A NIGHT AIRGLOW STUDY OF THE HYDROXYL (OH) ROTATIONAL-VIBRATIONAL MOLECULAR SPECTRA IN THE (8,3) SEQUENCE AND ITS DIURNAL TEMPERATURE AND INTENSITY VARIATION

by

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A spectrophotometer has been constructed using a tilting interference filter. Counting techniques along with digital means of recording data were used to measure diurnal variations of intensities and temperatures in the (8,3) sequence of the rotational-vibrational molecular spectra of the OH airglow.

Details of the apparatus peculiar to the use of the tilting interference filter are discussed as well as calibration and data reduction procedures. The usual methods used in deriving rotational temperature from the spectral information did not lead to a unique value of temperature for all of the observed lines.

A plot is shown comparing the diurnal variations through the night of the intensity and the rotational temperature.

"Thesis Supervisor: Giorgio Fiocco, Dr. Ing.
Title: Assistant Professor of Geophysics"

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INTRODUCTION

About one-half the light from the sky on a moonless, aurora-less night is due to the airglow (Bates, 1960). The source emitting the most total energy through the spectrum is the hydroxyl molecule (OH) (Meinel, 1950a).

First identification of OH spectral bands in the airglow was made by Meinel (1950a) in communication with Gerhard Herzberg. Similar spectra had been obtained by Dufay at about the same time.

Temperature measurements have been made at various times by Meinel, Wallace, Kvifte, Bates and Nicolet, Krassovsky and numerous others. Almost any paper cited in the list of references at the end of this thesis involves to some degree temperature measurement. Temperature measured are indicative of altitudes of 60-80 KM. The altitude of the emitting layer of OH has been measured by Roache (et al, 1950) from intensity variation with elevation above the horizon as 70 KM. Later measurement by direct rocket flight (Packer, 1961) place 90% of the OH emission between 70 and 105 KM.

Perhaps the most debated in the literature aspect of the OH airglow is the excitation mechanism of the emission. The first suggestion was made by Bates and Nicolet (1950) and Herzberg (1951a) independently.

$$O_3 + H \rightarrow OH^* + O_2 \quad (v \leq 9)$$

This reaction is referred to as the ozone hypothesis. Enough energy is liberated only to populate up to the 9th vibrational level in the OH. This is consistent with the lack of observation of vibrational bands for transitions from the 10th or greater levels to lower levels either in the night airglow or in laboratory sources of OH emission using ozone (O_3) and atomic hydrogen (McKinley et al, 1955).

Krassovsky (1955) raised the following objections:

a. Population of levels ($v \geq 10$) should be depleted before radiating by the reactions:

$$OH^*(v \geq 10) + O_2 \rightarrow O_3^* + H$$

$$OH^*(v \geq 10) + N_2 \rightarrow N_2O^* + H$$

This would be true in the atmosphere and in a laboratory experiment.

b. The number of photons absorbed at 60 KM is one-tenth the number of OH molecules formed at these altitudes. To have enough ozone present above 60 KM vertical mixing from 30 to 60 KM would have to exist.

Krassovsky (1955) then offered the following reaction:

$$O_2^* + H \rightarrow OH^* + O \quad (v \leq 27)$$

This reaction is referred to as the vibrationally excited molecular oxygen hypothesis. The main attraction is that the atomic oxygen (O), which is necessary to form vibrationally excited molecular oxygen (O_2^*), is copiously available above 60KM. Another difference is that according to the Bates and Nicolet's (1950) chemistry of the upper atmosphere the reaction rate of the (O_3) reaction would be maximum at 70 KM or so, but Krassovsky's (1955) (O_2^*) reaction rate would peak at 100 KM or so. Unfortunately measurements of temperature and altitude of the OH emission have been neither accurate nor reliable enough to possitively select the (O_2^*) hypothesis over the (O_3) hypothesis or vice-versa.

Ballif and Venkateswaran (1962) and (1963) respectively have made two observations:

a. Correlation of the diurnal variation of the OH and Na intensities in the airglow reflects the variation of the concentration of ozone at the common level of origin of the OH and Na. (Krassovsky (1963) makes the same statement regarding the (O_2^*) concentration.)

b. The reaction rate for the ozone reaction should show some sort of diurnal variation, the exact type of diurnal variation dependent

> on initial concentration of ozone in the upper atmosphere at twilight. However, the reaction rate for the (O_2^*) reaction should remain essentially constant. They go on to emphasize that since various types of diurnal variations in the OH airglow emission intensity have been noted by various observers (Armstrong, 1955, for example) then the ozone hypothesis of Bates and Nicolet (1950) is probably predominant.

Wallace (1960b and 1961) notes that the temperature's dependence on geographic latitude is similar in both hemispheres. This symmetry about the geographic pole perhaps is an indication that influx of corpusles (symmetric about the geomagnetic pole) plays no important part in the emission mechanism of OH.

A spectrophotometer with digitally recorded output has been constructed using a tilting interference filter. The apparatus scans roughly 7300 to 7400 Å covering the (8,3) sequence (7280 Å band origin) of the rotational-vibrational molecular spectra of OH.

This thesis will report on the diurnal variations in intensity of the (8,3) sequence of the OH airglow and the diurnal variations of the excitation temperature.

DESCRIPTION OF THE APPARATUS

The OH spectrometer gathers light from a region of the night sky and scans a tilting interference filter so that a swept spectrum from 7300 - 7403 Å impinge upon a photomultiplier. The block diagram, Figure 1, shows the overall scheme. Light from an approximately f/4 cone (approximately 1/6 steradian) of the sky illuminates an aperture which is at the focal point of a lens which collimates the light. The nearly parallel rays pass through an interference filter which is mounted on pivots so that as it is tipped, the rays pass through the filter at angles from 0^{o} to approximately 15^{o} from the normal. The light of wavelengths which are transmitted by the filter at a given angle, impinge upon the photocathode of a low-noise photomultiplier tube which is cooled to $-77^{o}C$ for dark current noise reduction.

The output of the photomultiplier is in the form of pulses, each representing one photoelectron emitted by the photocathode. The pulses are amplified by a pulse preamplifier and then counted by a counter. Counts for successive 10 second periods are recorded by a printer which at the same time also records the angular position of the filter. The filter is continuously being swept back and forth angularly by a reversing motor and lead screw.

