Stars can be clearly noted.

Calibration is done by noting star readings; however, when the radium sources have been well enough calibrated they will be relied upon to furnish calibration and only occasional checks will be made by means of the stars. The process of calibration is rather involved and is explained

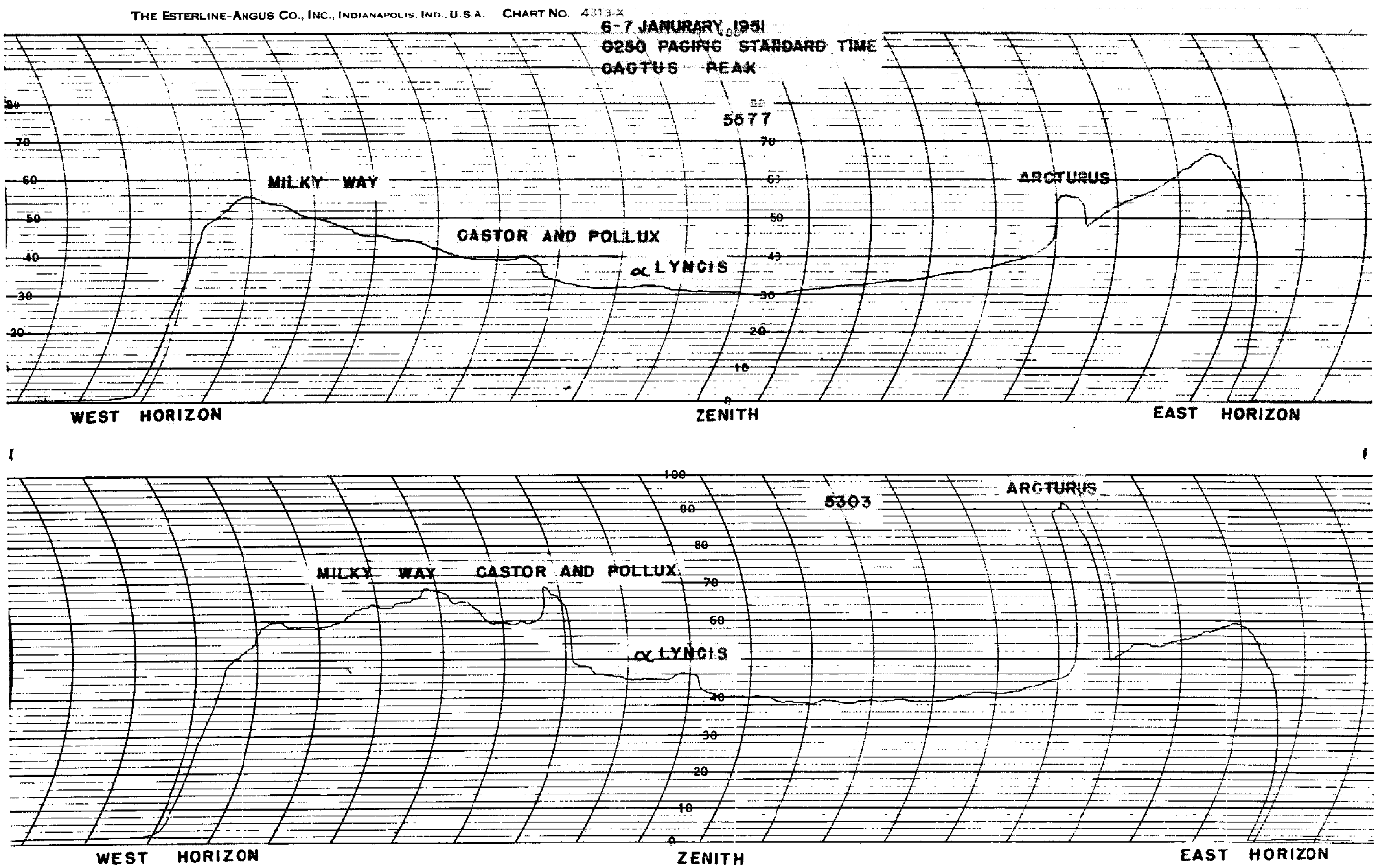


Figure 19. Typical night sky records made by the photometer. Note the brightning near the horizons.

in the section on calibration and in ROACH AND PETTIT (1951) and BARBIER, DUFAY AND WILLIAMS (1951).

This instrument has been in use since January, 1951 and already enough information has been accumulated to require several years to digest. Possible Improvements: There are a number of improvements possible in the design of the apparatus, some of them minor, others of such proportions as to warrant complete revision.

1. The overall stability could be improved by use of an optical system with a greater light gathering power. A logical step would be to use a Fresnel lens, constructed of plastic film, for an objective, in conjunction with a negative lens to render the light essentially parallel before passing it through the filter. A larger light input would permit a smaller field of view to be employed as well as the use of lower amplifier sensitivities.

2. The use of "end-on" type photomultipliers would greatly improve the uniformity of response over the field of view of the instrument and in addition, permit a shorter telescope without the tube housing at right angles to the optical axis.

3. In instruments intended to measure the height of the emitting layers it seems desirable to restrict the field of view to an oblong or rectangular shape, so that the vertical dimension does not exceed one degree. The earlier instrument has such a field of view, although it was not defined by a field lens. Such a field of view will reduce

errors in height determination due to averaging over too great a vertical angle, resulting in estimations of height which are too great.

4. Construction of the yoke so that the telescopes could easily be removed and the axis aligned would improve the accuracy of the instrument and facilitate repair and adjustment of the telescepe.

5. Use of wrought iron or mild steel in construction of the telescope tube and photomultiplier housing would eliminate the need for additional magnetic shielding.

6. There are uses for which such an elaborate instrument is not necessary. It would be nice to have an instrument, somewhat simpler, which would observe a fixed position in the sky at a variety of wavelengths and using a slow chart feed, draw a graph of the nocturnal variation of intensity of a number of the lines and of the continuous spectrum every few minutes throughout the night. This could be accomplished by the use of a large number of interference filters mounted upon a moving track or by the use of a spectroscopic grating rotated by an electric motor so that different portions of the spectrum fell in turn upon a slit placed before the photomultiplier tube.

General Remarks

The apparatus seems well suited to the measurement of night sky illumination, although it would be desirable to have it survey the sky in a much shorter time. This development awaits the availability of a more rapid recording system of modest cost and weight, and more sensitive photomultiplier tubes such as the E.M.I. Types.

Certain changes in the design of the 1P21 could be made which would result in improved performance. These have been suggested before by KRON (1946) and by DEWITT AND SEYFERT (1950) but are worth repeating. That portion of the dark current which is due to amplified thermionic emission could be reduced by decreasing the sensitized area of the photocathode to a small square about 3/8 inch on a side. The leakage currents in the tube base and around the socket could be reduced by bringing the anode lead out the top of the glass envelope.

PART III

Nightglow Data

The data for the nightglow, presented herein, were obtained from the Cactus Peak Observatory of the U.S. Naval Ordnance Test Station at China Lake, California. On the nights for which data is presented, surveys of the heavens were conducted in the manner described in the section of instrumentation. However, for reasons of simplicity and convenience, only those values read at the north celestial pole are used for direct comparison with the ionospheric data.

The north celestial pole was chosen because the background light there is relatively constant. The starlight there does not change during the night and there is very little zodiacal light. In essence the correction for extratelluric light simply becomes that of subtracting a constant. Data was also read for the intersection of our field of view with the ionosphere over Stanford University. Here the nightglow record was rougher, much irregularity being introduced by the passage of the milky way past the point of observation. Zodiacal light is rather strong in this direction also.

The general trend of the data in both places is the same if one disregards the short period fluctuations. Therefore in this investigation we have confined ourself to working with the light from the pole, where the matter of extra-terrestrial light is not so likely to cause trouble.

Estimation of the background light; i.e., the extra-telluric, portion was done by the two color technique developed by ROACH AND BARBIER (1950), ROACH AND PETTIT (1951), and BARBIER, DUFAY AND WILLIAMS (1951). In this process the light of the night sky is observed at two different wavelengths, one containing the emission line, the other containing only relatively weak nightglow radiation. The wavelength selected for this was 5300 Angstrom units. Here there are no bright emission lines and only the continuous portion of the night glow spectrum. The response at the two wavelengths to an incremental change in extra-telluric light is estimated from deflection of star images and from crossings of the milky way. From this a ratio can be established between the light at one wavelength and that at the other. All the light recorded by the control wavelength is then subtracted from the light observed at the emission wavelength.

This method may be applied in two ways, using star deflections, the magnitude of the star corrected for spectral type to that of a GO star which is assumed to be the spectral distribution of integrated starlight. Using the milky way deflections, the light is uncorrected since the light of the milky way is assumed to be representative of integrated starlight.

The estimation of the energy involved in the radiation is made by selecting star images of sufficent amplitude and proper spectral class. The reading given by the star is corrected to the reading that a GO star of the same photo-visual magnitude would have made at our zenith. The magnitude of the sun is known and from this the ratio of the light received from the star to that received from the sun is known. The spectral distribution of energy from the sun is known from the work of MINNEART (1924), PETTIT (1940) and others. Combining these and correcting for the transmission and equivalent width of the filters used it is possible to obtain the energy of the radiation in absolute units. This is reduced to quanta/cm^2/sec by use of Planck's law and by correcting for the field of view of the instrument.

The expression used for calibration is as follows:

$$\log q = \log \left[\frac{\lambda \pi}{h c} \frac{r^2}{l^2} \frac{\int_0^\infty T d\lambda}{T} I_\odot \right] - \log R - 0.4(26.72) - 0.4m - D - E$$

Where q is a factor for converting chart readings into quanta/cm^2/sec/column.
- λ is the wavelength
- h is Planck's constant
- c is the velocity of light
- r is the radius of the field lens in the photometer
- l is the focal length of the objective lens
- T is the transmission of the filter
- $I_\odot$ is the intensity of solar radiation at the distance of the earth from the sun, outside our atmosphere.
- R is the chart reading produced by the star
- m is the magnitude of the star
- D is the correction for the color of the star
- E is a correction for extinction by the atmosphere.

It is necessary to assure oneself that the reading of the star image is a true representation of the light received from the star. Since the field of view of the instrument is not quite uniform it is necessary to choose every star crossing one can find and then attempt to determine an average value of q. The best way of doing this is to map the field of view by letting a star drift across the field of view in azimuth as the instrument is rotated up and down in altitude. This permits attaining a very accurate value for the average sensitivity over the field of view.

The chief uncertainties in this method aside from the irregularity of the field of view is that in the determination of the magnitude of the sun. This is done by reducing the light from the sun to a level comparable with that of the stars and then comparing the magnitudes. The error herein results from the reducing process, any process reducing the light by a factor as large as this must involve considerable uncertainty. E. Pettit has told the author that he personally thinks the magnitude of the sun is known to only one decimal place and that not too accurately. Errors of estimation of color correction and of extinction are of lesser importance.

While this method boasts the convenience of having stars already in the sky and therefore one does not need a standard source, it is difficult to distinguish star images when superposed upon the brighter emission lines. Therefore we would like to point out the desirability of using a secondary standard, composed of a radio-active light source which has previously been calibrated by some laboratory specializing in this sort of work.

The ratio of intensity of one spectral line to another is of considerable theoretical importance and for this reason it seems desirable to be able to determine relative intensities by the most accurate means possible. This could be done quite easily and with great precision through the use of a radioactive standard with a known spectral distribution of energy.

Values of nightglow data used are presented in the following tables. The observations were made largely by D. R. Williams and F. E. Roach and the author. The records were read by H. Pettit, F. E. Roach, D. R. Williams, D. D. Locanthi and Einer Hondsberg-Hanssen and the author all employed by the Aerophysics group.

TABLE III

SAMPLE CALCULATION 14/15 Dec. 1952

Survey No.	Time P.S.T. Hours	READINGS IN CHART UNITS R5300	R6300	R5893	R5577	INTENSITY IN quanta/cm²/sec x 10^{-8} I6300	I5893	I5577
1	18.40	19.5	41.0	40.0	25.5	4.96	3.35	2.32
2	18.93	17.5	34.0	33.5	22.0	3.95	2.69	2.00
3	19.45	17.5	33.0	34.5	22.0	3.77	2.82	2.00
4	19.88	17.5	32.0	33.0	22.0	3.59	2.62	2.00
5	20.50	18.0	30.5	33.0	21.5	3.27	2.59	1.92
6	21.02	18.0	30.5	34.0	21.5	3.27	2.71	1.92
7	21.55	19.7	30.5	35.0	23.0	3.08	2.69	2.04
8	22.07	19.0	28.0	32.0	23.5	2.71	2.37	2.11
9	22.58	20.0	28.5	32.5	25.0	2.69	2.34	2.25
10	23.12	20.7	29.0	35.0	27.0	2.69	2.60	2.45
11	23.63	21.0	30.0	36.0	29.0	2.83	2.70	2.89
12	00.15	20.5	29.3	35.5	28.5	2.76	2.68	2.82
13	00.68	19.7	28.5	34.5	28.5	2.73	2.62	2.63
14	01.20	19.5	27.0	34.0	27.0	2.48	2.57	2.47
15	01.72	19.8	29.0	36.0	28.0	2.80	2.80	2.58
16	02.33	19.0	32.0	39.0	27.0	3.42	3.26	2.48
17	02.77	19.0	32.0	41.0	25.5	3.42	3.52	2.32
18	03.28	19.0	31.0	42.0	24.5	3.24	3.65	2.21
19	03.82	18.5	30.0	40.0	24.5	3.13	3.43	2.22
20	04.33	18.5	30.5	39.0	24.0	3.22	3.30	2.17
21	04.85	19.5	31.0	39.0	24.0	3.19	3.21	2.15
22	05.38	20.0	31.0	37.0	24.0	3.13	2.92	2.14
					Σ	70.33	63.44	50.09
					M	3.20	2.88	2.28

$$I_{6300} = 1.77 \times 10^{7}(R_{6300} - 0.667\ R_{5300})$$

$$I_{5893} = 1.28 \times 10^{7}(R_{5893} - 0.712\ R_{5300})$$

$$I_{5577} = 1.07\ (R_{5577} - 0.2\ R_{5300})$$

TABLE IV

SUMMARY OF NIGHTGLOW DATA, 6300, Quanta/cm^2/sec x 10^{-8}

Hours P.S.T.	22/23 May	23/24 May	18/19 June	19/20 June	21/22 July	22/23 July	23/24 July	18/19 Aug	19/20 Aug	20/21 Aug	19/20 Nov	14/15 Dec	14/15 Jan	15/16 Feb	Mean
18.0															
18.5											4.76	4.70			(4.73)
19.0											5.12	3.90	3.30		(4.11)
19.5											4.95	3.75	3.00	(3.50)	(3.80)
20.0											4.50	3.60	2.95	3.65	3.68
20.5									4.80	3.15	3.80	3.27	2.75	3.30	3.51
21.0	2.95	2.70		4.05	4.40		2.50	3.40	4.10	2.75	3.95	3.27	2.80	2.85	3.31
21.5	2.10	2.90	3.50	3.75	3.50	1.60	2.50	2.90	3.15	2.55	4.20	3.10	2.60	2.30	2.90
22.0	1.80	2.05	2.45	3.40	2.80	1.52	1.90	2.45	2.90	2.45	3.85	2.70	2.70	1.95	2.49
22.5	1.62	1.72	1.60	2.55	2.10	1.00	1.50	2.25	2.30	2.20	3.65	2.70	3.05	1.90	2.15
23.0	1.55	1.52	1.50	2.01	1.91	0.72	1.50	2.10	2.30	2.25	3.60	2.70	3.08	1.50	2.02
23.5	1.43	1.20	1.40	1.55	1.95	0.71	1.30	1.80	1.90	2.40	3.70	2.80	3.31	1.35	1.91
00.0	1.10	1.00	1.30	1.50	1.95	0.60	1.35	1.55	1.80	2.60	3.70	2.80	3.36	1.00	1.83
00.5	1.10	0.95	1.30	1.57	2.05	0.65	1.25	1.45	1.80	2.45	3.80	2.75	2.90	1.05	1.79
01.0	0.92	1.10	1.25	1.58	2.12	0.82	1.15	1.40	1.80	2.30	4.30	2.60	2.65	1.15	1.80
01.5	0.80	1.30	1.25	1.53	1.95	0.89	1.30	1.45	1.70	2.50	4.60	2.50	2.60	1.15	1.82
02.0	0.77	1.25	1.60	1.50	1.80	0.82	1.35	1.90	1.60	2.55	4.75	2.90	2.80	1.05	1.90
02.5	0.78	1.15	1.75	1.57	1.72	0.83	1.15	2.30	1.70	2.45	4.70	3.55	2.90	1.05	1.97
03.0	0.62		1.60		1.80	0.91	1.25	2.30	2.05	2.40	4.40	3.30	3.35	1.30	2.11
03.5					1.00			2.25	2.50	2.55	4.35	3.15	3.70	1.50	2.62
04.0								1.30			4.75	3.15	4.00	1.55	2.95
04.5											5.05	3.25	4.15	1.85	(3.58)
05.0											(5.20)	3.20		2.05	(3.48)
	1.35	1.88	1.71	2.21	2.22	0.92	1.54	2.05	2.43	2.50	4.35	3.17	3.10	1.85	

14/15 Jan, 15/16 Feb. in 1953, all others 1952.

Values interpolated to even hours and half hours.

TABLE V

SUMMARY OF NIGHT GLOW DATA, 5577

Hours P.S.T.	22/23 May	23/24 May	18/19 June	19/20 June	21/22 July	22/23 July	23/24 July	18/19 Aug	19/20 Aug	20/21 Aug	19/20 Nov	14/15 Dec	14/15 Jan	15/16 Feb
18.0														
18.5											2.70	2.25		
19.0											3.90	2.00	1.95	
19.5											4.55	2.00	2.05	0.95
20.0											5.15	2.00	2.45	0.85
20.5											6.55	1.95	2.70	0.80
21.0	2.65	3.05		4.20	2.30	1.90					6.65	1.95	2.80	0.80
21.5	3.10	3.60	3.95	4.80	2.25	2.00					7.80	2.05	3.20	0.75
22.0	3.50	3.87	3.95	5.20	2.30	2.00					8.00	2.10	2.90	0.80
22.5	3.42	3.40	4.60	4.90	2.30	1.80					8.50	2.25	2.60	1.00
23.0	3.60	3.15	5.25	4.65	2.30	2.20					8.50	2.40	3.10	1.05
23.5	4.12	3.25	5.15	4.80	2.20	3.25					8.00	2.70	3.30	1.00
00.0	3.85	3.43	5.82	5.25	2.18	4.20					7.90	2.85	3.40	1.70
00.5	3.80	4.30	5.30	5.40	1.90	4.55					8.10	2.75	2.90	1.80
01.0	4.18	3.60	5.40	4.50	1.70	3.70					7.90	2.50	2.65	2.00
01.5	4.50	3.95	6.30	4.00	1.70	2.90					7.50	2.50	2.60	2.60
02.0	5.00	3.25	7.25	3.75	1.75	3.40					7.50	2.60	2.80	2.85
02.5	5.95	2.57	6.80	3.60	1.75	4.65					7.10	2.40	2.80	3.00
03.0	5.55	2.55	5.85		1.80	3.85					6.60	2.25	2.70	3.05
03.5											6.10	2.20	2.50	2.75
04.0											6.30	2.20	2.40	2.40
04.5											7.10	2.15	2.30	1.85
05.0											6.80	2.15		2.05
Mean	4.09	3.38	5.46	4.39	2.03	3.11								

14/15 Jan., 15/16 Feb, 1953, all others 1952

Values interpolated to even hours and half hours.