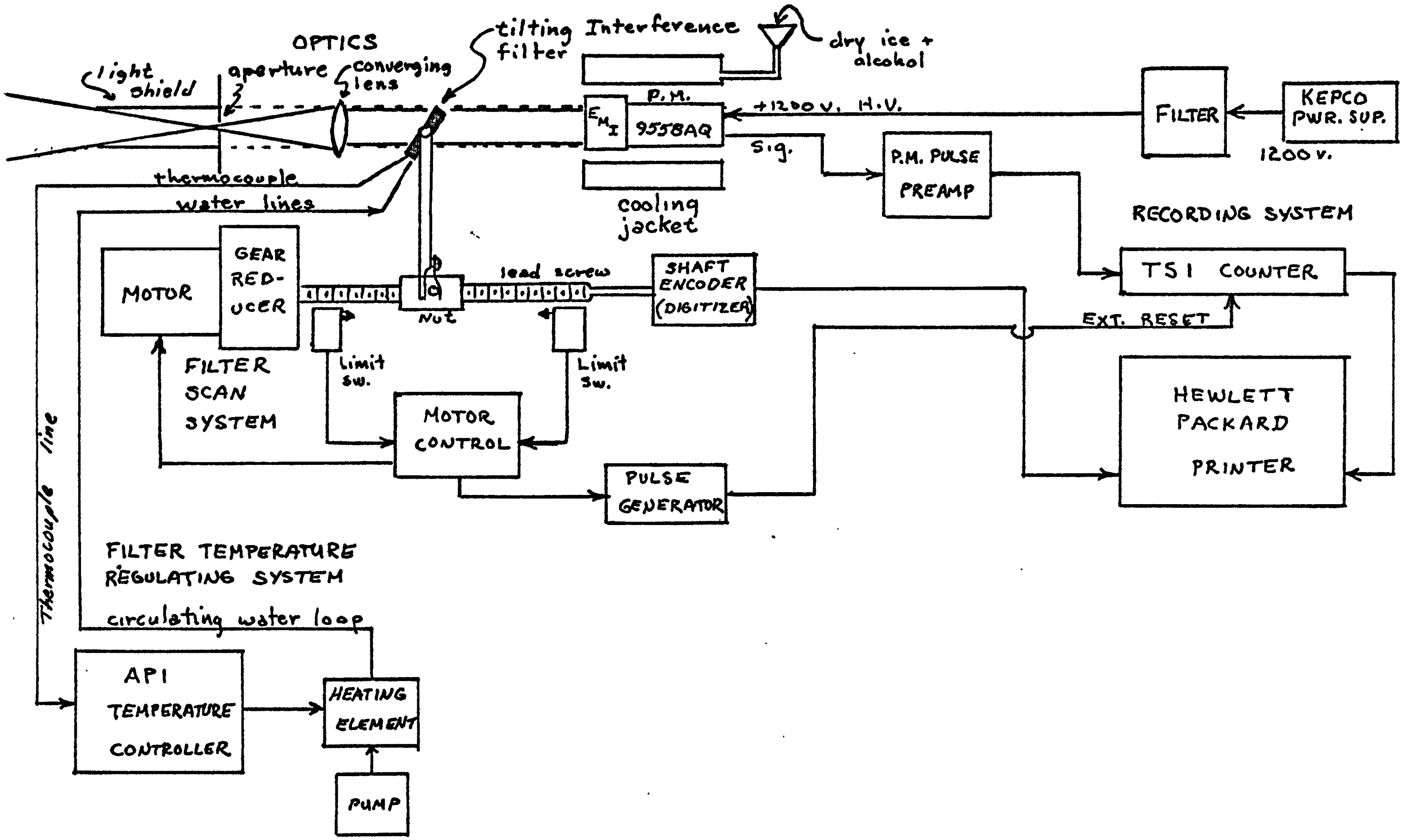


Figure 1 - Block Diagram of OH Spectrometer System

The lead screw is connected to a shaft encoder which supplies digitally coded output to the printer. The temperature of the filter is monitored by a thermocouple and controlled by a circulating water loop with a heating element.

<u>OPTICS</u> The light shield prevents light from sources not within the field of view from illuminating the edges of the aperture where extraneous light could be diffracted or reflected into the aperture. This excludes the light of low, local lights and the more intense man-made sky glow near the horizon. The aperture imposes the constraint that the light passing through the lens must have passed near the focal point of the lens so that the light emanating from the other side of the lens will be nearly parallel.

The aperture is at the focal point of a 170 mm. focal length lens so the rays emanating from the aperture which pass through the lens are parallel to a macimum deviation (from a median) of one-half the total angle subtended by the aperture from the center of the lens. The diameter of the aperture is 3mm.; hence, the maximum departure that a ray may have from being parallel to the axis of system as it passes through the interference filter is one-half a degree.

The light gathering capability of the system is proportional to the area of the aperture, however, the width of the spectral response of the system increases as the rays passing through the filter become less collimated since there is a wavelength dependance on angle. Therefore, it is desirable to use as large an aperture as possible, yet not so large as to broaden the spectral response of the system enough so that adjacent lines in the OH band would not remain separate and distinct when observed.

The interference filter was made by Thin Films, Incorporated of Cambridge, Massachusetts, and nominally has a 2.5 Å wide pass-band at 7400 Å for normal incidence of radiation at room temperature, 25°C. As the filter is tipped, the wavelength of maximum response drops, the bandwidth increases and the transmission drops rapidly necessitating accurate calibration. The above parameters are also strongly dependent on temperature. For example, near normal incidence (approximately 7400 Å) the wavelength of maximum response increases 1 Å for every 4 C°. This characteristic makes temperature control of the filter necessary if accuracy is to be achieved under different ambient conditions as might be expected where the apparatus is used out-of-doors at night and calibrated in-doors. However, this characteristic has been used to advantage in this experiment. The filter is heated to 40°C, extending the wavelength response to 7403 Å making it possible to use the $P_1(5)$ (7401.5 Å) line in the (8,3) band of OH rotational-vibrational emission.

The filter is in a sealed housing which is closed by the lens at the front end and by a window at the rear end which thermally separates the filter housing from the cooled photomultiplier housing. The filter housing is valved to permit flowing a dry gas (compressed nitrogen) through it to flush out moisture. In the present configuration this prevents condensation from forming on the filter side of the window. On the photomultiplier side of the window, condensation does not form since the cooling jacket (described later) becomes very cold before anything else in the photomultiplier housing (also sealed), and, any moisture in the photomultiplier housing condenses on the cooling jacket rather than on the window. The only optical element with a surface exposed to the atmosphere is the front side of the lens, however, the lens is kept slightly above the temperature of the apparatus by the heat lost by the filter temperature control system which operates at 40°C. The temperature of the apparatus is less than the ambient air temperature since the apparatus is operated under open sky and radiational cooling is enough on a clear summer night to cool the apparatus below the dew point of the moisture-laden air. Condensation on optical elements was a problem in developmental designs.

Light which passes through the filter impinges normally upon an EMI 9558AQ photomultiplier. The photomultiplier is surrounded by a cooling jacket through which alcohol, from dewars containing a mixture of dry ice and alcohol, is poured every 20 to 30 minutes. Large amounts of CO_2 are soluble in ethyl or methyl alcohol at temperatures between -77^oC (sublimation temperature of CO_2) and -56^oC. The heat of mixing is quite high with the net effect in this application that the alcohol (with CO_2 absorbed in it) when undergoing heating appears to have a very high specific heat between -77^oC and -56^oC since most of the heat which is added to the alcohol serves to drive off CO_2 rather than increase the temperature of the mixture. The photomultiplier, the cooling jacket, and the dynode resistor chain (See Figure 2.) are enclosed in a thermally insulated housing with a window and shutter. The shutter is protection for the photomultiplier against high light levels during periods when observing is not taking place. In order to achieve a dark current of 35 photoelectrons or less per second, the photomultiplier must be kept in the dark or under low light level conditions with high voltage applied to the tube for several weeks.