The Ionosphere

High above the earth where the atmospheric pressure is very low, exists a region wherein there are many free electrons which have been shorn from the atoms and molecules of the air by the intense ultraviolet irradiation of the sun, the impact of corpuscular bombardments and collision with other atoms and molecules. Here, an electron once freed from its parent particle may remain in a free state for a comparatively long while because collision with another particle is an infrequent event.

There are at least four distinct ionospheric regions, and often more. The most commonly occurring regions are the D, E, F1 and F2 regions, listed in order of height. The distribution of these regions is shown in Figure 20, which is drawn to scale. The F layer has the greatest electron density and exists both day and night. During the day however, it consists of two and occasionally more layers. The new layer, the F1 forms between the E and F2 layer and together the two take on the form of a huge blister. The F1 layer is present whenever the sun is very far above the horizon and disappears before sunset. By nightfall, the F1 layer has recombined and the F2 layer is then called the F layer. Infrequently a third layer may be seen above the others and this is called the F3 layer. More rarely a multiple stratification is observable within both the F1 and F2 layers.

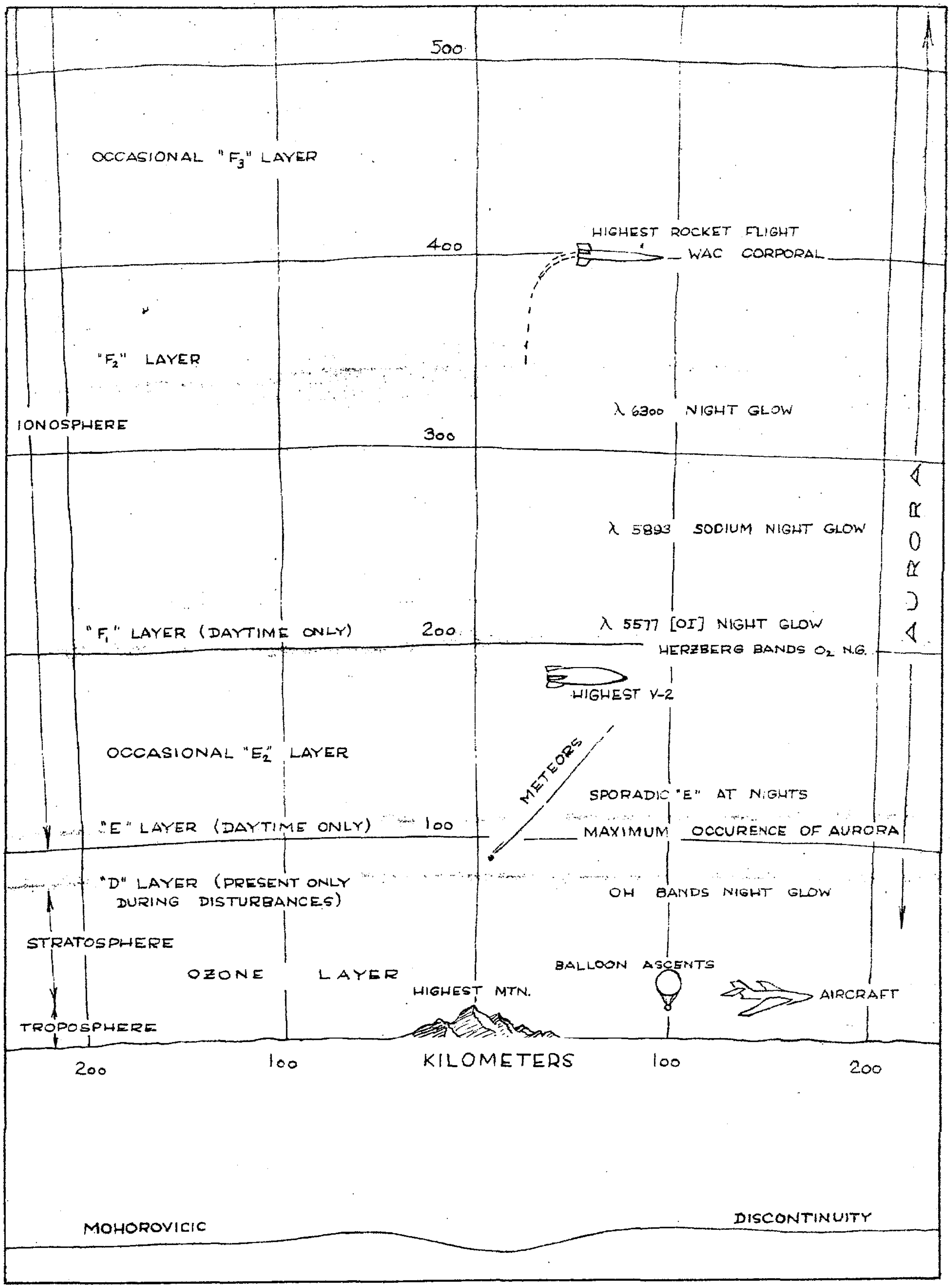


Figure 20. Schematic representation of the various layers in the high atmosphere--the earths outermost statigraphy.

The E layer is present during the day whenever the sun is above the horizon and recombines before it sets. At night, and during some days, a new layer forms, sometimes above, sometimes at the same height and sometimes below the E layer. This layer is called the sporadic E layer, because of the irregular occurrence. It consists largely of broken clouds of ionization which float about the nocturnal sky, driven from place to place by violent winds, frequently at the rate of several hundred kilometers an hour. This layer is not always present and on some nights does not form at all. It is usually very thin although it at times thickens to over 30 kilometers. There is some opinion at present that the sporadic E features may not be ionization giving ionic reflection in the classical sense, but regions of turbulence in the atmosphere which give partial reflection of the exploring radio wave.

Once in a while, a region is observed to form between the regular E region and the F region. This is called the E2 layer. It is observed mostly during the daytime and usually only when the sun is high.

The D region is present only during ionospheric disturbances and consists of a layer of dense ionization wherein the collisional frequency is quite high. This layer recombines rapidly once the ionizing agent is removed.

In general, the space between the ionized regions is not devoid of ionization, but the layers blend into each other with regions of reduced ionization between.

Many excellent papers and review articles are available for the reader who wishes to familiarize himself with this matter. The author can recommend for example, the book TERRESTRIAL MAGNETISM AND ATMOSPHERIC ELECTRICITY, written by a group of experts in the field and edited by J. A. FLEMING (1939). Chapter IX by L. V. BERKNER is especially good.

Because there are a plethora of free electrons in the region and because the collisional frequency is low, the electrons can move in response to the electric field set up by an impinging electromagnetic wave. The electrons move in the direction of the electric field and in doing so constitute an electric current which has the effect of producing a conduction or convection current of the same period and phase as the Maxwellian displacement current in the region, but of opposite sign. The result is that the total current flowing in the region is diminished. This has the effect of reducing the velocity with which electromagnetic energy may traverse the region. When the electron density becomes high enough the conduction current may equal the displacement current for a given wave frequency and the total current becomes zero. When this occurs, the wave is propagated with zero group velocity and the index of refraction of the medium becomes zero for that frequency, reflection occurs and the wave is sent back out of the medium.

The property of being able to reflect electromagnetic waves permits exploration of the ionized regions by use of radio transmitters, pulsed like a radar unit, which send energy up to the ionized regions from which it is reflected and a portion then recovered by a receiver capable of measuring the elapsed time.

The basic theory of propagation of electric waves in the ionosphere was pointed out by Eccles in 1910 and elaborated by Larmor in 1924. MITRA(1948), page 143 et seq., outlines the theory and derives the following formula for the index of refraction:

$$\mu = (1 - 4\pi Ne^2/m\omega^2)^{\frac{1}{2}}$$

here N is the electron density in the region, e is the charge on the electron, m is the mass of the electron and ω is the angular frequency of the wave.

For an electromagnetic wave of frequency, $f = \omega/2\pi$,mcs., impinging at normal incidence upon an ionized region, the index of refraction will be zero when:

$$N = 1.24 f^2 \times 10^4 \text{ electrons/cm}^3$$

and reflection of the wave will result.

The pulse from an ionosphere apparatus consists of a plurality of frequencies and the pulse propagates with a velocity nearly that known as the group velocity. The group velocity in a medium of this sort is $u = \mu c$, see BERKNER(1939). The group velocity is usually less than the velocity of light in an ionized medium and approaches zero when the index of refraction is zero. Hereafter we shall speak of group velocity. The group velocity in the ionosphere changes gradually and upon entering an ionized layer there is a transition from a region of very low electron density to one gradually increasing electron density culminating in a region of maximum density and then one of decreasing electron density. Hence when a wave enters such an ionized media it begins to slow down and continues to do so until it reaches an ion concentration great enough to reflect it, or it passes through the layer. The point is that the group velocity of the wave was less than the velocity of light the whole time the wave was in the region. The time spent in the region is dependent upon the rate of change of electron density with distance in the media. The distance into an ionospheric layer, we shall call h so that dh = μ c dt. Now let us consider a distance dh' over which a wave would have traveled had it not been in the ionized media for the interval dt. Now, dh' = cdt so we may say that

$$h' = \int dh/\mu$$

h' is called the virtual height, the distance to which a wave appears to go before reflection from a perfect reflector.

In practice, the ionosphere is explored by sending pulses of radio energy upwards to be reflected from the medium and recording the elapsed time. As can be seen above, the elapsed time consists of two periods, one where the wave was traveling at or near the velocity of light, the other, the time during which it was in the medium traveling much more slowly. The height calculated directly from the elapsed time, assuming the wave to have been travelling at the velocity of light all the while, is the virtual height discussed above; that height to which a wave would have gone in the same time, had it not been in a dispersive medium.

Ionosphere transmitters change frequency while in operation, recording the virtual height in that portion of the spectrum between about 0.5 and 16 or so megacycles. Figure 2d shows the appearance of a typical day time record. This record was made at Stanford, California, 1230 P.S.T., 31 August, 1951. The horizontal bars are hundred kilometer markers and the vertical bars are one megacycle frequency markers. The dark line at the bottom is called the base line and marks the instant of departure of the radio pulse from the transmitter. The trace above it on the left hand side is the reflection from the E layer. The E layer is fairly thin as ionospheric layers go and the wave passes into it without great retardation until the layer is penetrated. This occurs at the point marked foE. At frequencies above this the echoes return from the F1 layer (in this particular record the F1 and F2 both show remarkable small scale stratification). The drop in the virtual height of the F1 region as the frequency departs from that of the foE is due to a decrease in retardation from the E layer. As the frequency is increased, the wave penetrates farther and farther into the F1 layer. At first the wave finds a frequency from which it can be reflected without going too

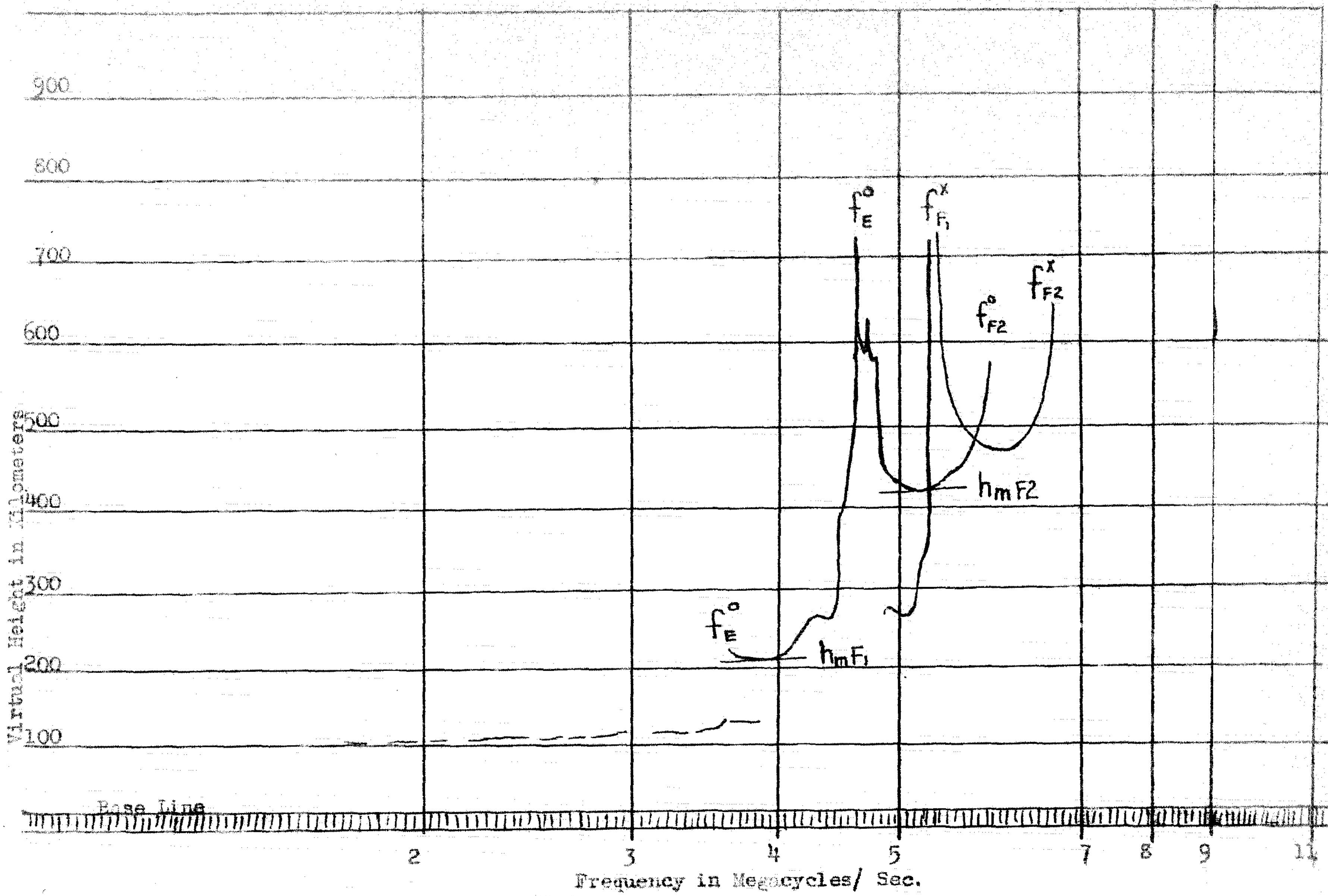
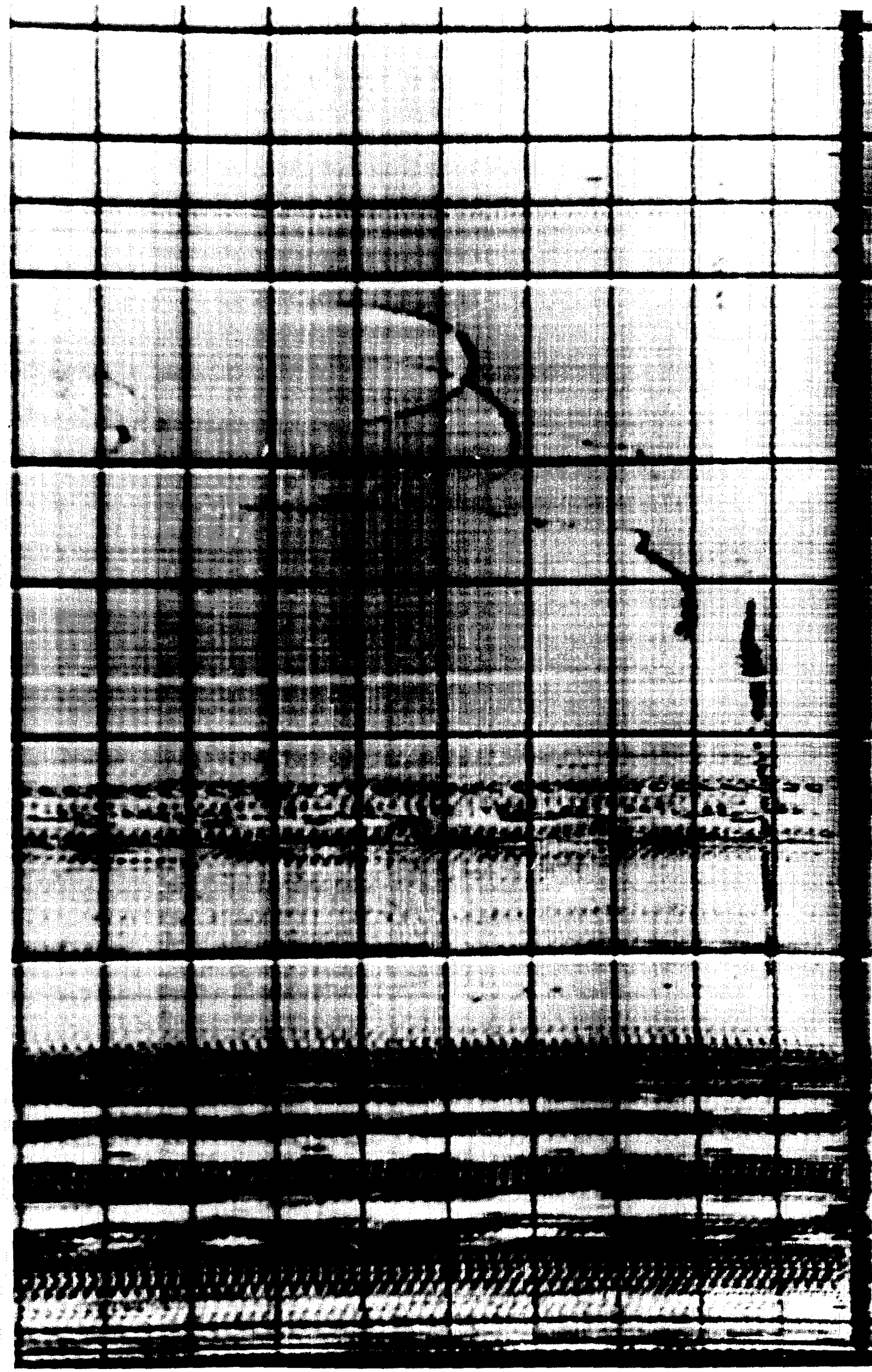


Figure 21. Typical daytime ionosphere record.



far into the F1 layer. At higher frequencies, as the wave approaches the height of maximum ion density (ignoring the small scale stratification) and the rate of change of electron density, and hence refractive index with height becomes small, the wave must spend more time in the media seeking a density from which it can be reflected. As it passes through the maximum ion density and the rate of change of index of refraction with distance is zero, tremendous retardations are noted resulting in great virtual heights. Such a circumstance is marked by the cusp at the point marked foF1. The point where the layer is eventually penetrated and where the great retardations occur is called the critical penetration frequency, or penetration frequency or simply critical frequency. The electron density here has reached a maximum for that layer. All frequencies higher will go through to the next layer which will in turn exhibit the same behavior.

The retardation at the beginning of the F2 trace in diagram 21 is due to the long time the wave spent in the F1 region. As the frequency is increased, the index of refraction of the F1 ion-density for the higher frequencies is nearer to unity and at some frequency the F2 trace becomes horizontal where the rate of change of retardation from the F1 region becomes equal and opposite in sign to that from the F2 region. This point defines what is recorded as the minimum virtual height of the region.

The dark vertical streaks below 2 megacycles are due to broadcast stations. The presence of a D layer is attested to by the cessation of echoes at about 1.8 megacycles. The collisional frequency in the D layer is so high that it is an absorbing rather than a reflecting region. The reflection in the E region extending beyond the foE is a partial reflection from the E region.

The second set of traces noted is called the extraordinary component and this results from the presence of the earths magnetic field in the ionized medium. This makes the medium doubly refracting and gives two values of frequency at which the index of refraction becomes zero. The equations describing reflection from an ionized medium in a magnetic field are very complicated and will not be dealt with here, except to say that fortunately, the conditions for reflection of the ordinary ray is the same as that in a space free from a magnetic field. On occasion, 3 magnetic components can be seen.

The second sample trace, Figure 22, shows the condition of the ionosphere just after ionospheric sunset. This was taken at 1830 P.S.T. 31 August, 1951 at Stanford. The adsorbtion from the D region has lessened, the regular E region has probably recombined and the sporadic E region is returning all reflections below 2.5 mcs. Above this frequency, partial reflection occurs and we see both the E and F regions. In the F region, the F1 has recombined and the F2 has become thinner and uncomplicated. There is some evidence that the

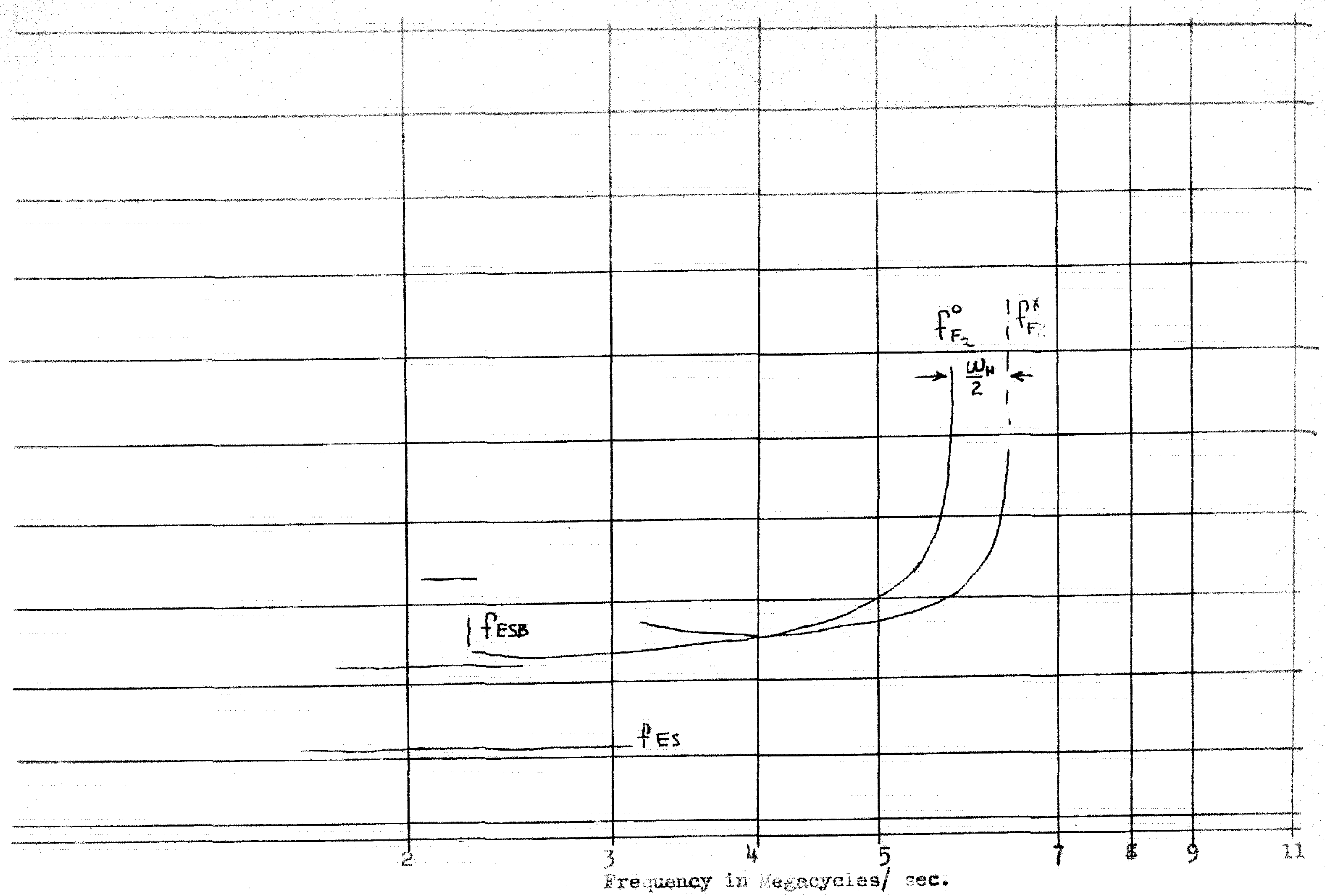
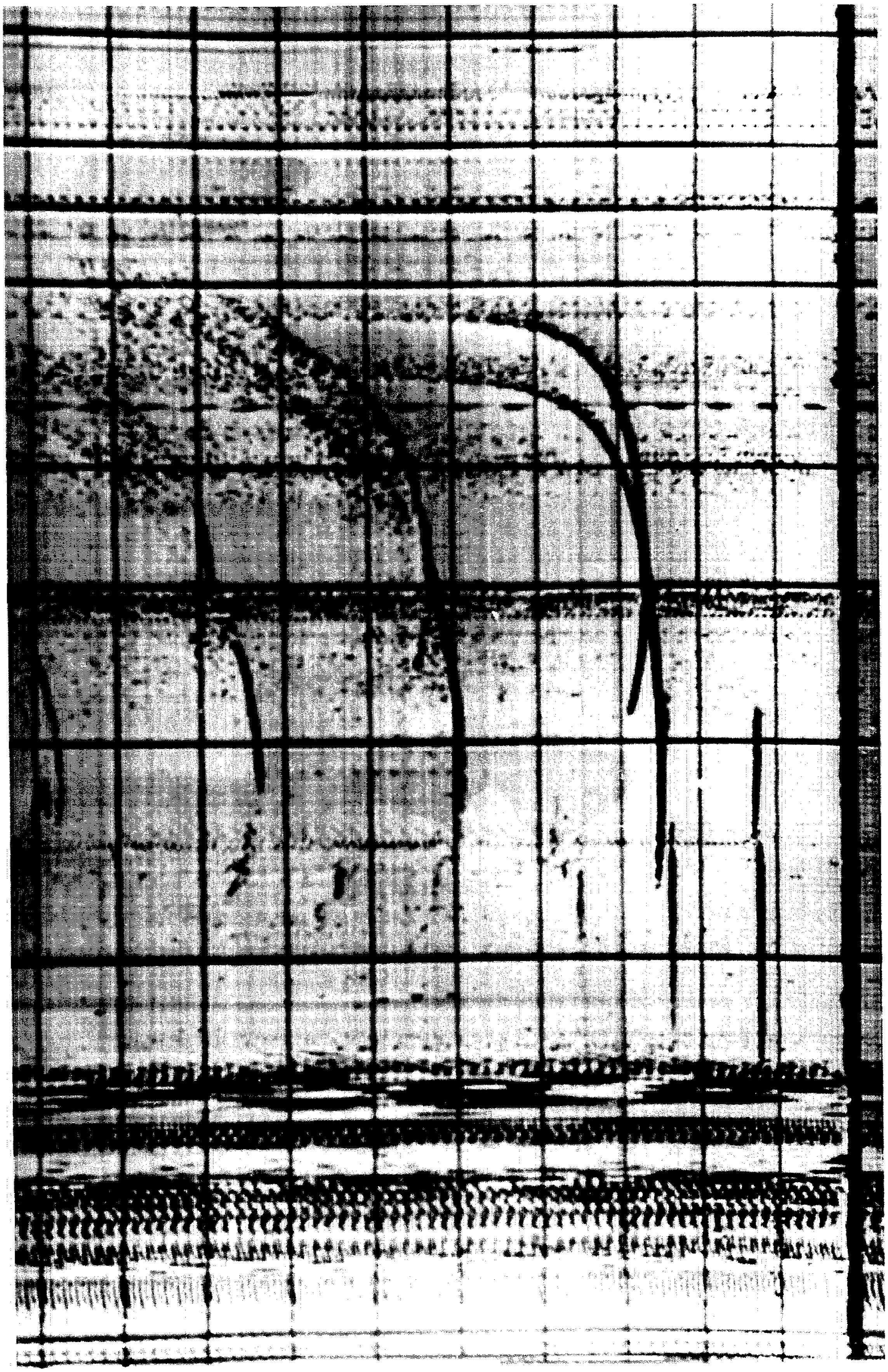


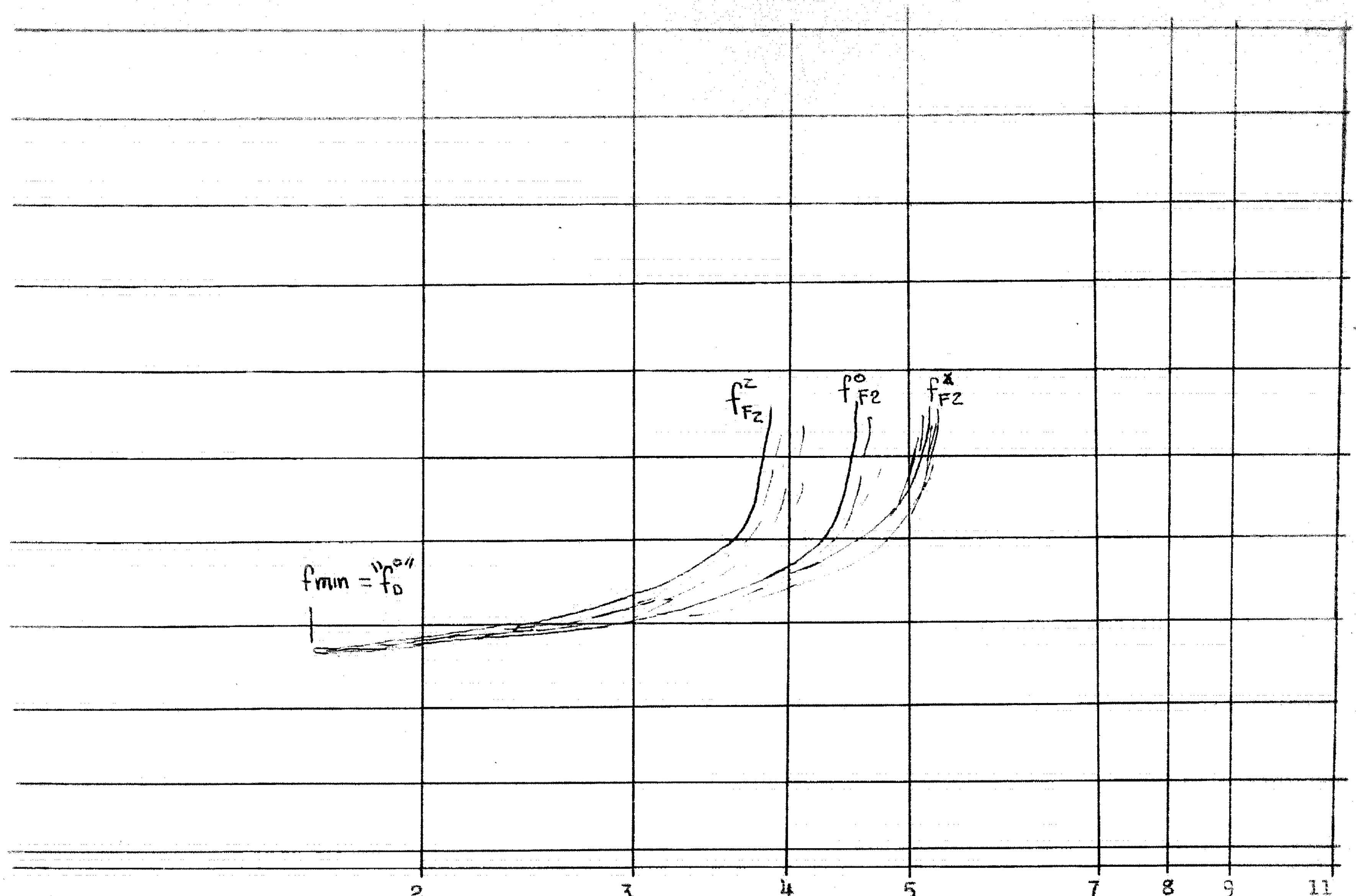
Figure 22. Typical early evening ionosphere record.



extraordinary component is being retarded near the gyrofrequency. The separation of the ordinary and extraordinary rays is quite clear and is seen to be about 0.7 mcs. Since this is equal to half the gyrofrequency, $w_H = He/mc$, we could if we wished calculate, the value of the earths magnetic field at the height of reflection. Multiple echoes may be seen above both the E and F regions echoes. These have made the journey from the earth to the ionosphere and back as many as four times on this trace. The lack of E region retardation should be noted.

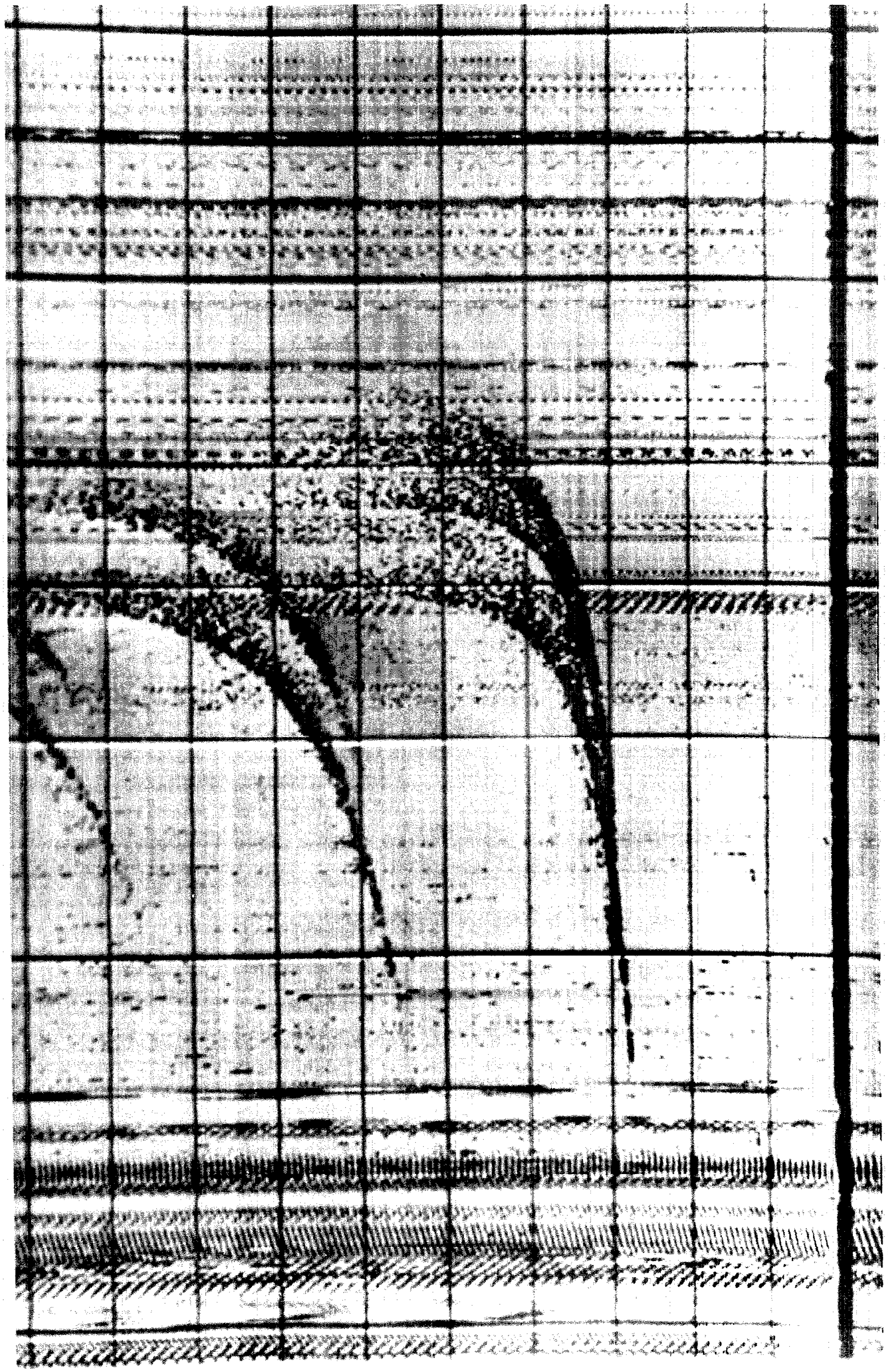
The next two traces illustrate the decrease in ionization throughout the night. On both of these the F region has become cloudy or patchy and instead of one single reflection from a smooth layer, echoes are arriving from a number of distances, indicating that the layer is no longer smooth.

The fifth trace illustrates an aberrant condition, of considerable importance. The F region is all but obscured by a dense sporadic E region. Up to seven multiples of sporadic E reflection may be seen. The sporadic E region is not a smooth layer at one height, but appears to be at at least four and possibly more heights. Partial reflection occurs at frequencies where the F region may be seen. Below this frequency the reflection is said to be of the "blanketing type" above it of the "boundary layer type". The frequency at which the layer is first broached is called fbEs, the maximum frequency of reflection is called fEs.



Frequency in Megacycles/sec.

Figure 23. Night time ionospheric record showing triple splitting of echo. Note elevated fmin.