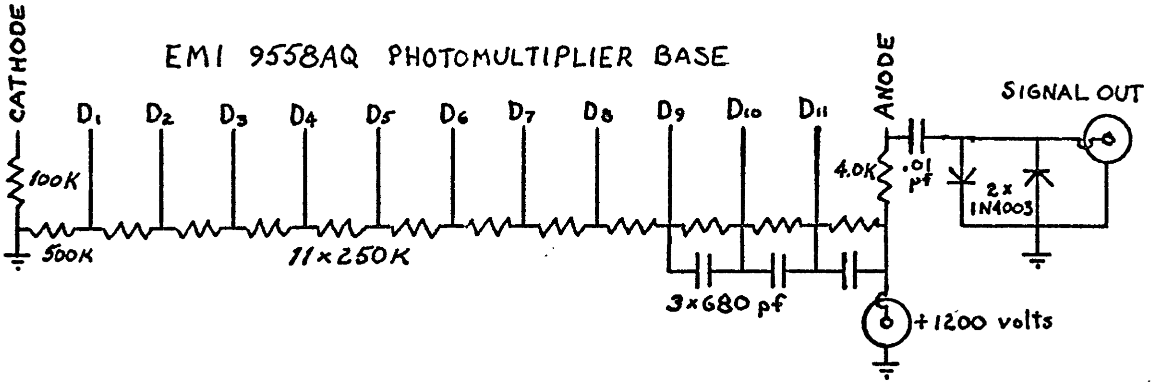


Figure 2 - Photomultiplier Wiring

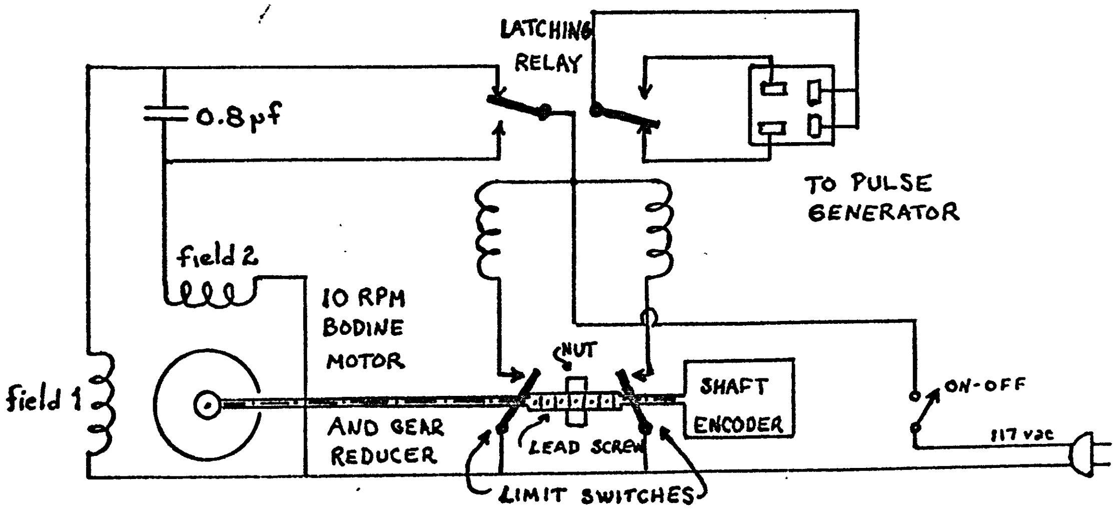


Figure 3 - Motor Control

FILTER TILTING MECHANISM An arm is mounted on the same shaft as the filter. The arm rests on a nut which moves along a lead screw (micrometer thread of 40 threads/inch) which in turn is driven by a 10 rpm Bodine motor through a gear reducer with ratios of 1:1, 2:1, 5:1, 10:1, 20:1, 50:1 available. The 2:1 position was used almost exclusively giving a shaft speed of 5 rpm. The range of 7300 Å to 7403 Å in this position was covered in 11 minutes; Thus, the rate of scan was fast compared to changes in background light. Adjustable position limit switches sense extreme displacement of the nut on the lead screw and reverse the motor driving the lead screw. (See Figure 3.)

At the moment the motor is reversed, a signal is sent via a pulse generator (Figure 4) to the counter. The pulse resets the counter to zero and starts the time base at the beginning of a new 10 second interval. This gives recorded output at similar positions of the lead screw for successive scans in the same direction. The position of the lead screw is digitized by a Chicago Dynamic Industries three section thumbwheel switch with two Geneva movements between the sections. The first section is directly connected to the shaft of the lead screw; Thus, the digits of the thumbwheel switches represent the posi-

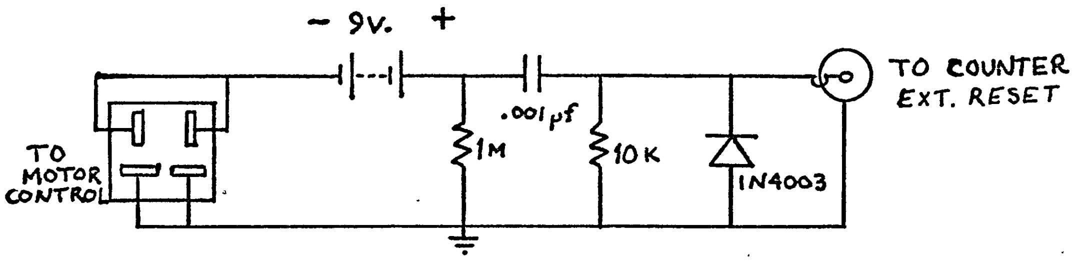
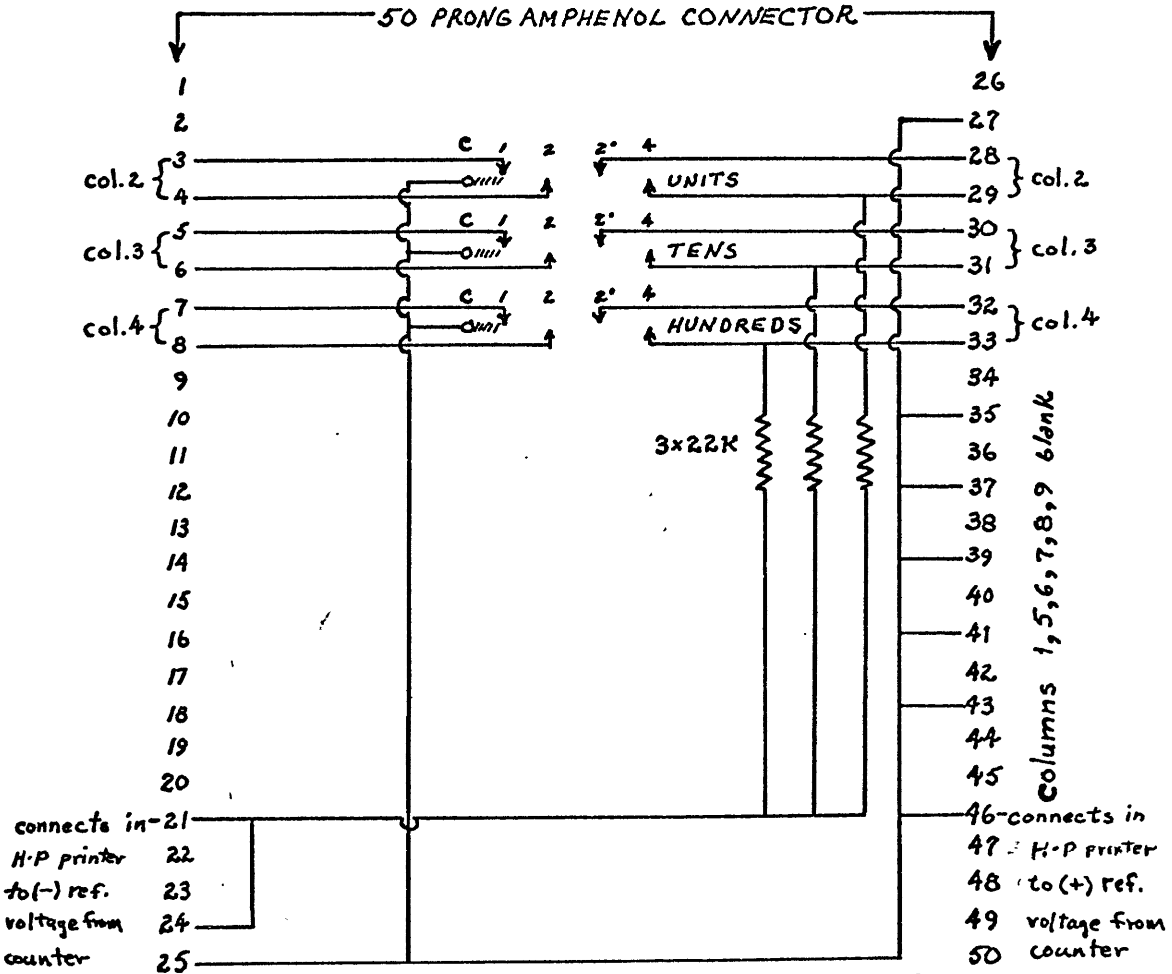


Figure 4 - Pulse Generator



column numbers referred to above apply only to numbers on board connectors in H-P printer. The board that a given connector is plugged to is arbitrary