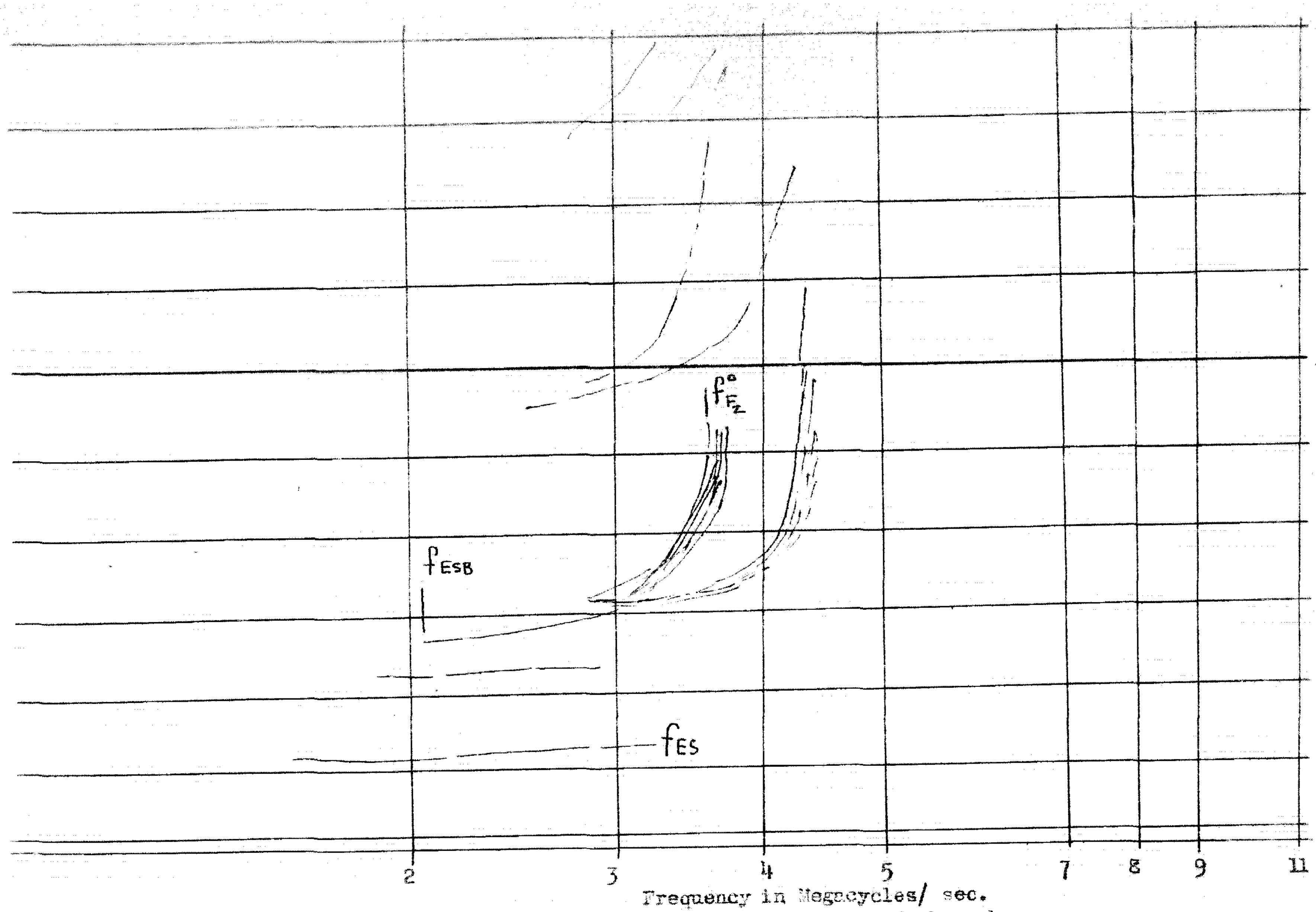
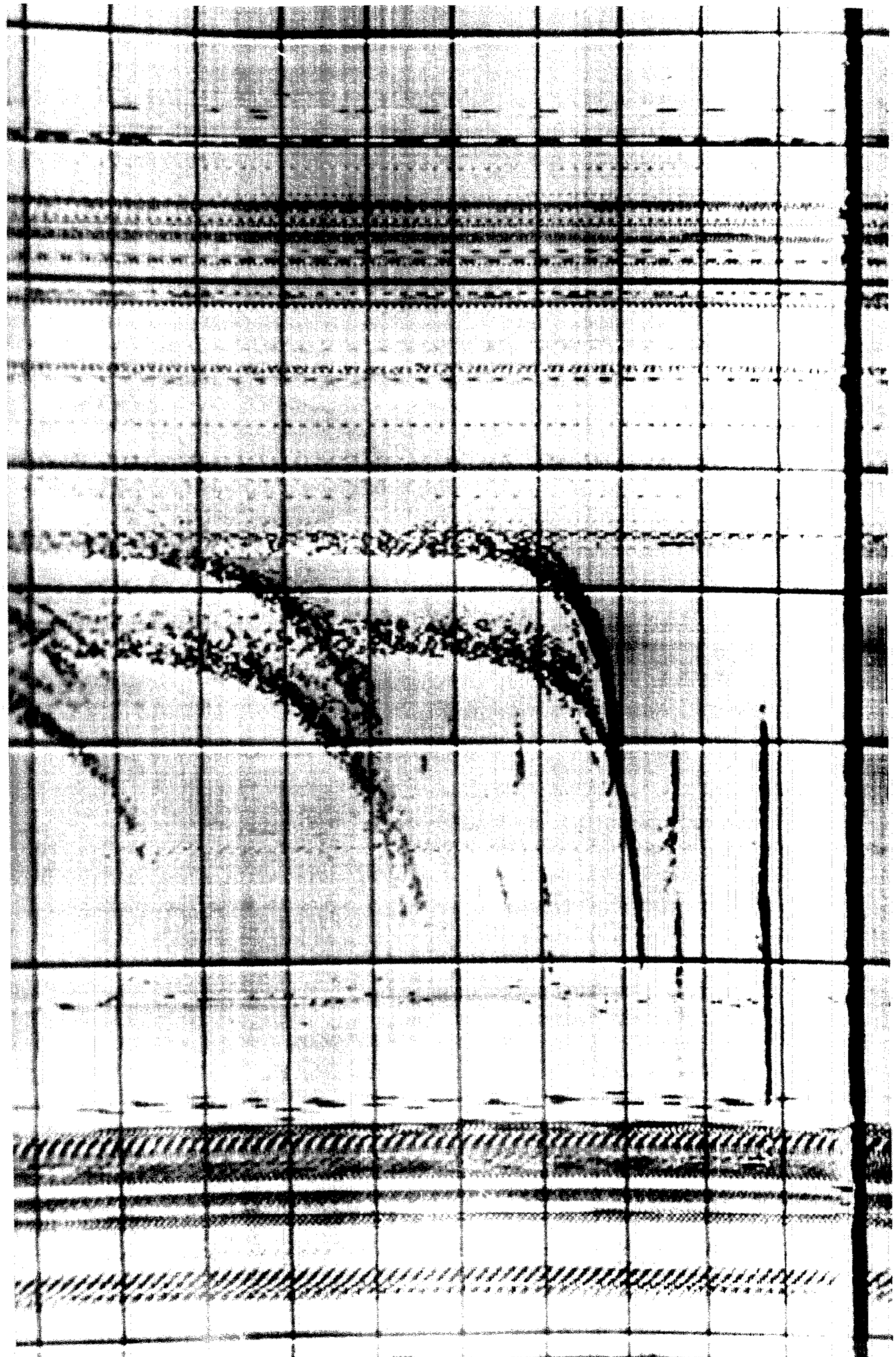


Figure 24. Typical nighttime ionosphere record. Note the diffuse nature of the echoes.



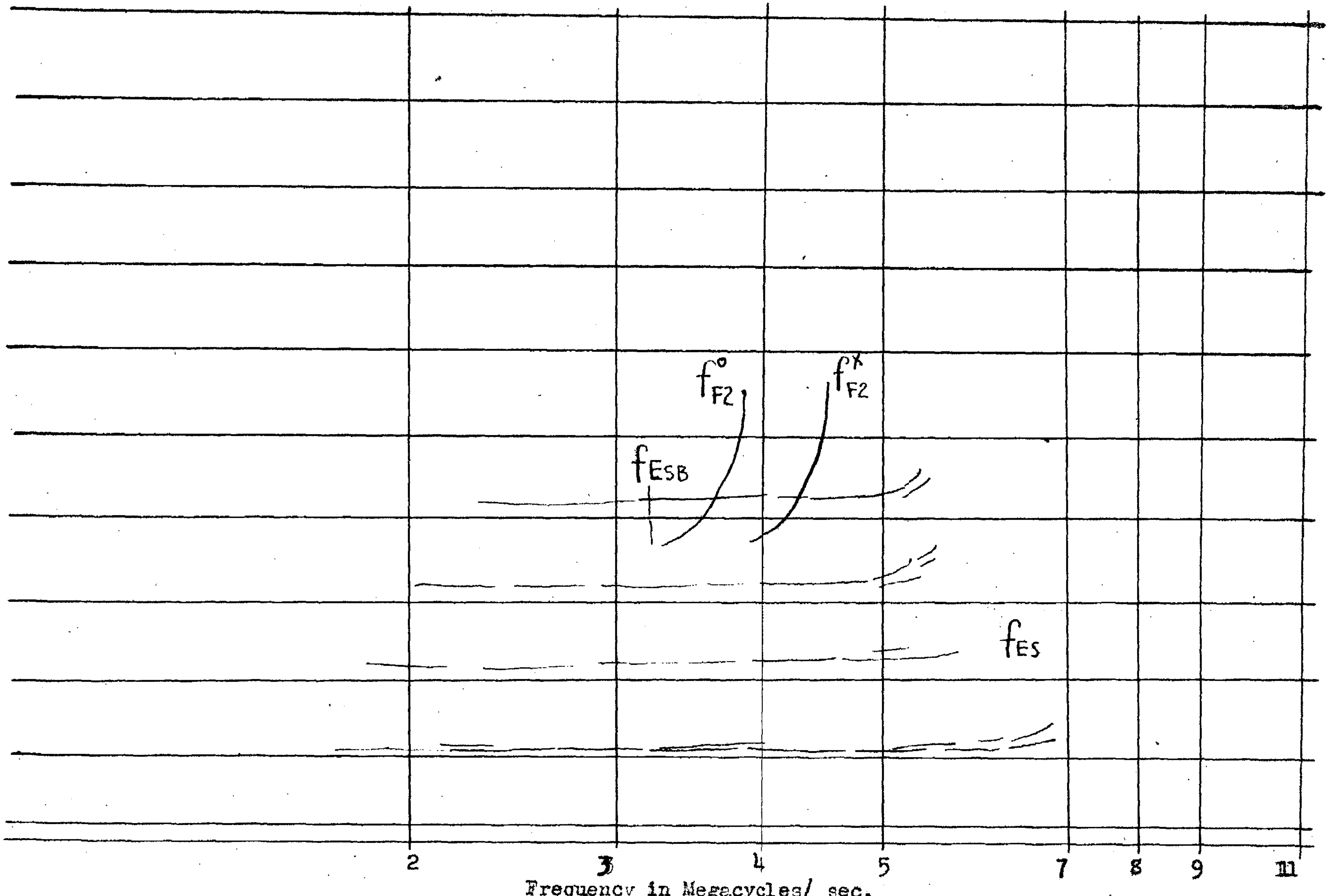
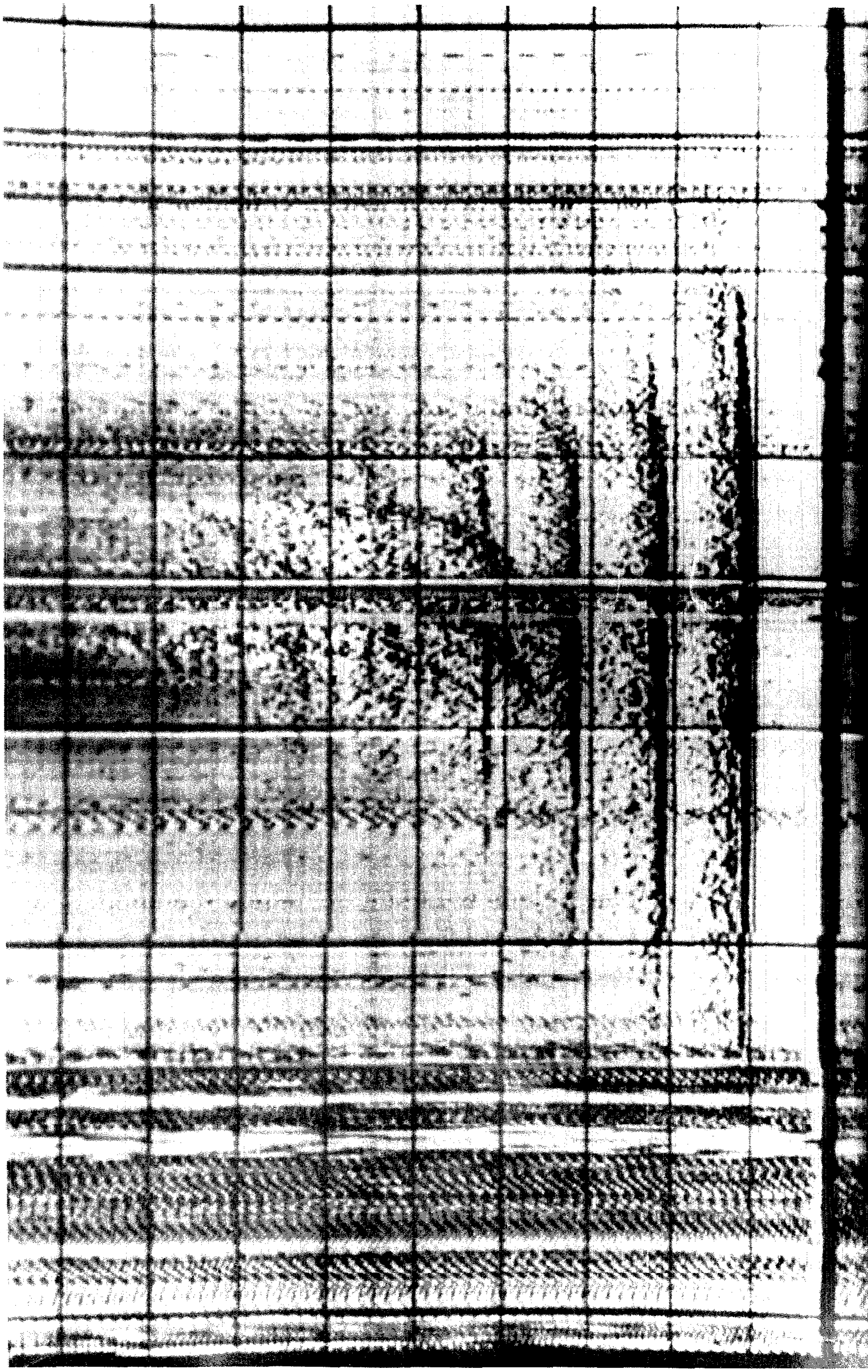


Figure 25. Nighttime ionosphere trace showing typical sporadic E invasion.



The maximum number of electrons per cubic centimeter in a region may be determined by reading the critical frequency of the region and applying the equation for electron density:

$$N = 1.24 f^2 \times 10^4.$$

The height to the bottom of the region may be estimated by reading the lowest point on the trace. The bottom of the E region in the daytime and of the F region at night may be assumed to be given by the minimum virtual heights, because in the absence of retardation from lower layers the minimum virtual height and the real height is the same.

APPLETON (1937) and others have shown that the distribution of ionization may be represented as a parabolic function of height up to the level of maximum electron density. This assumption permits certain simplified methods to be used to determine the heights of maximum ion density as well as the real height at frequencies less than the penetration frequency. The most useful of these techniques is that developed by BOOKER AND SEATON (1937). This consists in finding the virtual height from which a wave of frequency

$$f = 0.84 f_c$$

was returned. Here fc is the penetration frequency.

In the absence of this lower layer, this may be taken as the real height of maximum electron density. In the daytime, allowance must be made for the retardation in the F1 region, the retardation of the E region is usually so low that it may be ignored. At night, the time with which we shall be concerned, it is possible to assume that the minimum virtual height is the real height of the bottom of the layer. The semi-thickness of the layer, Υ , is estimated by subtracting hm, the minimum virtual height from hM, the height of maximum electron density.

Integration over the bottom half of the layer yields n, the number of electrons per unit column up to the height of maximum ion density.

$$n = \int_{hm}^{hM} N dh = 2/3 \Upsilon N_M = 8.27 \ f_c^2 \times 10^8$$

Here, n is in electrons per square centimeter column, is in kilometers and f_c is in megacycles per second. An excellent discussion of this operation is given by RATCLIFFE (1951) who developed a graphical means for making the determination which is somewhat faster, although it lacks the accuracy of the technique as applied by Booker and Seaton.

At this stage it must be said that this operation yields the electron content up to the height of maximum electron density. There may well be twice this many electrons in the region. There may also be layers above any of the usual layers, but having a lesser ion density and hence never observed. It is possible for a layer, for example, to exist above the F layer, with an ion density less than that of the F layer and yet which might have a total electron content equal to or greater than that of the F layer.

Since the parameters of height, ion-density and total ion content are used later in the discussion it might be well to discuss here the error in these quantities which might be expected in the course of normal observation.

The heights are recorded with a readable accuracy of 5 kilometers. The minimum virtual height however, can not always be read with this accuracy, because of the presence of sporadic E ionization or because of interference by local broadcast stations. This always results in determinations which are too high by perhaps as much as 20 kilometers, if the lowest frequency at which the F region can be seen is so high that retardation in the F layer prevents observation of the trace at the point where it becomes sensibly horizontal. The height of maximum ion density is dependent upon the assumption that the layer is parabolic and the validity of the operation is subject to departures from this distribution. The assumption, however, is a good one and this is probably the smallest source of error in height determinations. The frequency at which the height of maximum ion density is read is dependent upon the precision with which the penetration frequency is read and errors in this determination will result in errors in this height. Errors from this source will not often exceed ten kilometers.

The error in estimation of ion density can be estimated from the accuracy with which the ionospheric traces can be read. This is easily done to 0.05 mcs unless there is serious scattering, splitting or forking of the echo. During these times, the errors of frequency determination may be as high as 0.5 mcs. These are exceptional circumstances. It is possible to estimate the magnitude of an error in calculation of ion density from the ionospheric records using the law of propagation of errors.

$$dN = 1.24\ (2)f \times 10^4\ df$$

or, to use the notation of numerical calculus

$$N = 2.5\ f\Delta f \times 10^4 \quad \text{electrons/cm}^3$$

Thus during a night we may expect errors as large as 0.48×10^4 electrons per cubic centimeter. This amounts to 2.5 percent of the ion density.

Calculation of the total electron content of the region is of course subject to much larger errors amounting at times to as much as 25 percent of the total electron content. Just how many electrons are above the height of maximum electron density is a mystery.

There is a possible systematic error of considerable magnitude involved in the determination of electron density which is dependent upon the theory. This involves the so-called Lorentz polarization correction term. The theorists have never satisfactorily cleared this point up and it is possible that all values of electron density should be 1½ times those given here. The matter is rather involved and the reader is referred to a general discussion of the problem to MITRA (1947).

The ionosphere data used in this investigation was scaled from the records of the ionospheric station at Stanford University, Stanford, California, 37° 26' N, 122° 11'W. The data are taken there by a group headed by R. A. Helliwell. The data are collected for the National Bureau of Standards.

The apparatus makes a complete run over a frequency range of 1 to 30 megacycles per second in the course of 2 minutes. A complete run is made every 15 minutes. The data are good, except for the region between 1 and 2.5 mcs where local broadcast station interference makes it difficult to read minimum virtual heights. Part of the data was scaled during a visit to Stanford in August, 1952, the remainder during a visit in March, 1953.

A tabulation of ionosphere data follows.

TABLE VI

SUMMARY OF IONOSPHERIC DATA, ELECTRON DENSITY, ELECTRONS/cc x 10^{-5}

Time P.S.T.	22/23 May	23/24 May	18/19 June	19/20 June	21/22 July	22/23 July	23/24 July	18/19 Aug	19/20 Aug	20/21 Aug	19/20 Nov	14/15 Dec	14/15 Jan	15/16 Feb	Mean
18.0															
18.5											1.12	1.70			1.41
19.0											(0.86)	1.27	1.19		1.11
19.5											0.90	0.97	1.19	1.79	1.21
20.0											(0.92)	1.19	0.97	1.52	1.15
20.5									(2.29)		(0.96)	0.78	1.04	1.27	1.58
21.0	4.92	5.41		5.24	2.51		2.29	(2.08)	1.79	2.51	(1.02)	0.78	1.27	0.84	2.56
21.5	4.61	4.46	3.22	4.17	1.79	2.51	(1.90)	(1.89)	(1.45)	(2.20)	1.12	0.90	1.52	0.71	2.32
22.0	4.17	3.48	2.29	2.86	1.52	1.61	1.79	(1.79)	1.19	1.89	1.19	1.27	2.08	0.71	2.00
22.5	3.62	2.98	1.79	2.40	1.52	1.35	(1.55)	(1.61)	(1.20)	(1.60)	(1.17)	1.43	2.29	0.50	1.79
23.0	2.40	2.62	1.70	2.08	1.43	1.35	1.35	(1.43)	1.35	1.35	(1.16)	1.19	2.29	0.84	1.61
23.5	2.40	2.29	1.61	1.61	1.52	1.27	(1.31)	(1.43)	(1.25)	(1.30)	(1.14)	1.19	2.40	0.90	1.54
00.0	2.19	2.29	1.52	1.61	1.61	1.19	1.27	1.43	1.16	1.27	1.12	1.04	1.89	0.97	1.47
00.5	2.19	2.08	1.61	(1.70)	1.35	1.19	(1.31)	(1.35)	(1.20)	(1.20)	(1.23)	1.27	1.70	1.04	1.46
01.0	1.98	1.98	1.79	(1.79)	1.27	1.19	1.35	1.27	1.35	1.16	(1.08)	1.27	1.43	1.04	1.42
01.5	1.89	1.89	1.61	1.79	(1.07)	1.19	(1.31)	(1.35)	(1.24)	(1.16)	1.04	1.27	1.43	1.19	1.39
02.0	1.89	1.89	1.79	1.79	(1.04)	1.16	1.27	1.43	1.19	1.16	1.04	1.35	1.52	1.27	1.41
02.5	1.52	1.79	1.79	1.79	1.04	1.19	(1.27)	(1.40)	(1.12)	(1.16)	1.12	1.27	1.52	1.27	1.32
03.0	1.52		1.43		1.04	0.97	1.27	1.35	1.04	1.16	1.12	1.35	1.70	1.43	1.28
03.5					1.04			(1.30)	(0.94)	(1.00)	1.19	1.35	1.70	1.35	1.23
04.0								1.27			1.19	1.35	1.79	1.27	1.37
04.5											1.27	1.19	1.70	1.52	1.42
05.0											1.19	1.19		1.35	1.24
	2.71	2.76	1.84	2.40	1.41	1.35	1.48	1.49	1.32	1.44	1.10	1.21	1.63	1.14	

14/15 Jan., 15/16 Feb. in 1953, All other nights in 1952.

Values shown only when night glow data is available.

TABLE VII

SUMMARY OF IONOSPHERIC DATA, HEIGHT MAX. ION DENSITY

Time P.S.T.	22/23 May	23/24 May	18/19 June	19/20 June	21/22 July	22/23 July	23/24 July	18/19 Aug	19/20 Aug	20/21 Aug	19/20 Nov	14/15 Dec	14/15 Jan	15/16 Feb	Mean
18.0															
18.5											2.40	245			
19.0											(290)A	250	255		
19.5											275	275	260	260	
20.0											(275)A	250	270	250	
20.5											(280)A	240	315	230	
21.0	310	310		270	300						(280)A	300	335	235	
21.5	295	280	300	260	350	275					270	290	300	230	
22.0	280	290	325	265	340	330					275	300	305	250	
22.5	280	300	300	310	355	330						260	325	305	
23.0	280	315	360	300	365	330						300	300	300	
23.5	300	330	345	310	365	360						280	305	335	
00.0	320	330	365	390	365	385					(315)A	300	250	325	
00.5	330	330	360	375	360	370					(325)A	285	260	340	
01.0	330	330	355	380	370	350					(330)A	280	285	385	
01.5	330	325	340	360	(360)	330					320	300	275	330	
02.0	350	330	345	345	(370)A	315					320	300	300	310	
02.5	360	330	325	350	(365)	315					325	350	315	350	
03.0	360		340		340	280					315	340	325	295	
03.5					330						315	330	340	280	
04.0											315	330	315	300	
04.5											335	340	330	280	
05.0											330	320		240	

TABLE VIII

SUMMARY OF IONOSPHERIC DATA, MINIMUM VIRTUAL HEIGHT

Time	22/23 May	23/24 May	18/19 June	19/20 June	21/22 July	22/23 July	23/24 July	18/19 Aug	19/20 Aug	20/21 Aug	19/20 Nov	14/15 Dec	14/15 Jan	15/16 Feb	Mean
18.0															
18.5											2.10	215			
19.0											245	210	230		
19.5											225	230	230	210	
20.0											(225)A	220	230	215	
20.5											(230)A	215	260	200	
21.0	250	250		210	240						(230)A	265	250	210	
21.5	230	230	245	220	270	220					(240)A	240	255	225	
22.0	225	220	250	220	280	250					(240)A	230	250	220	
22.5	220	230	280	230	300	280					A	220	270	(250)	
23.0	230	240	(295)	245	310	290					A	230	250	250	
23.5	240	260	290	240	310	290					A	230	230	300	
00.0	260	280	300	(280)A	320	310					A	230	230	280	
00.5	255	270	(320)	(300)A	(315)	310					A	230	230	300	
01.0	250	275	320	(300)A	320	290					A	230	230	300	
01.5	270	260	310	(300)A	(320)	275					A	230	230	280	
02.0	280	270	300	(300)A	325	265					(280)A	230	250	250	
02.5	295	250	280	(300)A	330	260					280	250	255	255	
03.0			290		300	250					280	250	265	250	
03.5					280						270	240	270	220	
04.0											270	270	255	230	
04.5											270	275	255	235	
05.0											280	280		215	

PART V

Correlation of the Nightglow with the Ionosphere

Many people have attempted to show that the light of the night sky originated in, or was associated with one or another of the ionospheric layers. Previous attempts at relating the intensity of the airglow to the various ionospheric parameters have not met with much success and this attempt may also fall into that category when more is known of this fascinating subject. MITRA (1947) has striven to establish the F region as the source of the night sky luminosity. MARTYN AND PULLEY (1936) have pointed out morphological resemblences between seasonal variations of the intensity of the 5577 radiations and those of the maximum electron content of the F region at noon on the preceeding day. MARTYN (1952) contends that the nocturnal variations of the 5577 radiation resembles that of the height of the F region in moderate latitudes and suggests that variations of collisional frequency with changes in height of the ionized region may be the cause of changes in intensity. This matter will be discussed in detail later. BRADBURY AND SUMERLIN (1940) attempted to correlate nocturnal E ionization to the light of the night sky and concluded that no clear correlation could be found. MOORE (1951) on the other hand showed that radio reception conditions on short waves was correlated with aurora, indicating that some form of ionization was associated with the polar aurora. HEPPNER ET AL. (1952) has demonstrated that the polar aurora is clearly related to sporadic E ionization.

As we have seen in Part I, the nightglow consists of a variety of emissions having a variety of sources, and being it appears, at a variety of heights in the atmosphere. It seems unreasonable, therefore, to attempt to assign all the nightglow or even all of one radiation to one height or layer.

Similarily, there is a plethora of geophysical and cosmical data which one may try to correlate with anything he pleases. It is possible to narrow the field somewhat by attempting to choose parameters which are not arbitrary and which appear to offer some promise, being by nature related to light producing processes. The negative results by many early workers are, I suspect, due to a failure to isolate and investigate one facet of the phenomena at a time. BRADBURY AND SUMERLIN'S experiment proved nothing, although they worked hard and earnestly; had they been able to isolate one or more spectral lines and had they been sure that they were actually recording the presence of sporadic E instead of boundary layer reflections, they could have perhaps shown a positive correlation between sporadic E and the 5577 illumination, since it has been many times reported that outbursts of aurora and sporadic E occur together.

This investigation proceeded one spectral line at a time, each line intensity being compared in turn with one ionospheric parameter at a time. Early investigations were carried out with the 5577 radiation and the suggestion of

Dr. Martyn was checked. No other clear correlation with the green line was noted. In April, 1952, an improved filter combination and an increased photometer sensitivity permitted accurate recording of the red [OI] 6300-6364 doublet. It appeared from a casual inspection that the intensity of the lines was related to the number of electrons in the F region.

In order to make a specific check on this point the ionosphere data from Stanford were compared with the night-glow data from Cactus Peak. Although the point of observation of the night glow and of the ionosphere were a large distance apart, see Figure 26, the F region is comparatively smooth, changing slowly with distance. It was thought therefore that, although some uncertainty would certainly be introduced by the distance, in the absence of observations at the zenith at an ionosphere station, that a preliminary trial might be made using the Stanford data.

Figures 27, 28 and 29 show the nocturnal variation of both the intensity of the red lines and the maximum number of electrons per cubic centimeter in the F region. The curves for the two phenomena are morphologically similar, those for the summer months resembling each other in detail. The curve for the winter months is however different. Here the variations in the ion density are not very great. If the values of brightness for the spring months are plotted against the ion density a straight line ensues. Figure 30 shows such a plot. However, if the values for the early

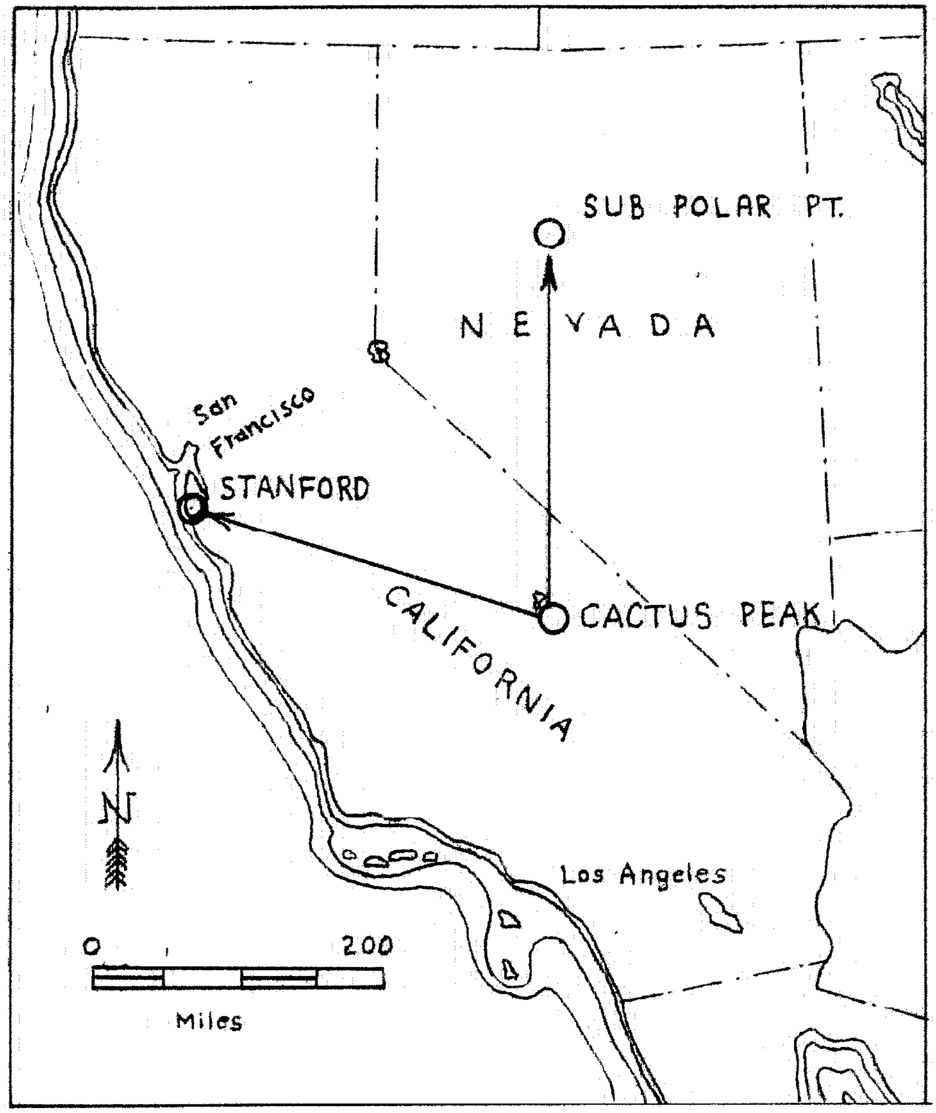


Figure 26. Map showing the relative locations of the points where the nightglow and the ionospheric measurements were made.

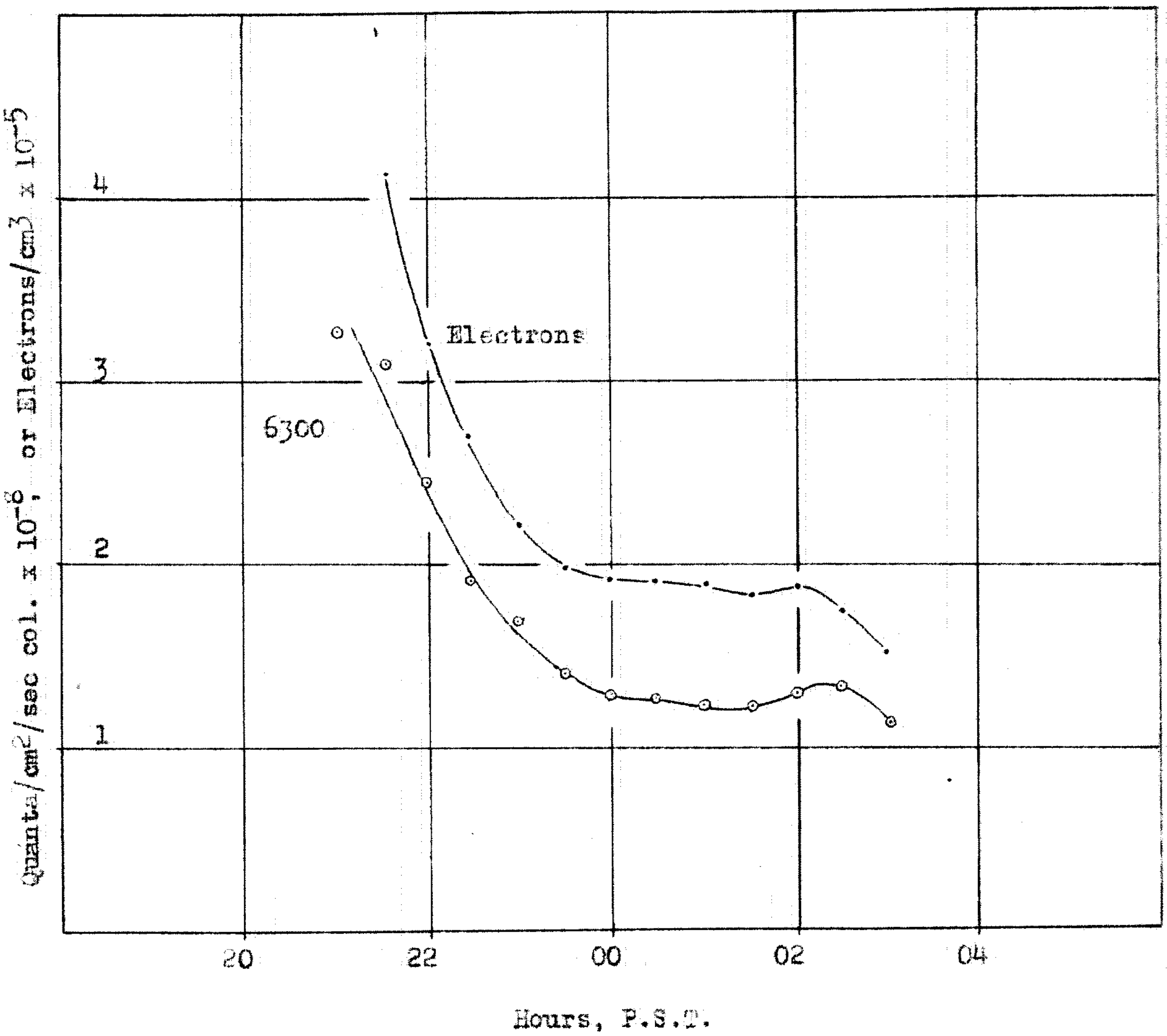


Figure 27. Plot of diurnal variations of the maximum electron density of the F region and of the intensity of the OI 6300 nightglow. Values are means for May and June 1952.

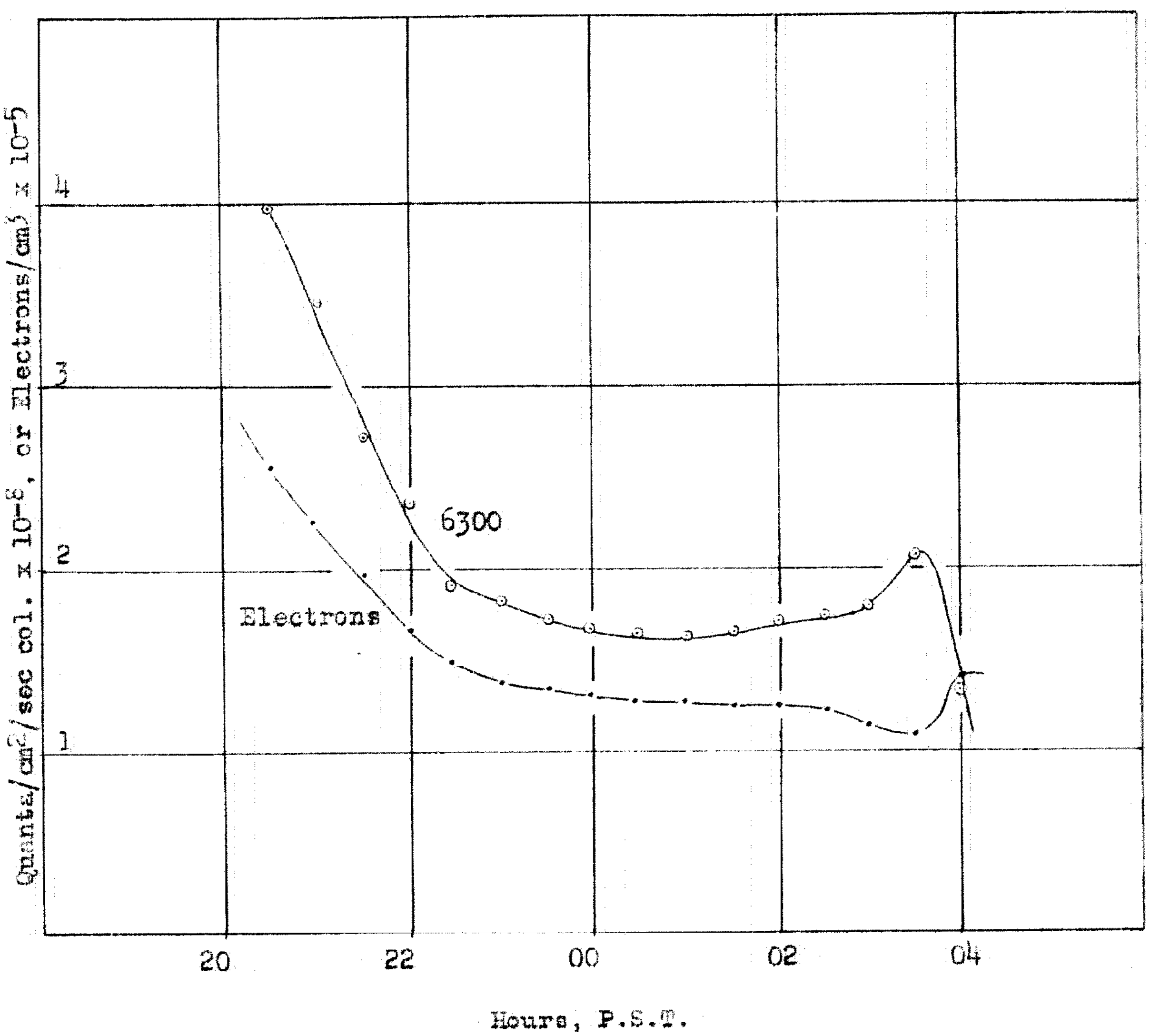


Figure 28. Plot of the diurnal variations of the maximum electron density of the F region and of the intensity of the OI 6300 nightglow. Values are means for July and August 1952.