Figure 5 - Shaft Encoder (Digitizer) Wiring

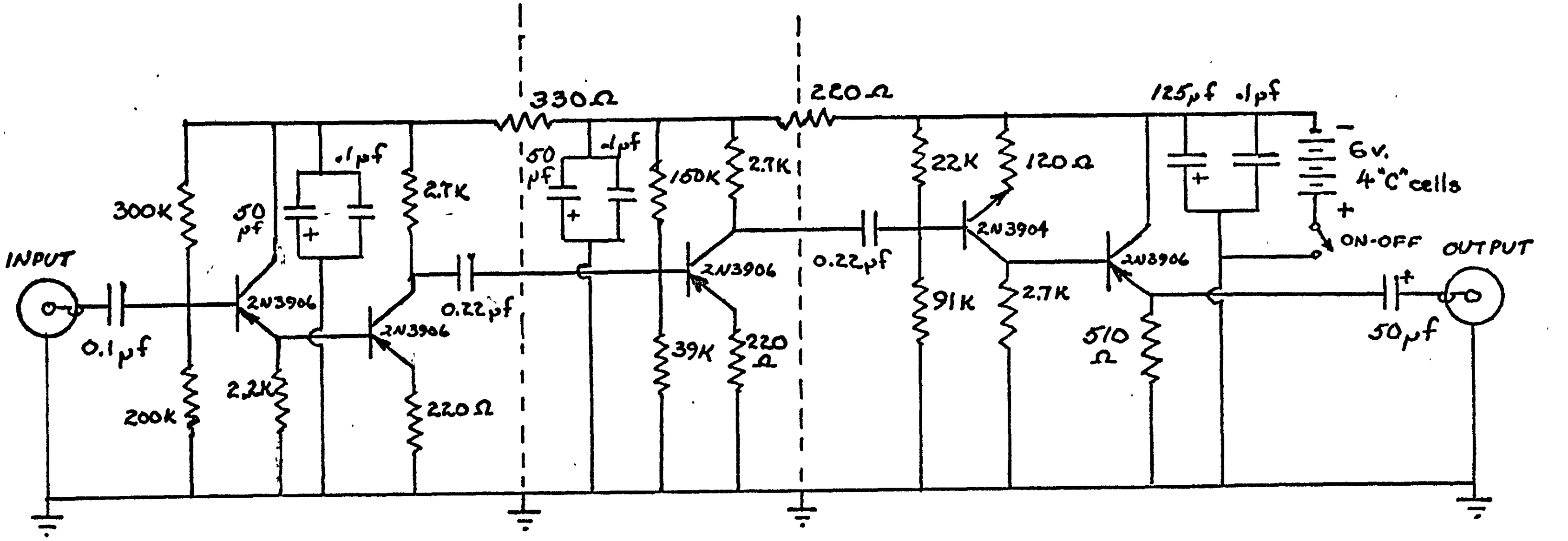
tion of the leadscrew in 1/10 turns from 0 to 99.9 turns. The switches are designed for a 1-2-2-4 BCD output code. (See Figure 5.) Power to enable the switches to supply voltage levels to drive the printer are supplied by the Transistor Specialities counter through an interconnection in the Hewlett-Packard printer.

RECORDING APPARATUS The photomultiplier is operated at 1200 volts which is recommended by EMI as the optimum voltage for the best signal to noise ratio. Independent tests showed the signal to noise ratio at very low light levels where the signal is comparable to the dark current (cooled) to be relatively independent of voltage over the range of 1200 to 2000 volts. 1200 volts therefore, was picked as safest for the tube and least demanding for actual current from the tube. Due to the fact that a counting scheme is used, the actual current is not important as long as discrete pulses can be counted. The average pulse rate is a function only of the quantum efficiency of the photocathode which is affected only slightly by the cathode - first dynode voltage drop. The 1200 volts is supplied by a Kepco 0-2500 volt, 2 ma. variable power supply. Further filtering by an additional filter is necessary to prevent transients generated in the power supply from being counted.

The output of the photomultiplier, taken at the anode load resistor, is amplified by a pulse preamplifier designed for low noise, high gain, high frequency response (1μs impulse response), and compact size (to permit connection very close to photomultiplier housing). (See figure 6.)

The output of the preamplifier drives a Transistor Specialties Incorporated (TSI) Counter, model 385R. The counter is set to count for a 10 second period, command the printer to print what the counter has just counted as well as what the position of the lead screw is, and wait for a dead period of 0.25 second until it starts counting again. This normal action of the counter is overidden by the external reset when the motor driving the lead screw reverses as previously mentioned. The printer is a Hewlett-Packard 562A printing on paper strip. (See Figure 10.)

FILTER TEMPERATURE CONTROL The filter temperature is measured by a Chromel-Constantan thermocouple in direct thermal contact with the filter. The thermocouple is connected by a Chromel-Constantan extension cord to a model 712 API Instruments Company time-proportioning temperature controller. The controller, besides indicating the temperature on a meter, controls a 450 watt heating element in a closed circulating loop of water driven by a small



GAIN	~ -1000X
FREQ. RESPONSE	100cps - 1 MC/S
INPUT IMPEDANCE	~ 100 K
OUTPUT DRIVE	93Ω
CURRENT DRAIN	~ 10 MA
MAX. OUTPUT	~ 1 v. p.-p.

Figure 6 - Photomultiplier Pulse Pre-Amplifier

pump and connected by hoses to a water passage on the filter holder. (See Figure 7.) The temperature is regulated at $40^{\circ}C \pm 1C^{\circ}$.

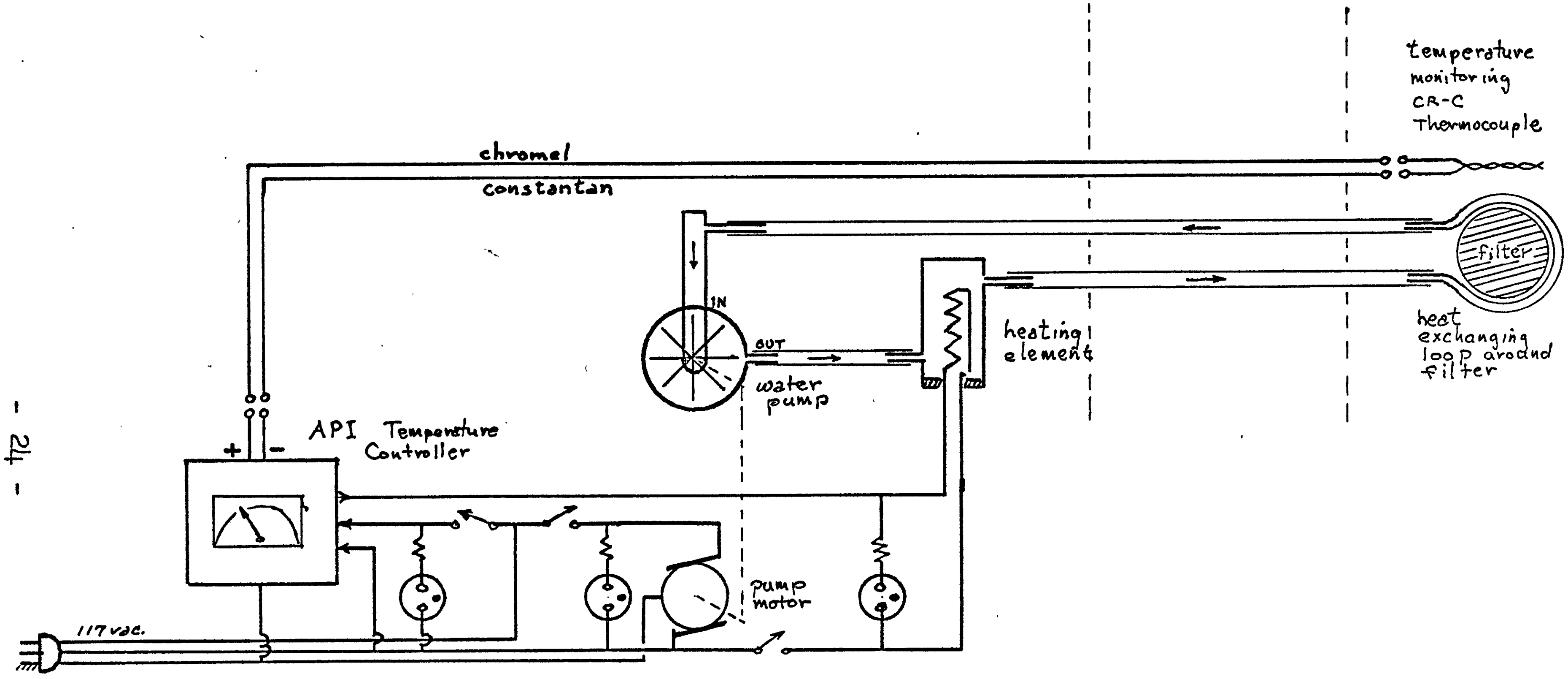


Figure 7 - Filter Temperature Control System

CALIBRATION PROCEDURE

The OH spectrometer must be calibrated in three respects. First, the wavelength of maximum response versus the digitally indicated position of the lead screw must be known to permit identification of the OH lines. Second, the relative amplitude of the response versus wavelength must be known to measure the true intensities of the OH lines. Third, the relative area under the response curve versus wavelength must be known to estimate the gradient in the recorded signal due to continuous (non-spectral) sky background from man-made sky glow, moon illumination of clouds and haze, zodiacal light, and star light.

The first two of the above calibrations are best done simultaneously. A Jarrell-Ash 1 meter grating spectrometer with the slits adjusted for a 1 Å 1/2 amplitude width of the slit function was used as a monochrometer between the OH spectrometer and a General Electric Quartz-Iodine lamp. The color temperature of the lamp was measured with a Leeds and Northrop optical pyrometer. With this particular lamp, a current of 6 amperes produced a color temperature of 2500°C (2800°K).

To a linear approximation the intensity of the quartz-iodine lamp increases 2.5% total as the wavelength observed is swept from 7300 to 7400 Å. The efficiency of the grating spectrometer is assumed constant over the range of 7300 to 7403 Å.

The exit slit of the Jarrell-Ash grating spectrometer illuminates a thin diffusing plastic sheet which in turn is looked upon by the OH spectrometer. The diffusing sheet fills the field of view of the OH spectrometer thus appearing as a spacially broad source as does the sky. The Jarrel-Ash grating spectrometer is set to various wavelengths in the 7300 to 7403 Å region and the OH spectrometer is allowed to sweep, tracing out, numerically, on the printer output, the response curve of the OH spectrometer at that wavelength. From this data, the lead screw position and relative amplitude of the response may be accurately determined at that wavelength.

Absolute wavelength calibration, realizing that significant linear error in the Jarrell-Ash grating spectrometer wavelength indicator exists, is provided by looking at an Argon line from a glow discharge tube at 7383.88 Å.

The third calibration can most accurately be done simply by looking at a source of known color temperature with the OH spectrometer and scanning from 7300 to 7403 Å. After corrections for the varying of the intensity of the source with wavelength, the measured number of counts, in a given time interval, will be proportional to the area under the response curve at the average position of the lead screw during that time interval. However, it has been determined that the response integrated over wavelength ("area" response) is very nearly constant with respect to position of the filter and considering that on a clear night the spectrally continuous background accounts for no more than 20% of the counts recorded at the peaks of the OH spectrum; no correction by this calibration is used in the calculations to derive temperature from the spectral information. Figures 8, 9 and 10, respectively, represent the wavelength, amplitude response and "area" response calibration of the OH spectrometer.

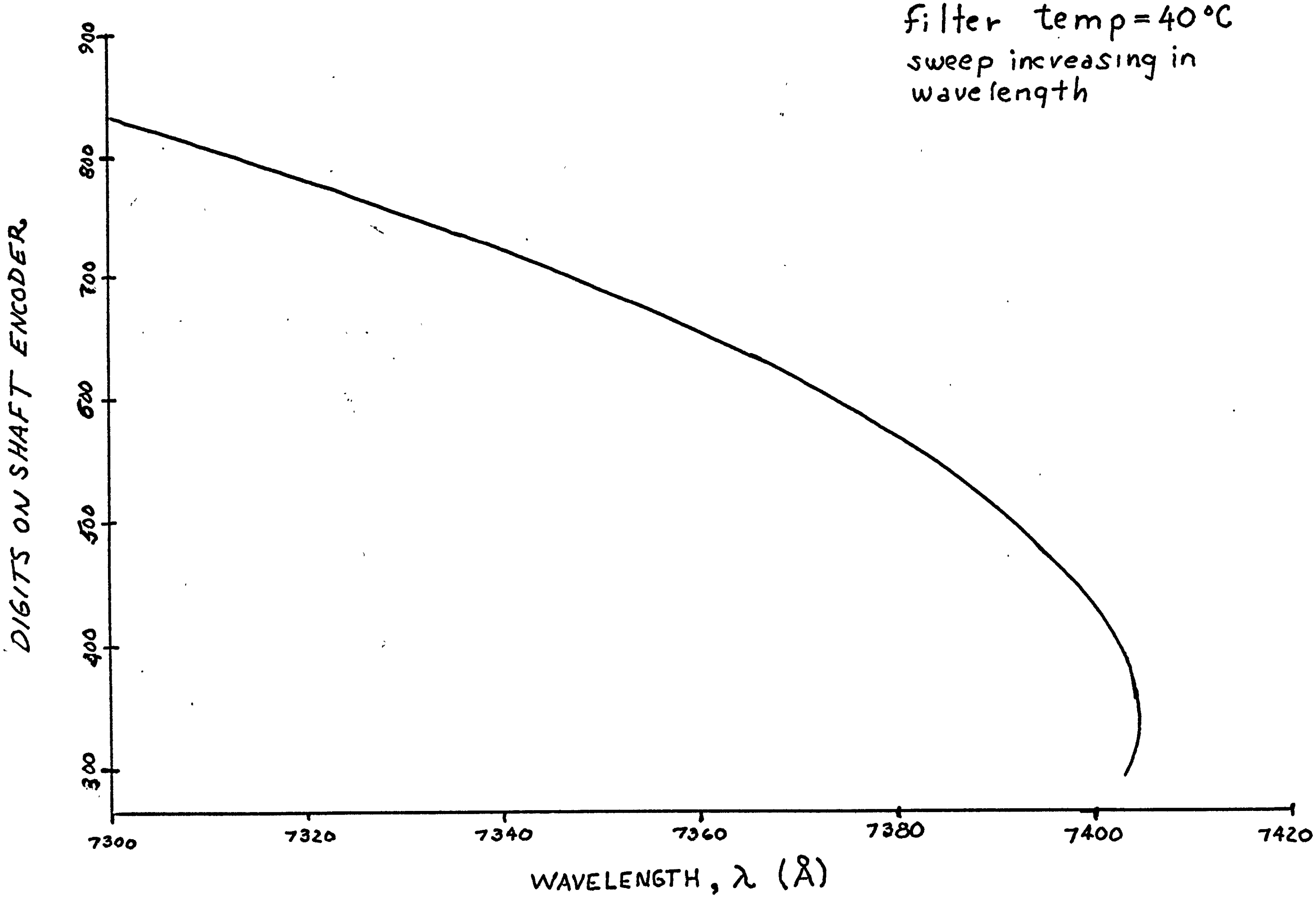
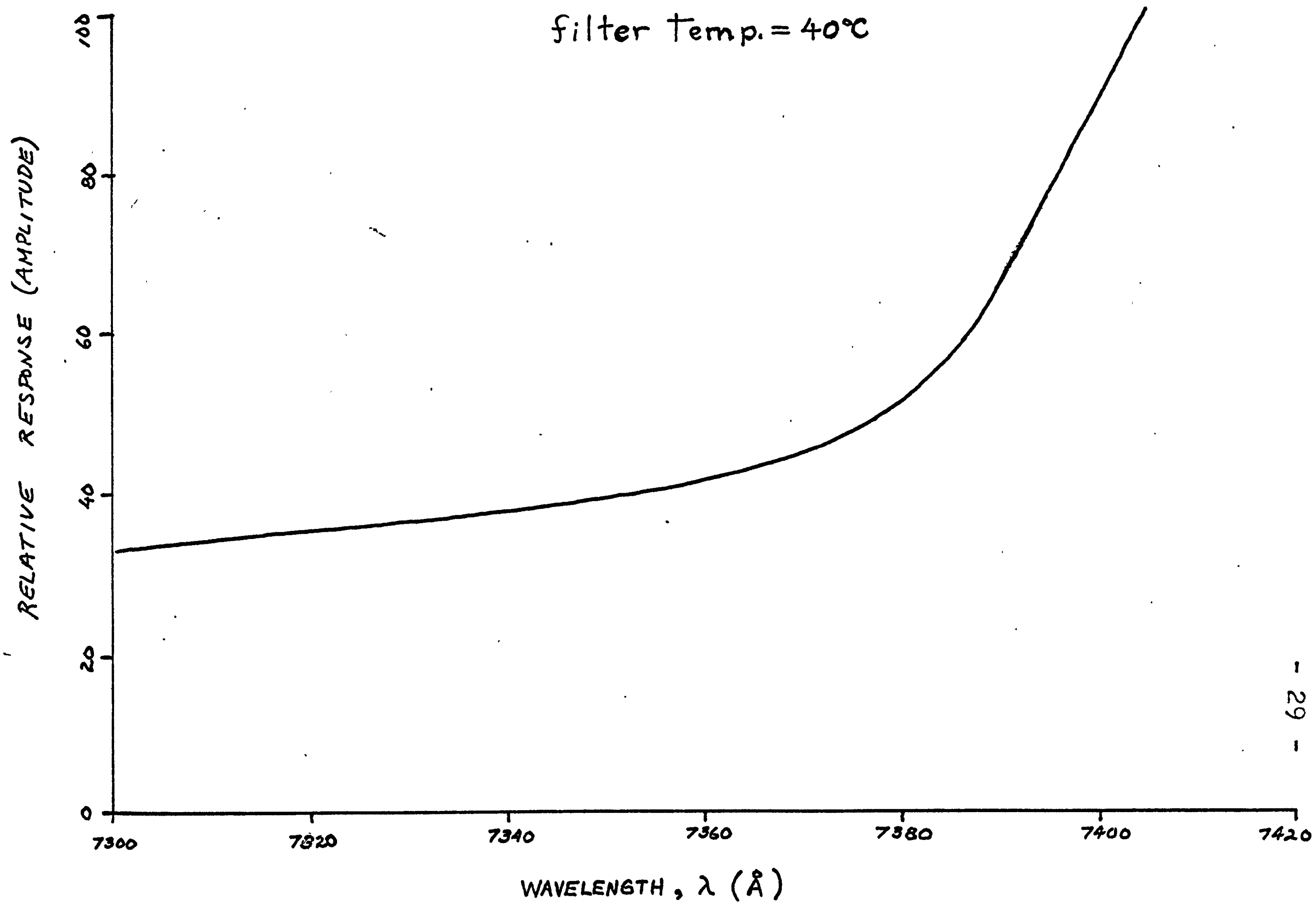