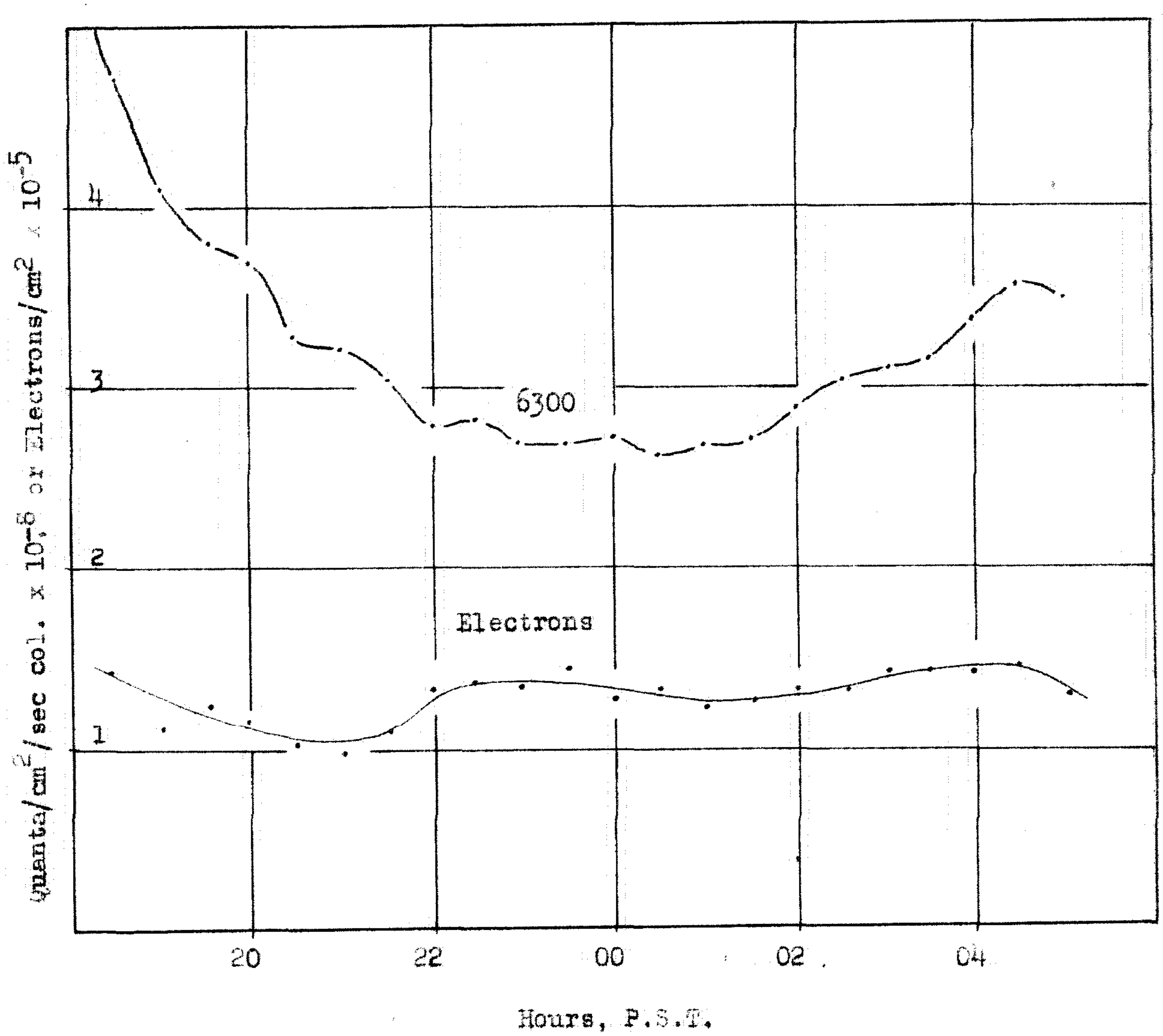


Figure 29. Plot of diurnal variations of the maximum electron density of the F region and of the intensity of the OI 6300 nightglow. Note the low level of ionization during the winter months of November, December, January and February.

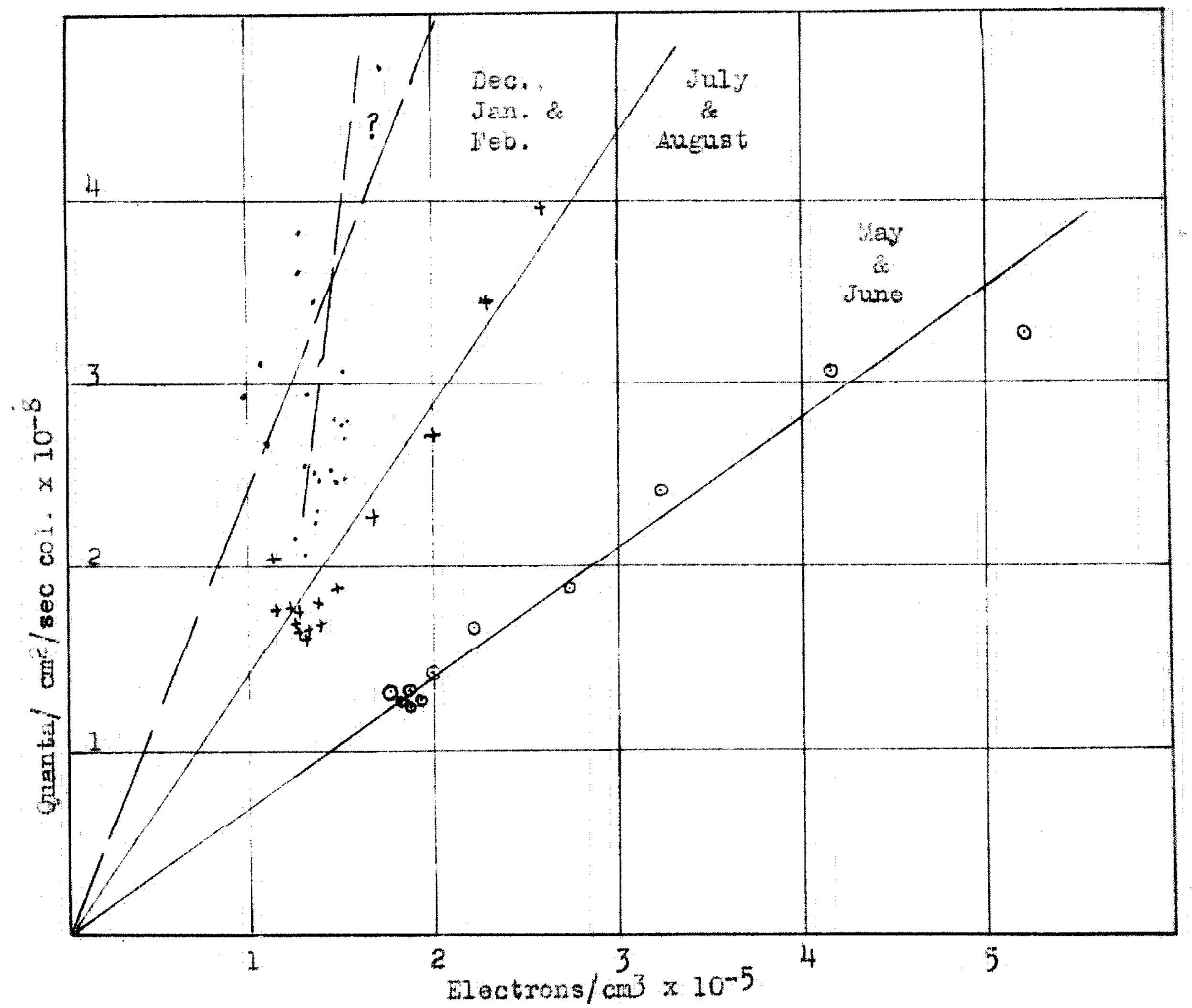


Figure 30. Plot showing relation of intensity of 6300 nightglow to electron concentration in F region. Note that the slope of the lines is a function of season of the year.

summer months are similarly plotted, the slope of the regression line is steepened. The slope for such a plot for the winter months is very steep, and whereas the curves formerly went through the origin, it no longer appears to do so.

Figure 31 shows a plot of the slope of these lines as a function of time of year. It is interesting to note that an orderly progression takes place between the months. It is regretable that data for September, October and the early months of spring were not readily available at the time of writing. Also plotted on Figure 31 is the mean value of red line intensity for each month for the nights observed and the mean value of ion density for the nights in each month on which the airglow was recorded. The two annual variations are certainly not similar.

During the spring and summer months the integrated ion density of the F region and the intensity of the red lines have a linear relation. This is not surprising, since the semithickness of the F region does not change greatly through the course of the night, when the average of several nights is taken. The measurement of the semithickness is subject to rather large errors and it is not as easy to tell much about the relation as one would like. Figure 32 shows the relation between the integrated ion content and the brightness of the red lines for the months of May, June and July lumped together.

When the intensity of the red lines is plotted as a function of the mean height of the emitting region for whole

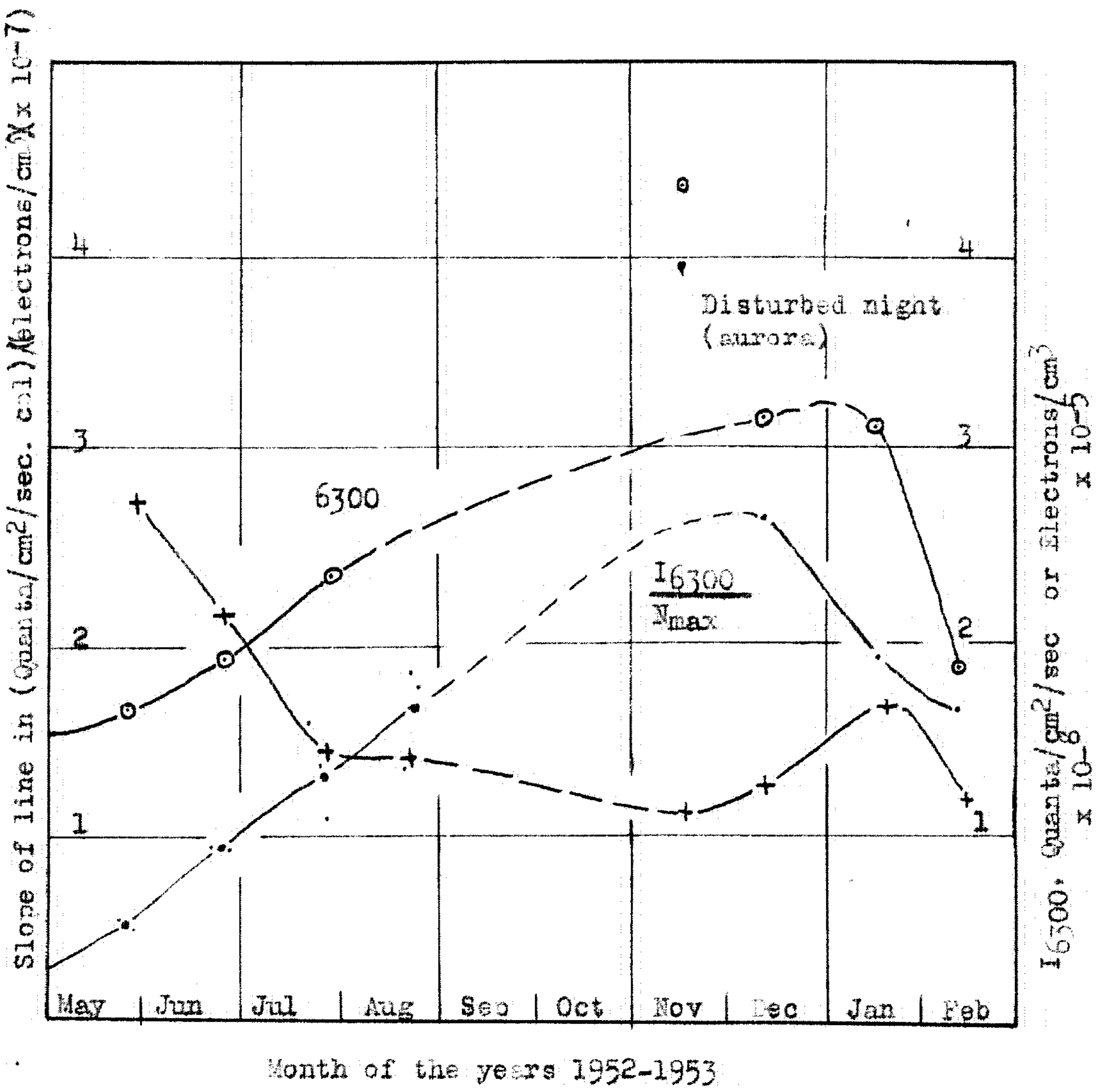


Figure 31. Annual variations in the slope of the proportionality constant between electrons and quanta and annual variations in electron density and the intensity of the 6300 nightglow. The night of 19/20 Nov. 1952 was marked by abnormal ionospheric conditions and a polar aurora was noted at several points, although not at Cactus Peak.

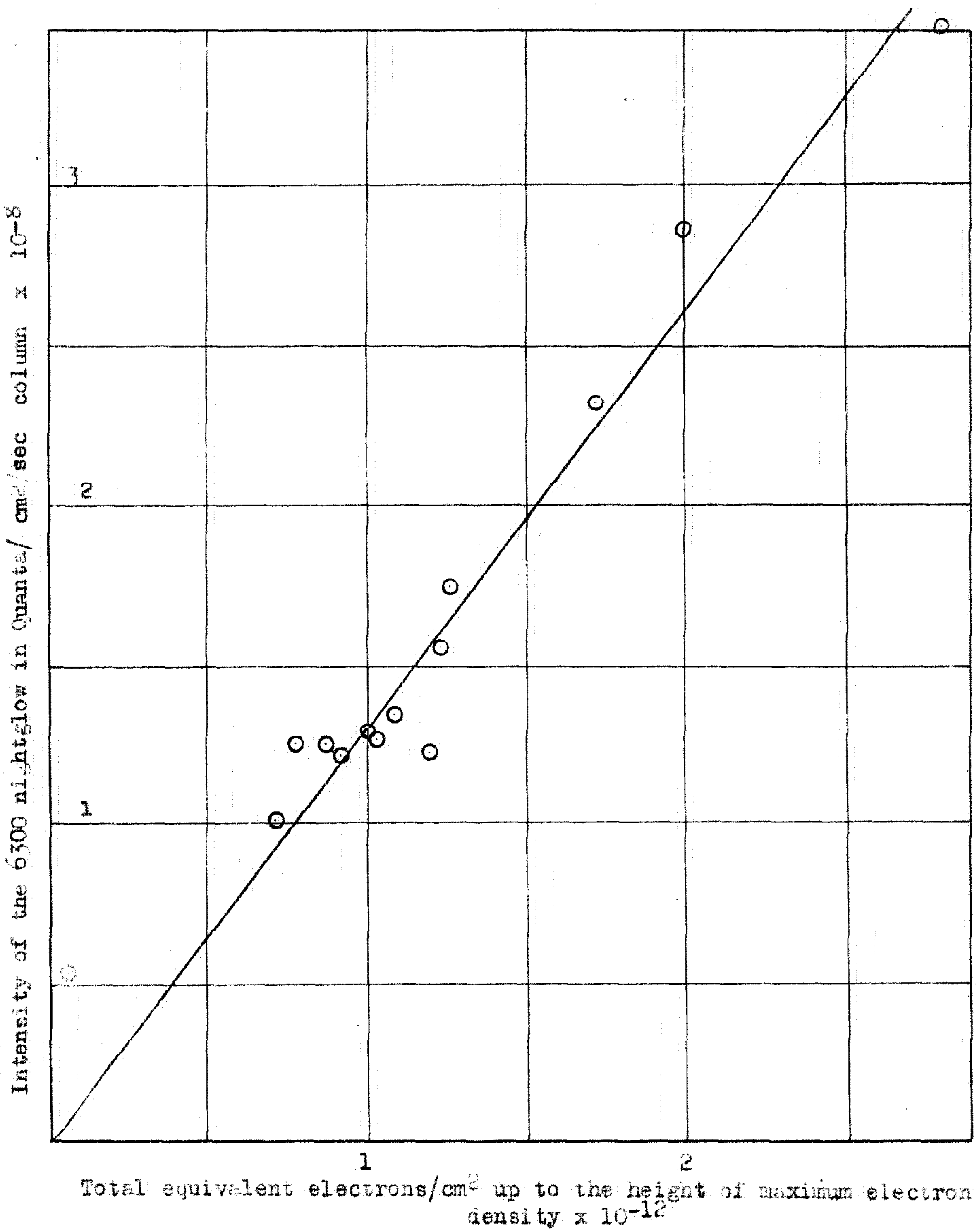


Figure 32. Plot showing correlation of total ion content per unit column up to the height of maximum electron density for the F region plotted against brightness of the red lines for the mean values of the months May, June and July 1952.

nights it appears that the intensity is a function of height. In the summer times the light is brighter when the region is higher, in the winter the opposite appears to be true. It does not seem that a conclusion here is justifiable at the present stage of the investigation.

The brightness of the red lines may be expressed at a function of at least two variables:

$$I_{6300} = f(N)\ g(H?)\ j(?)$$

The resemblence of the two kinds of curves may be coincidental. If both the parameters have smooth nocturnal variations, the function resulting from plotting one against the other will also be smooth, and if the annual variations are different, the situation could be exactly as we have found here. This possibility is a good one, and is the weak point of our argument that the nightglow is related to the ionosphere. This weakness is freely admitted since the object of scientific investigation is to uncover relations existing in nature, and not to sell ideas to others.

We feel however, that the relation is a real one and that the similarity of the curves is not incidental. It may be possible to explain the phenomena with an argument which will be developed as we go along.