Figure 8 - OH Spectrometer Wavelength Calibration

Figure 9 - OH Spectrometer Relative Amplitude Response Calibration



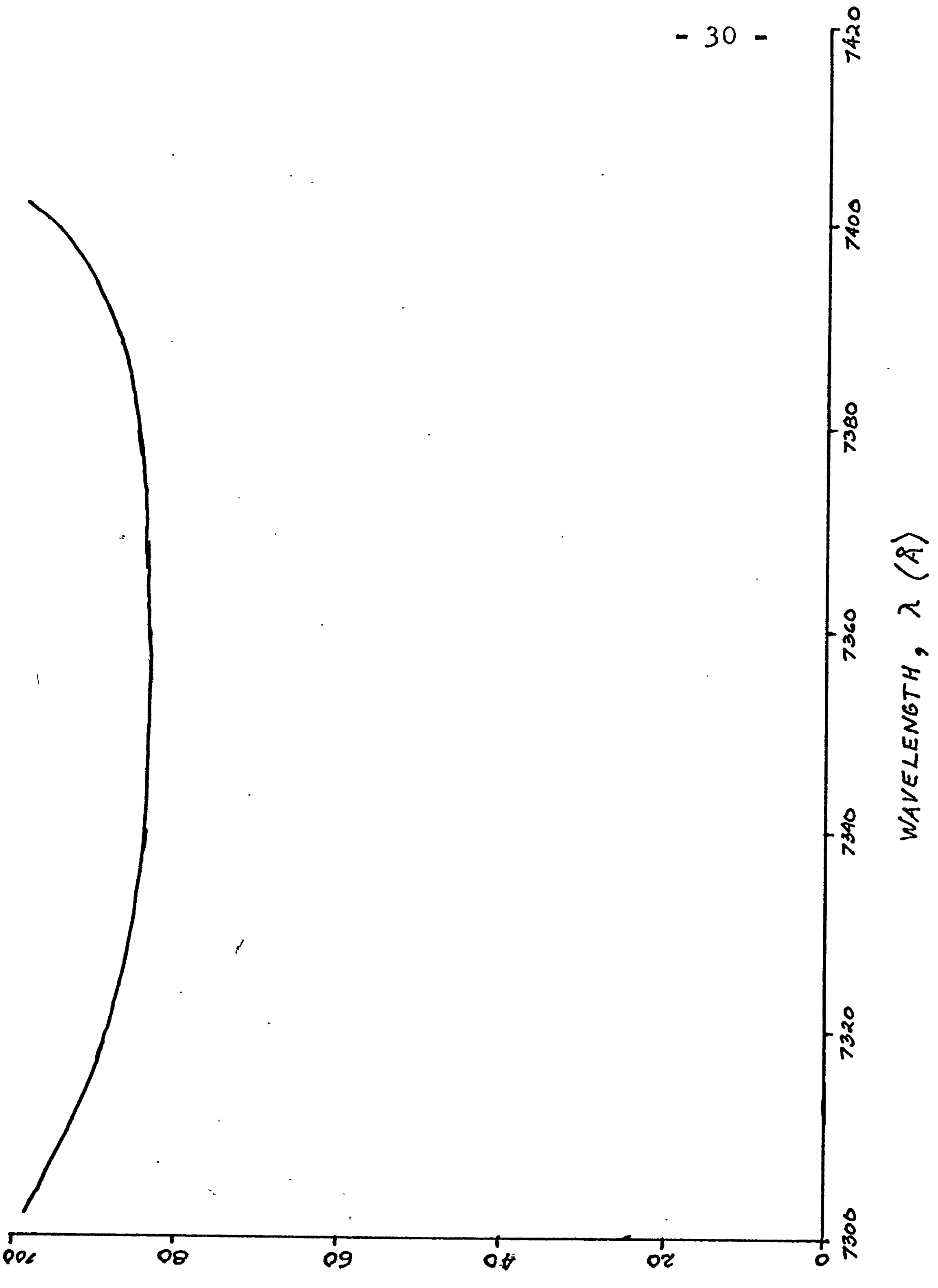


Figure 10 - OH Spectrometer Relative
"Area" Response Calibration

EXPERIMENTAL PROCEDURE

All of the data was taken in August, 1967, in Chelmsford, Massachusetts which is far enough away from cities for man-made sky background to be negligible. Most of the sky background was due to moon light scattering from haze or clouds and the Milky Way. The OH Spectrometer was aimed about 15° north of zenith since in general the haze and man-made light was more prevalent to the south. This choice of observation direction was not optimum, however, for avoiding having the Milky Way in the field of view at some time during the night.

Without doubt there would be two-fold advantage to operating this experiment in the winter months rather than the summer; first, the sky is generally clearer, and second, the Milky Way would not be directly overhead during the night.

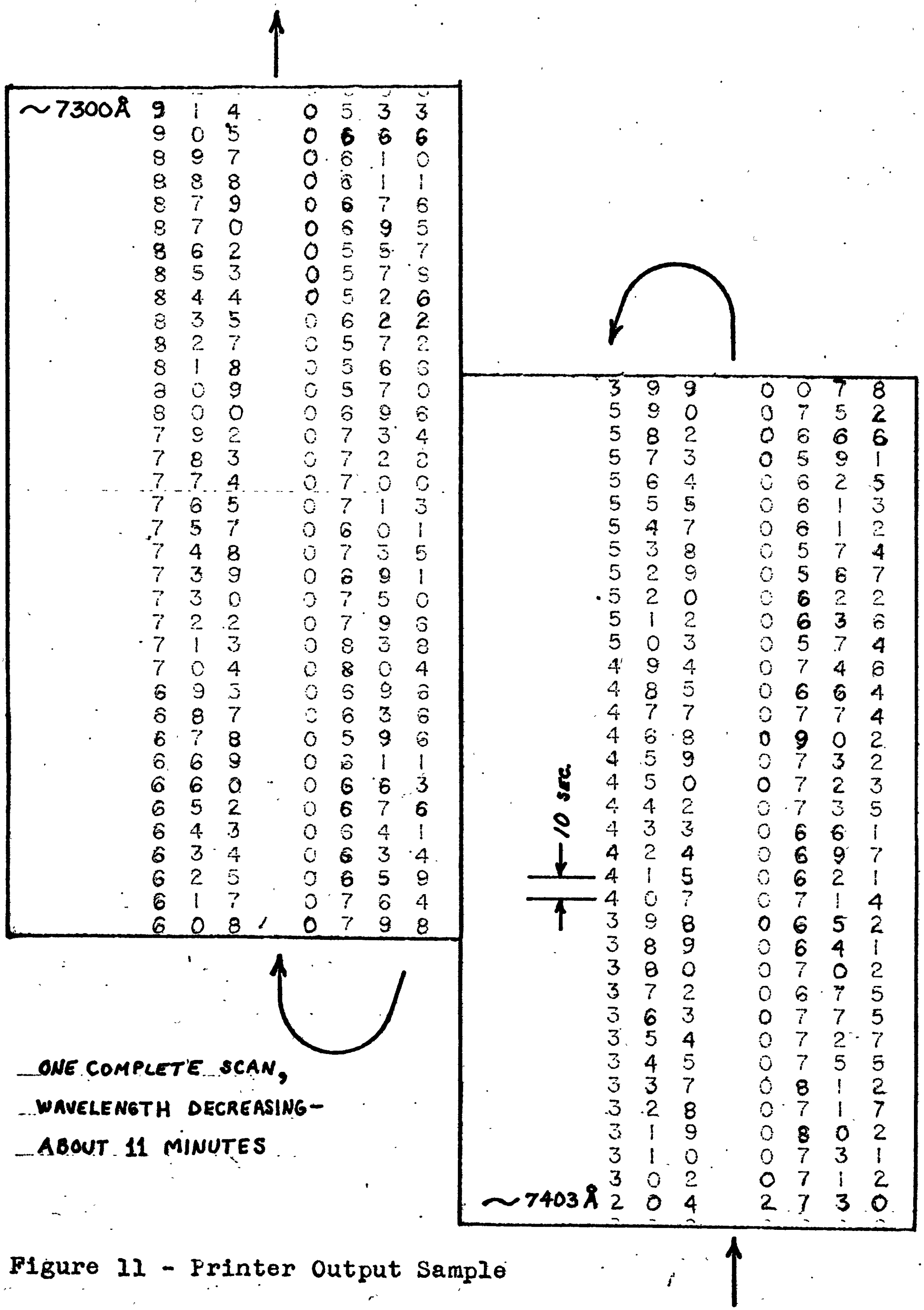
DATA REDUCTION PROCEDURE

Each night's observation resulted in approximately 2000 sets of data. Each set is three digits representing the position of the filter and three digits of the photoelectron counts for a 10 second period. (See sample - Figure 11.) The intended result of one night's data (2000 sets of data) is six measurements of temperature, about one per hour.

Figure 12 shows the average count per 10 second period versus filter position of six sweeps (three in each direction) from 7300 Å to 7403 Å. This represents about one hour and seven minutes of data taking.

All of the data was punched on IBM cards (three sets per card) and the program in Appendix I was used to average the counts from six sets of data and then plot it as above. Another program (Appendix II) was used to average and plot larger groups of data, for example, from one or two nights. A plot of data representing nine hours altogether, from two nights, is shown in Figure 13.

With the high signal to noise ratio inherent in this plot, the expected positions of the peaks agree very well with the plotted positions.



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9 0 5   0 6 6 6
8 9 7   0 6 1 0
8 8 8   0 6 1 1
8 7 9   0 6 7 6
8 7 0   0 6 9 5
8 6 2   0 5 5 7
8 5 3   0 5 7 9
8 4 4   0 5 2 6
8 3 5   0 6 2 2
8 2 7   0 5 7 2
8 1 8   0 5 6 6
8 0 9   0 5 7 0
8 0 0   0 6 9 6
7 9 2   0 7 3 4
7 8 3   0 7 2 8
7 7 4   0 7 0 0
7 6 5   0 7 1 3
7 5 7   0 6 0 1
7 4 8   0 7 3 5
7 3 9   0 6 9 1
7 3 0   0 7 5 0
7 2 2   0 7 9 6
7 1 3   0 8 3 8
7 0 4   0 8 0 4
6 9 3   0 6 9 6
6 8 7   0 6 3 6
6 7 8   0 5 9 6
6 6 9   0 6 1 1
6 6 0   0 6 6 3
6 5 2   0 6 7 6
6 4 3   0 6 4 1
6 3 4   0 6 3 4
6 2 5   0 6 5 9
6 1 7   0 7 6 4
6 0 8   0 7 9 8
```

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3 9 9   0 0 7 8
5 9 0   0 7 5 2
5 8 2   0 6 6 6
5 7 3   0 5 9 1
5 6 4   0 6 2 5
5 5 5   0 6 1 3
5 4 7   0 6 1 2
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5 2 9   0 5 6 7
5 2 0   0 6 2 2
5 1 2   0 6 3 6
5 0 3   0 5 7 4
4 9 4   0 7 4 6
4 8 5   0 6 6 4
4 7 7   0 7 7 4
4 6 8   0 9 0 2
4 5 9   0 7 3 2
4 5 0   0 7 2 3
4 4 2   0 7 3 5
4 3 3   0 6 6 1
4 2 4   0 6 9 7
4 1 5   0 6 2 1
4 0 7   0 7 1 4
3 9 8   0 6 5 2
3 8 9   0 6 4 1
3 8 0   0 7 0 2
3 7 2   0 6 7 5
3 6 3   0 7 7 5
3 5 4   0 7 2 7
3 4 5   0 7 5 5
3 3 7   0 8 1 2
3 2 8   0 7 1 7
3 1 9   0 8 0 2
3 1 0   0 7 3 1
3 0 2   0 7 1 2
2 0 4   2 7 3 0
```