Let us turn now to the green line. The 5577 radiation has a markedly different nocturnal variation. As MARTYN Has pointed out is similar to the diurnal variation in height of the F region in moderate latitudes. In Figures 33 and 34 the intensity of the green lines is plotted as a

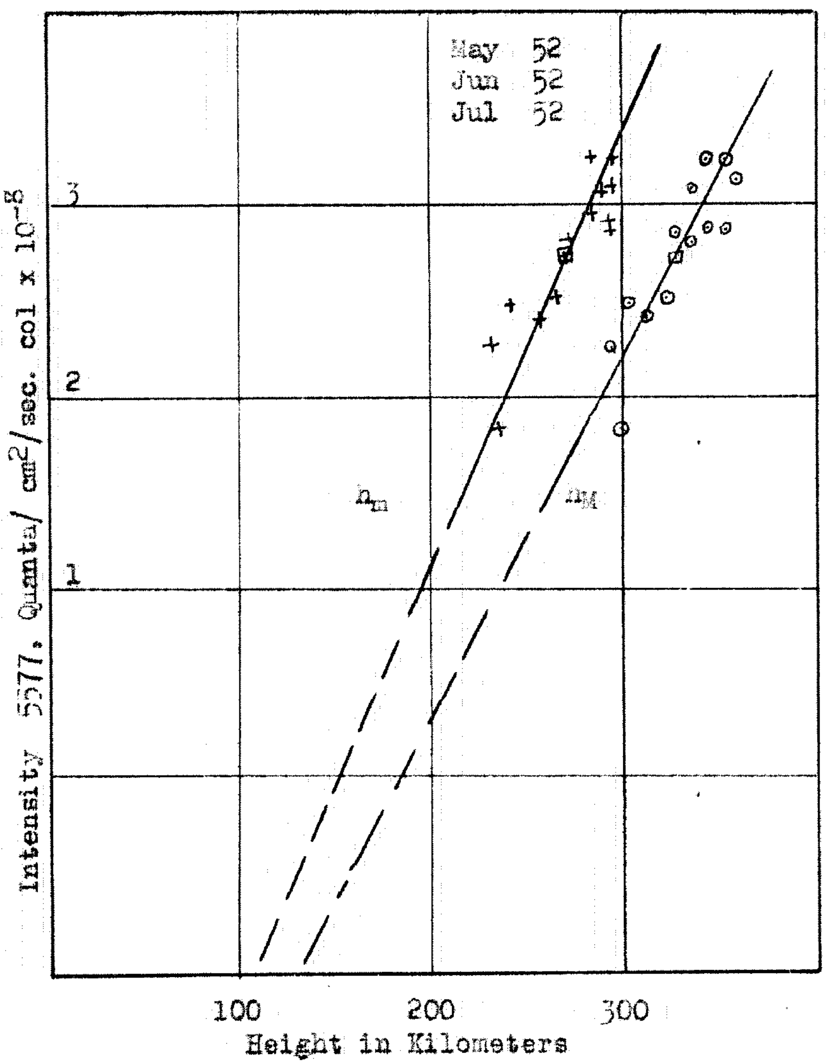


Figure 33. Plot of intensity of 5577 nightglow as as a function of height of the F region. It was suggested by Martyn that this might be so. Note that the ionosphere is higher than it was in Figure 34 and that the nightglow is a little brighter.

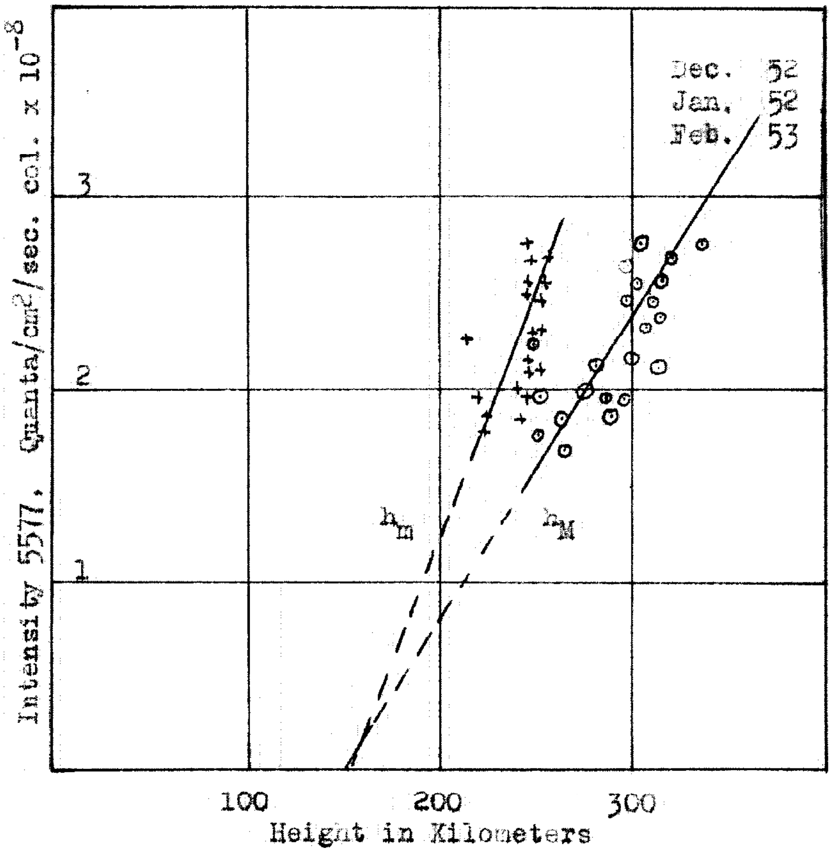


Figure 34. Plot showing relation between height of the F region and the intensity of the 5577 nightglow. There is reason for suspecting that a straight line would not necessarily be a good fit. Note that the ionosphere is lower than during the summer months.

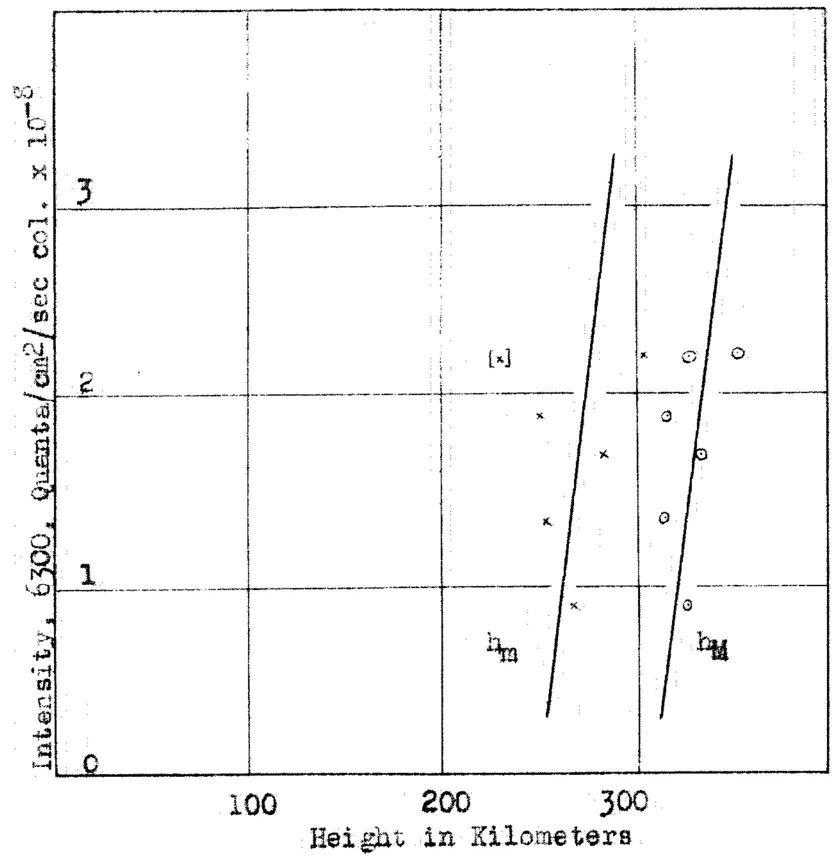


Figure 34A. Plot showing intensity of the red nightglow lines, 6300-6364 plotted as function of height of F region. This data is not conclusive because of the small number of points. The winter time trend appears reversed. Points shown are for May, June and July, 1952 function of height of the F region for the nights of May, June and July and for the nights of December, January and February. In both cases some sort of relation appears to exist between the two phenomena.

Let us now examine the nature of the atomic transitions with which we are dealing. The red and green lines come from the excited oxygen atom in its lowest energy levels. For many years, from 1895 to 1923 the green line was recognized and referred to as the auroral line. The origin of this line was unknown until it was shown that it resulted from a forbidden transition in the oxygen atom. Similarily the red lines were for a long time referred to as the nebular lines and they in turn were of an unknown origin. They have been produced in the laboratory, using a discharge tube into which a very small partial pressure of oxygen was introduced, along with some of the noble gases.

The two radiations proceed from so-called forbidden transitions, taking place from metastable states. The atom when excited to these states must remain in them for a comparatively long time before they can radiate. At ordinary temperatures and pressures radiation is precluded because the atom is removed from that state by collisional de-excitation before enough time has elapsed to permit radiation. The energy level diagram of the oxygen atom is shown in Figure 35, adapted from SWINGS (1951). For our

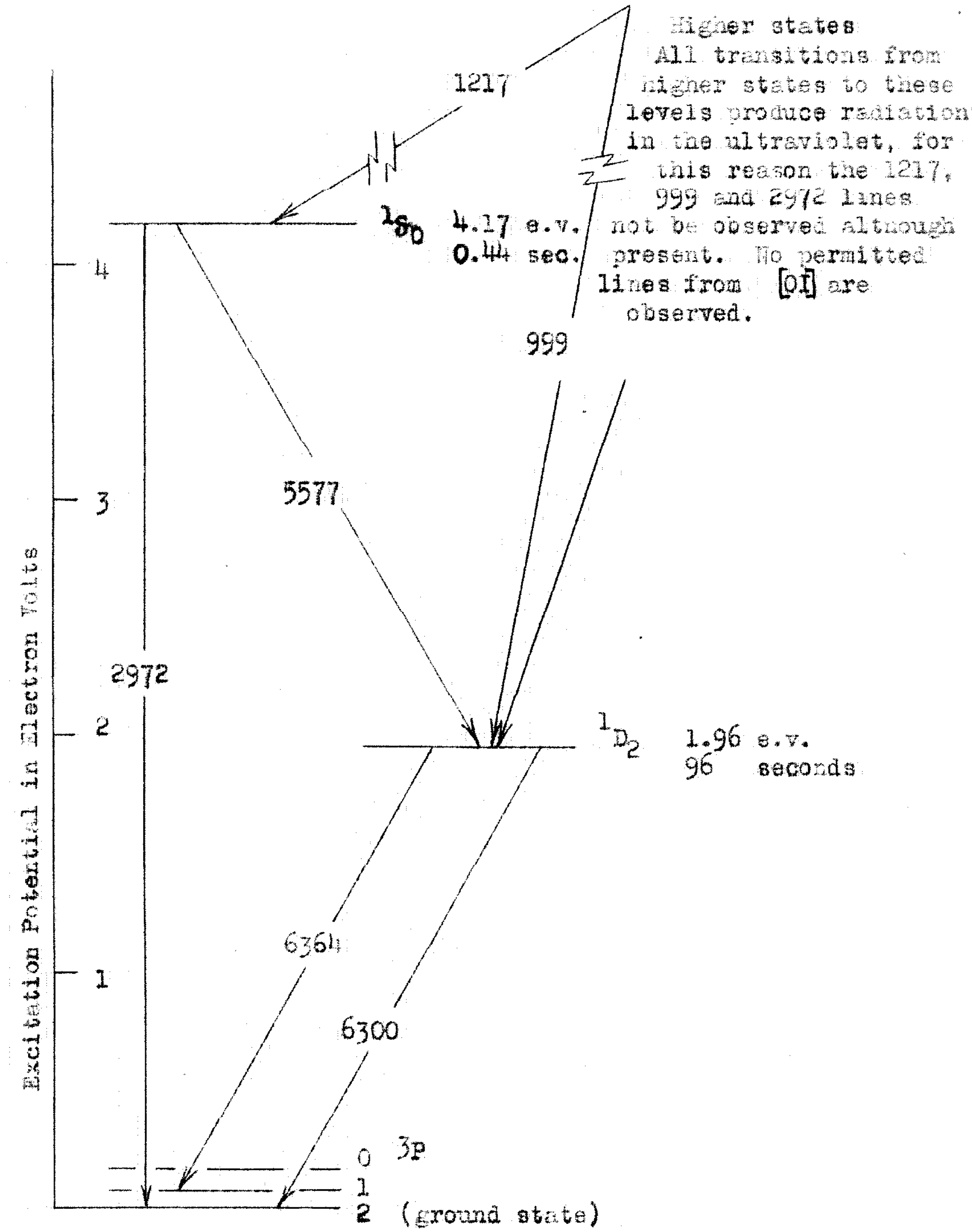


Figure 35. Simplified energy level diagram of oxygen one. The higher states have been omitted for the sake of simplicity.

purposes we can in general ignore the higher energy levels, because lines resulting from transitions from these states are missing from the light of the night sky. The lines resulting from transitions from the next highest energy levels are in the vacuum ultra-violet region of the spectrum and could not be detected easily and it may be for this reason that they are not found. However, permitted lines in the visible spectrum resulting from transitions from states directly above these would be easily detected. For this reason, it is felt that the permitted lines of oxygen are missing from the night glow spectrum because the states giving rise to the permitted lines are not excited by the process giving rise to the nightglow.

An atom raised to the S state must remain in that state for about one-half second before it can drop to the D state. In doing so it radiates the greenline 5577. Once in the D state it has the choice of dropping to the next lower state and this it will do if not removed by collisional de-excitation within a minute and a half. If permitted to drop to the ground state, the atom will radiate on one of three wavelengths. The wavelengths are 6300, 6364 and 6390 Angstrom units. The first two have been observed, the last not. This is in accord with the theory since the theoretical ratio of the intensity of these lines is 1:1/3:0, the third transition being multiply forbidden.

For every 5577 quanta produced, there should be some 6300 light produced. If however, the collisional frequency in the region where the 5577 is radiated is high, the intensity of the 6300 radiation may drop to a very low value. For this reason it is thought that the red line must be produced higher in the atmosphere than the green line. This is in accord with the experience of auroral workers who find that the ratio of the red to green lines increases with increasing height along auroral rays, HARANG (1951). The theoretical value of the ratio between 6300 and 5577 is 2/3 in the absence of collisional de-excitation. However, as in the case of the polar aurora, the intensity of the 6300 radiation in the nightglow frequently exceeds that of the 5577 radiation. Actually the ratio of the intensity of the red and green lines varies from night to night. The ratio appears lower in the summer and higher in the winter. In the summer, following recombination of the F region, the ratio of the red to green lines comes to about 1/3, as seen in Figure 36. The values during the winter are completely different. This phase of the investigation has not been pursued farther, because it is thought that a more accurate calibration is required before a critical comparison can be made. However, these facts, coupled with the different form of diurnal variation and the observation that the 6300 is actually higher in the atmosphere, made by a method to be described subsequently, coupled with the inference that some mechanism is placing the oxygen atoms in the D state independent of, and/or in addition to

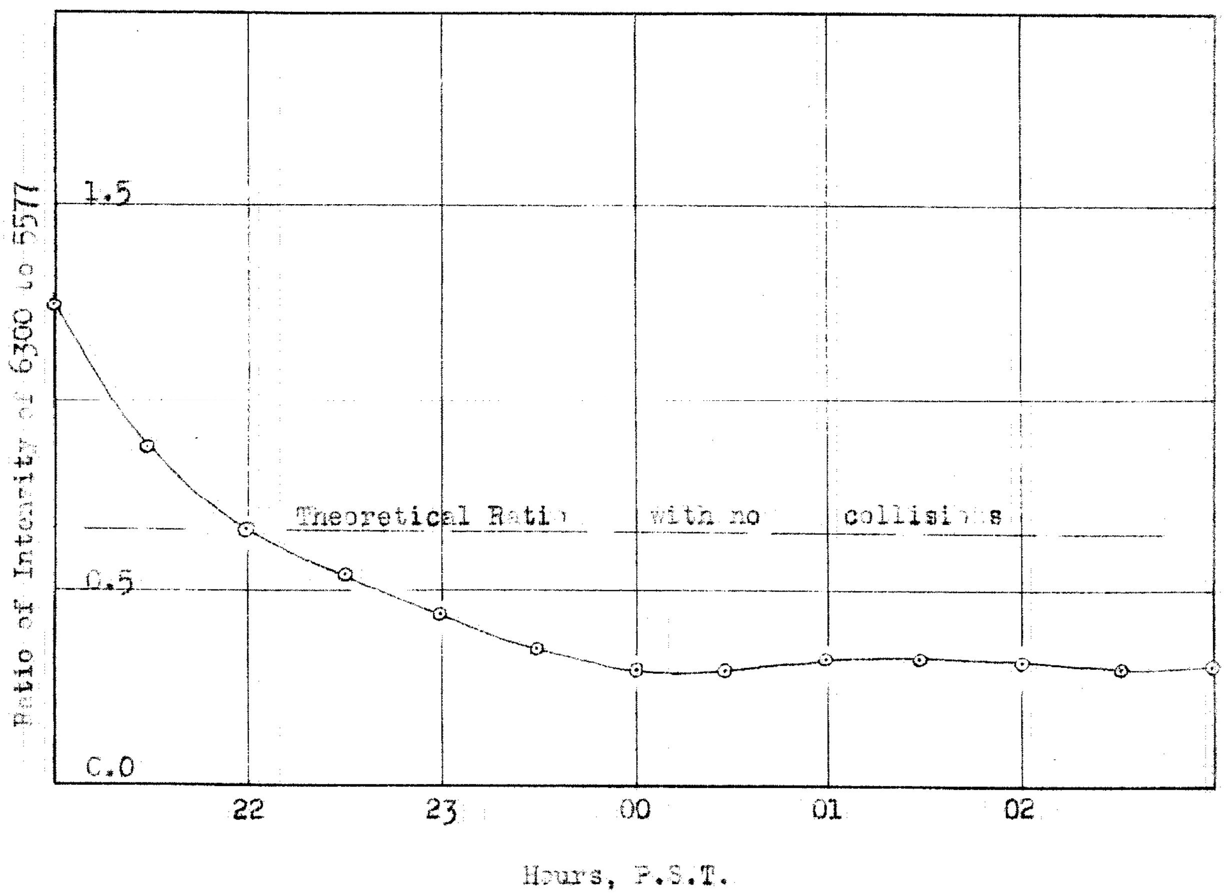


Figure 36. This curve gives the ratio between the brightness of the 6300 and 5577 nightglow radiations as a function of time. Note that the ratio appears to reach a constant value after midnight, i.e., at the end of F layer recombination.

contributions from the S state leads us to suspect that the modes of origin are different. A conclusion reached also by others, SWINGS (1951).

The height to the emitting regions is an important consideration, because if the light is produced in the F region of the ionosphere, for the 6300 emission at any rate, the height as measured by the various techniques should also lie in F region. This is not clearly the case, but the departures from the height of the F region may be explained on the basis of the different workers not taking into account all the variables involved in the calculation of the height to the emitting layers.

There are two methods in common use to determine the height to emissions in the upper atmosphere. One is the method of Van Rhijn, the other the trigonometric methods employed by the Norwegian and other investigators in measurements of the height of the aurora polaris. A third technique due to the present author has been tried by the workers at China Lake with indifferent success. The Van Rhijn technique will be dealt with first. The method was suggested originally by Van RHIJN (1921). The assumption is made that the brightness of the sky will be proportional to the number of radiating particles in the line of sight. The length of the line of sight through a thin emitting region in the upper atmosphere may be calculated from Figure 37.

Here if the radius of the earth by R, the height to the thin layer h, the angle with the zenith Z, the ratio of the

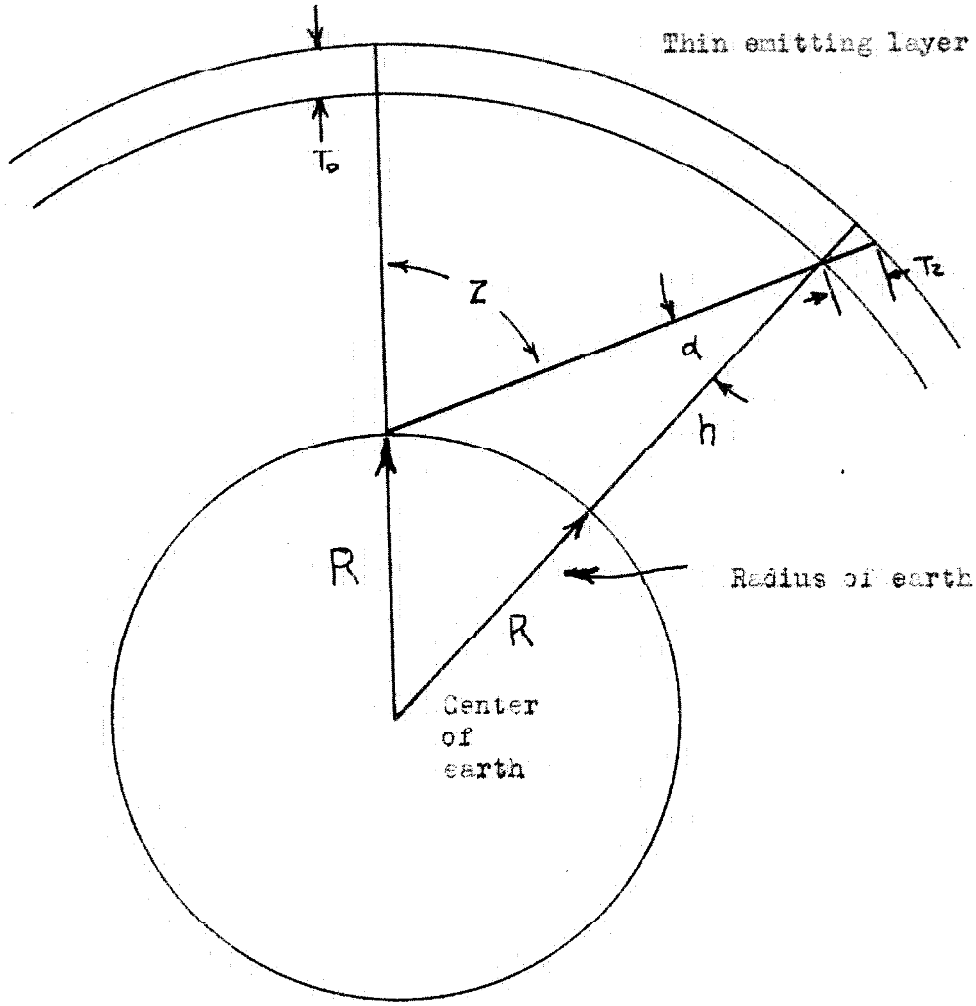


Figure 37. Illustrating the geometry of Van Rhijn's technique for measuring the height of the nightglow.

distance through the layer at zenith distance Z to that at the zenith may be calculated by the law of signs and a simple transformation:

$$I_z/I_o = T_z/T_o = \cos a = (1- (1/(1\ \ h/R))^2 \sin^2)^{\frac{1}{2}}$$

This expression would be true if the layers were thin and if there were no lower atomsphere. Light from space and from different components of the night glow admitted by the filter used, introduce great difficulties. Barbier has striven to account for the effect of the lower atmosphere. His expression for calculation of heights is as follows:

$$I_z/I_o = I_o\ (1-(1/(1\ \ h/R))^2 \sin^2 Z)^{-\frac{1}{2}}\ e^{-T1m} + J(1-e^{-T2m})$$

Here e is the base of the natural logarithms, m is the air-mass at the zenith distance in question and T_1 is an extinction coefficient for Rayleigh scattering with a correction added for absorption by ozone and/or water vapor. T_2 is a coefficient for Rayleigh scattering, J is an estimate of the amount of light to be scattered, usually taken as a spherical shell situated outside the atmosphere with an intensity equal to $I_o/2$. The first exponential term corrects for the attenuation of light coming through the atmosphere, the second term corrects for light scattered back into the field of view of the photometer by air molecules lying in the field of view.

This method neglects the effects of secondary scattering and the effects of reflection from the ground. In a recent publication, BARBIER (1952) has attempted to allow for these also, but time has not permitted a study of his latest work.

Apart from these objections, the emitting layers may not be thin enough to permit the amplification that T_z/T_0=cosa. Then too, if great zenith distances are used, the situation is worsened by the effect of atmospheric refraction wherein the lower edge of the field of view takes in more volume of the emitting region than the upper edge, because the refraction increases rapidly with zenith distance.

A more realistic approach would be to estimate the volume of emitting region intercepted by the field of view of the photometer. This leads to some unpleasant numerical integrations especially if the photometer field is non uniform in sensitivity. It would be desirable to construct photometers for height measurement purposes with a rectangular or oval field of view with the long demension horizontal.

HURUHATA (1950) has attempted to allow for this in his reductions, but the scattering and extinction corrections he made are so poor that his method is not too useful.

Using values of the above equation calculated by H. Pettit and selecting a combination of values of extinction coefficients and background light, the combination of values which gave the least scatter in the height as deduced at a number of zenith distances was for the red lines 325 kms ± 100 kms for then night of 22/23 May, 1952. Although in fairness, I should point out that ROACH has recently been finding heights in the 200-250km for the red line.

The values of height for the 5577 line usually comes out in the range 200 km $\pm$ 50 km. A sample of the results obtained when calculating heights by this technique is seen in F is where in the scatter in height is much less than usual.

A unique method (due largely to the present author) of determining the height of the 5577 radiation by triangulation was tried out by the Aerophysics group in the fall of 1950. Observations were made at Cactus Peak and at Mt. Palomar. The photometers, the Marlow-Pemberton version, were set up to sweep the sky in a common plane. Intersections of the line of sight of the one instrument with the other were selected, and correlation coefficients calculated for the variation in intensity at one station with respect to that at the other for each intersection. The many intersections were each plotted then, using height as the independent variable and the correlation coefficient as the dependent variable. The resulting curve showed a pronounced peak at about 110 kilometers and a general region of response extending up to 300 or more km.

This method while not used generally deserves a further trial because it makes no assumptions regarding extinction and scattering coefficients, subtraction of extra terrestrial light or even calibration of the instruments. There is however a drawback, if the variations of intensity with time are not confined to small areas the resulting picture is extremely generalized. The layer, or portion of a layer which changes most in brightness will be that which gives the peak on the curve.

Many suggestions have been made as to the origin of the light and the mode of excitation of the atoms. There are at present two general schools of thought. Those who feel that the light must be produced in the main from a chemiluminescent reaction and those who would ascribe the excitation to a more dynamic processes, such as winds, corpuscular bombardment, electric currents, etc..

BATES (1946), the leader of the chemiluminescent group, has suggested that dissociative electronic recombination of oxygen might account for the behavior of the red lines. A principal constituent of this reaction is molecular oxygen, however, and this is usually presumed to be absent at elevations much greater than 100 kms. If the light of the red lines is produced in the F region, it seems that this process must be excluded on this ground. The recent suggestion by Barbier, not yet in print, that the Herzberg bands of the oxygen molecule seem to come from a height of 200 or more kilometers would seem to indicate that our ideas concerning the distribution of atomic and molecular oxygen may be in error and that possibly, at night there is abundant molecular oxygen present in the atmosphere at heights in excess of 200 kilometers. Hence it may be possible that the red lines are produced by the process suggested by Bates.

Radiation by electronic recombination with oxygen atom ions might be supposed, but the concentrations of the constituents are generally supposed to be too low. If this were the case, the light should be proportional to the number of atoms recombining in unit time and if one is to use the usual expression $dN/dt = aN^2$, where a is presumably a constant the light should be proportional to the square of the number of electrons, rather than to the number. Moreover, the recombination process would result in the excitation of the permitted lines of the oxygen atom and these are not observed.

In any case, if the light is produced in the F region it does not seem possible to ascribe it to a chemiluminescent reaction, unless our present knowledge of distribution of material in the upper atmosphere is grossly in error, a fact well within the pale of possibility.

We are faced with the dilemma in the case of the metastable lines with the long lived states that if the concentrations of molecules and atoms is great enough to permit the reaction, the collisional frequency is so high that collisional de-excitation becomes important. Here of course we are hampered by having no very clear idea of what the concentration of materials in the upper atmosphere is, or of the quantitative effect of collisional frequency upon intensity of the lines.

One must then turn to other types of explanations for the lines. The corpuscular bombardment theory, wherein corpuscular radiation from the sun produces the illumination has been proposed from time to time. It seems unattractive in explanation of the red and green lines in the night glow because it would not be easy for particles with a low enough velocity to arrive at the level of the F region in these latitudes, if the particles were electrons and protons as is generally supposed. Atoms or molecules of the heavier elements such as calcium and sodium could of course do this and the presence of sodium in the night glow may be due in part to this process. The smooth variations of the red lines with time is not of the same sort however, as the dramatic pulsations of the polar aurora, a phenomenon usually assigned, at least in its initial stages to corpuscular bombardment from the sun.

If the light were due to recombination of electrons with ionized atoms, as discussed heretofore, it is interesting to note that there are enough electrons to last during the period of rapid decline, if one electron were used per quantum. The replenishment normally assumed to take place during the night to keep the F region in a state of quasi-equilibrium could furnish enough electrons to permit the light to be generated by recombination for the rest of the night. This replenishment is ordinarily assumed to take place by corpuscular bombardment, or by the falling back into the atmosphere of particles ejected to a great distance during the day.

The Maris-Hulbert theory of the aurora polaris is now thought to be inadequate to explain the polar aurora, because the ejected particles would not have the energy to reach the latitudes of the auroral zone. These particles are presumed to be ejected during the day by kinetic collision, to be ionized in sunlit space and then to fall back into the atmosphere after many hours. Recently Roach had invoked this mechanism to explain the nightglow although no calculations have been carried out to test the theory quantitatively. We do not quite see how the red lines could be explained by this theory, except the portion discussed above, where replenishment of the F region was considered.

One is tempted to look to the presence of the ions which permit the F region to conduct electricity for an explanation of the light. Perhaps the currents which disturb the earth's magnetic field flow in part through the region, and perhaps they are greater here when there are more ions. The conductivity of the F region is not very high however, there being only the order of 10^5 electrons per cubic centimeter and the presumed collisonal frequency of the order of 10^2 to 10^{-1} per second per cubic centimeter.

Perhaps small changes in the earth's magnetic field tend to separate the positive and negative ions and produce an electric potential in this manner, the resultant return of the electrons to the region of the positive charges giving enough current to excite the atoms. In any case a very minute current would produce a considerable voltage gradient.

Lately DR. OLIVER WULF (1945) has proposed, although he has not as yet elaborated it, a new theory. In this scheme, zonal winds in the upper atmosphere, produced by the diurnal meridional heating, drive charges through the earth's magnetic field, producing voltages as they do so. The presence of wind systems in the upper atmosphere is receiving a great deal of attention at present and it appears that there is abundant thermodynamically induced motion of the air molecules to produce the effects described by Dr. Wulf. His theory may go a long way to explanation of the airglow.

At any rate it does not seem possible that the red lines can be explained by a chemi-luminescent reaction of the usual sort and this is an important point. Should later work confirm the identification of the F region with the red nightglow (6300) this will give additional confidence in the heights determined by the Van Rhijn technique.

Returning for a moment to a consideration of the change of intensity with height of the emitting region we should like to point out that in the F region where we think the 6300 light originates, the height changes by several tens of kilometers during the course of the night. Perhaps the extension downward of the line in Figure 34 might be interpreted as indicating the minimum height at which the red lines could be expected to be produced in measurable quantity. The same can not be said of the green lines because it is hard to tell where in the ionosphere they originate. However, it is interesting to note that if they are extended both the lines would meet at the zero brightness line at about 115 kms, near, coincidentally the height of the bottom of the aurora. Perhaps the effect is due to a decrease in density by dilatation of the emitting region when the F region rises. It must be remembered that we have no justification for assuming that the function of brightness versus height is a straight line, or that the evidence is physically valid. However, Dr. Martyn's suggestion also find favor in the observation by KARANDIKAR (1934) made at Poona, India that the nocturnal variation of 5577 shows a nightly minimum rather than a maximum because it appears that the height of maximum ion-density of the F region also passes through a minimum during the night there.

If the electrons in the F region produce the light, and the production is proportional to the ion density, the region emitting the light at λ 6300 must rise and fall with the F region. If not the changes in brightness would be very irregular, because at any one height within the region, the density of electrons changes greatly from a change in height of a few kilometers, if the region has the generally assumed parabolic distribution. Calculations based on this assumption, using the mean values of the six nights in May, June and July, and the following formula to represent the distribution:

$$N_h = N_M \left(1- \frac{hm-h}{T}\right)^{\frac{1}{2}}$$

show that the ion density at the 300 kilometer level can change by a factor of 30 in 3 hours as the result of a change in height from 300 to 359 kilometers, at the center of the region.

If one assumes that the intensity of the red lines is proportional to the electron content, he must explain the seasonal variation in the coefficient of proportionality. This is not easy to do, but one factor comes immediately to mind, the temperature of the F region. In the summer, higher temperatures would increase the collisional frequency and make production of the red lines scantier. A greater number of electrons would be needed to produce a given amount of light. In the winter however, the light production being less influenced by collisional frequency, what electrons there were present would be more than adequate and the brightness variations would then be dependent on what ever other factors enter into the production of the light. Although this is an ad hoc hypothesis it is not unlikely that the ionospheric temperatures are much lower in winter and the theory merits consideration.

There is another facet of the problem which we should consider. ELVEY (1946), CABANNES AND GARRIQUE (1936) and STORMER AND VEGARD (Harang 1951) have noted that the presence of sunlight greatly enhances the brightness of the red lines. The last investigators noted this phenomenon in the aurora polaris. This has been called the twilight enhancement and has been the subject of much conjecture. The number of redline transitions seems so great that

ELVEY AND FARNSWORTH (1942) were tempted to say that the observations indicate a much slower decrease in the number of oxygen atoms with height than previous theoretical considerations had indicated. SWINGS (1951) took them to task on the basis of failure to consider collisional de-excitation and its decrease with height as a mechanism for enhancing the red lines. We should like to suggest that perhaps the effect noted by Elvey and the others was due in part to the large number of ions present during that period as well as to the decrease in de-excitation. It does not seem that we are investigating the twilight enhancement in this paper because during all the hours of observation, the sunlight was striking the atmosphere well about 400 kilometers. The phenomenon remarked upon by Elvey occurred during astronomical twilight. It might be possible to obtain information about collisional de-excitation by comparing the actual light observed during astronomical twilight with that expected upon the basis of density distribution, and possibly also ionization.

PART VI

Discussion

It seems that in treating matters of correlation of the ionosphere and airglow that the best results might be obtained when the two observations were made in the same place. If this were done a smaller amount of the emitting region would be included in the field of view of the instrument and the sampling point would be nearer to that made by the ionosphere apparatus. It seems desirable to install an ionosphere apparatus at Cactus Peak for a year or two in order to finish the comparison which is only just begun in this work.

Correlation of the E region with the nightglow is not possible from such a distance as Cactus to Stanford because the E region at night is a cloudy affair with patches of ionization only a few tens or hundred of kilometers across. The low zenith distance at which they must be observed to see the ionosphere over the ionosphere station precludes any conclusions about a correlation. Then too, if the E region does emit light, the values of correlation with the F region might be altered by the presence of a radiating cloud in the line of sight without it being apparent on the ionosphere data.

Scattered light at great zenith distances generalizes patterns and changes in the night glow. Near the horizon most of the light is scattered from the rest of the sky. In fact at the horizon, according to VAN DE HULST (1951) only scattered light is seen. The effect of this scattered light is to obscure whatever pattern is in the sky and give instead an average value for the light from the whole sky, both in the visible and invisible hemisphere. Thus readings made near the horizon should not change rapidly with time, because the integrating effect of all changes from all parts of the sky will almost tend to render it constant. It might be remarked here that the so-called "snap-shot" isophotes of the night sky and the isophotal maps published to show excitation patterns will sometimes show closed figures within a thousand kilometers of the observing station because of the generalization by scattering at low zenith distances. Hence, any triangulation based on comparison of patches noted at two stations will be confused by this effect.

It would be very useful if the ionospheric stations would regularly report the height of maximum ion density as calculated by the method of Booker and Seaton. In addition to being very useful they are frequently obtainable when the minimum virtual heights are not, and are often more accurate. We should like also to recommend that the stations report the blanketing frequency of sporadic E whenever that is readable. This parameter has more meaning in terms of ion density than the boundary layer reflections which are ordinarily reported and which are no indication of anything except transmitter power and receiver sensitivity. It is possible that this type of reflection lead Bradbury and

Sumerlin to suspect that there was more sporadic E present than there actually was.

MC NISH AND GAUTIER (1949) and subsequently others, have shown that for the tropics, the phase of the moon has a significant effect upon the ion density of the F region. Although this effect is not pronounced late at night, it does hold over to the period of decline in the evening while the layer is recombining. This leads us to suspect that an effect of the phase of the moon might be found in the night glow 6300 radiation. It seems desirable to observe the night glow for a period of several months, whenever the moon is not in the sky. It might even be possible to do so during periods when the moon was up, if the two color technique were used with filters of very narrow bandwidth. Such observations could be confined to the zenith or to the north celestial pole. An extension of the twilight enhancement might appear in the moon lit sky.

PART VII
Conclusion

In concluding one is inclined to skip lightly over statements which had perhaps best be forgotten and to forget to properly qualify all the statements he thinks are worth repeating. Let us hope that the reader will forgive such lapses as occur in this respect. The following conclusions are to be regarded as tentative although they are stated as facts to prevent the obscuration of important points by unnecessary qualification.

1. The 6300-6364 night glow is related to the ionization of the F region of the ionosphere.

2. The intensity is directly proportional to the maximum electron density of the F region.

3. The constant of proportionality is a function of time of year, the ratio of light intensity to electron density being greatest in the winter and least in the summer.

4. The 5577 night glow changes brightness with changes in height of the F region, as predicted by Martyn.

5. It seems that the heights in the vicinity of 200 kms as measured by the Van Rhijn technique for the [OI] radiations are probably more correct than those based upon chemical theory which fall in the 100 km region, although some light may well be produced at this level.

6. Unless our ideas of atmospheric density and composition are in grave error, the light can hardly be produced by the usual sort of chemiluminescent reaction.

7. Although the evidence for cascading from the S to the P to the D state of the metastable oxygen atom is not conclusive, one way or the other, it is possible that an alternative explanation of the nocturnal variation could be made this way.

8. We may expect the green lines to be produced lower in the atmosphere than the red lines.

9. The processes producing the two radiations are different.

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