ONE COMPLETE SCAN,
WAVELENGTH DECREASING-
ABOUT 11 MINUTES

Figure 11 - Printer Output Sample

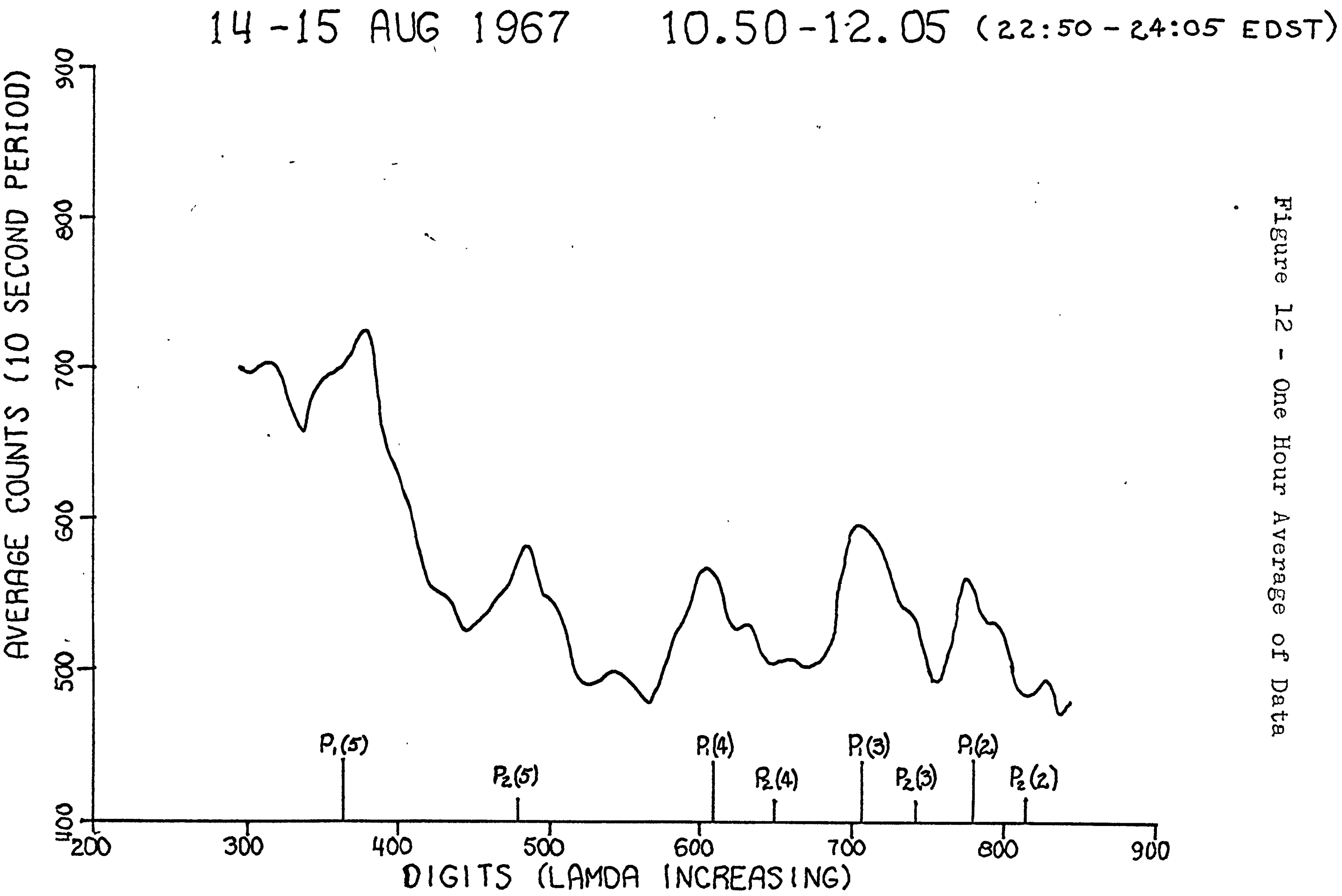

Figure 12 - One Hour Average of Data

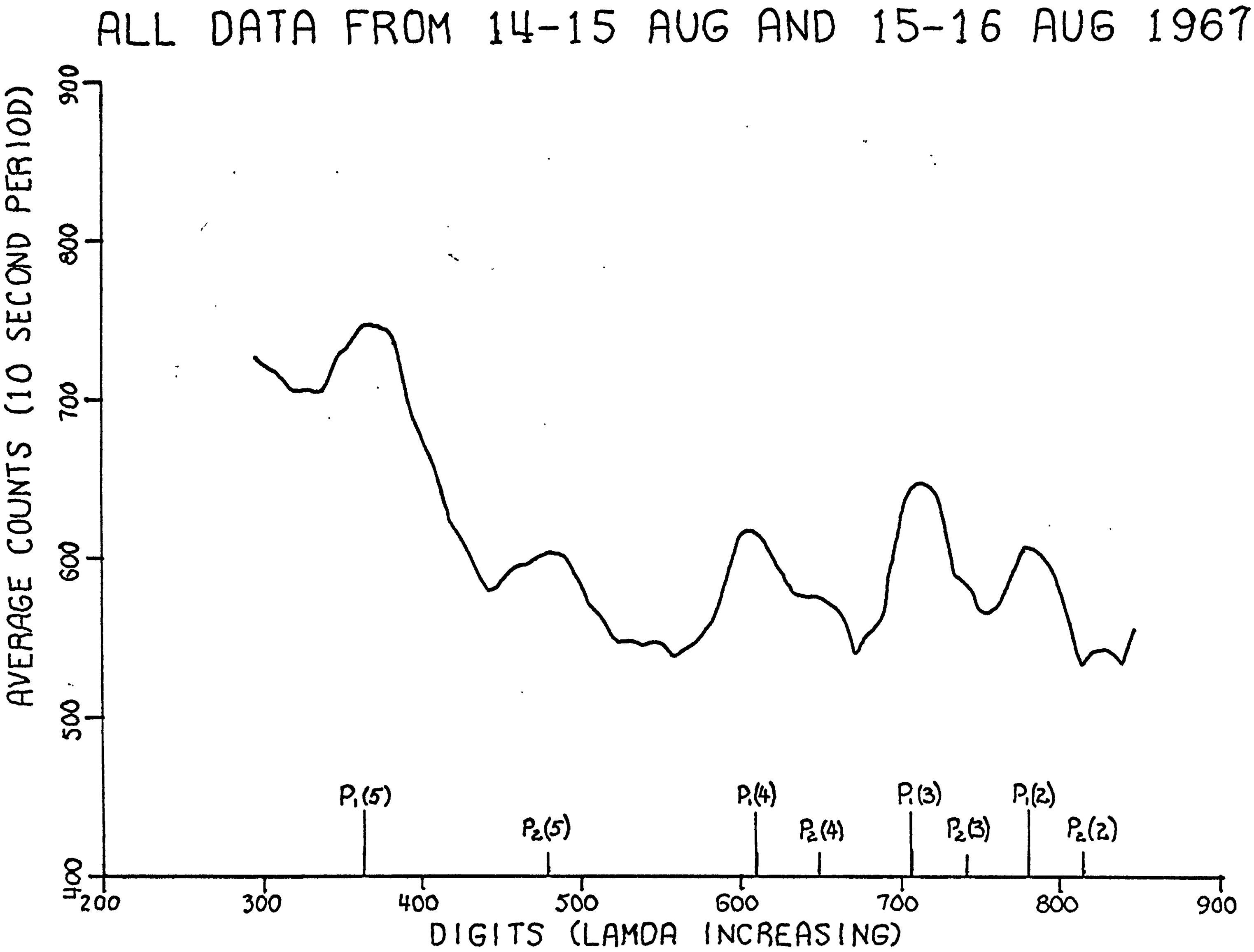

Figure 13 - Nine Hour Average of Data

MOLECULAR SPECTRA

The spectral lines being observed here represent the different rotational transitions (of one rotational quantum number, J; $\Delta J = 1$) which occur during the transition from the eighth to third vibrational level (8,3). Figure 14 shows the energy level diagram.

The band of all P_1 branch and P_2 branch rotational spectra occuring with vibrational transition (8,3) is located within the range of 7300 Å to 7403 Å. (See Table 1.)

A band such as this is sometimes identified by the band origin, the wavelength of the transition from the upper to lower vibrational level with no rotational transition occurring which in the case of the OH molecule is an imaginary concept. The band origin of the (8,3) band is 7280 Å, approximately.

This band is one of the weaker rotational-vibrational bands of the OH molecule and the eighth vibrational level is the least populated vibrational level (Heaps and Herzberg, 1952). However, the lack of suitable photocathode surfaces necessary to implement a spectrophotometer with reasonable quantum efficiency at longer wavelengths where more intense bands lie and the availability of the interference filter used in this experiment limited

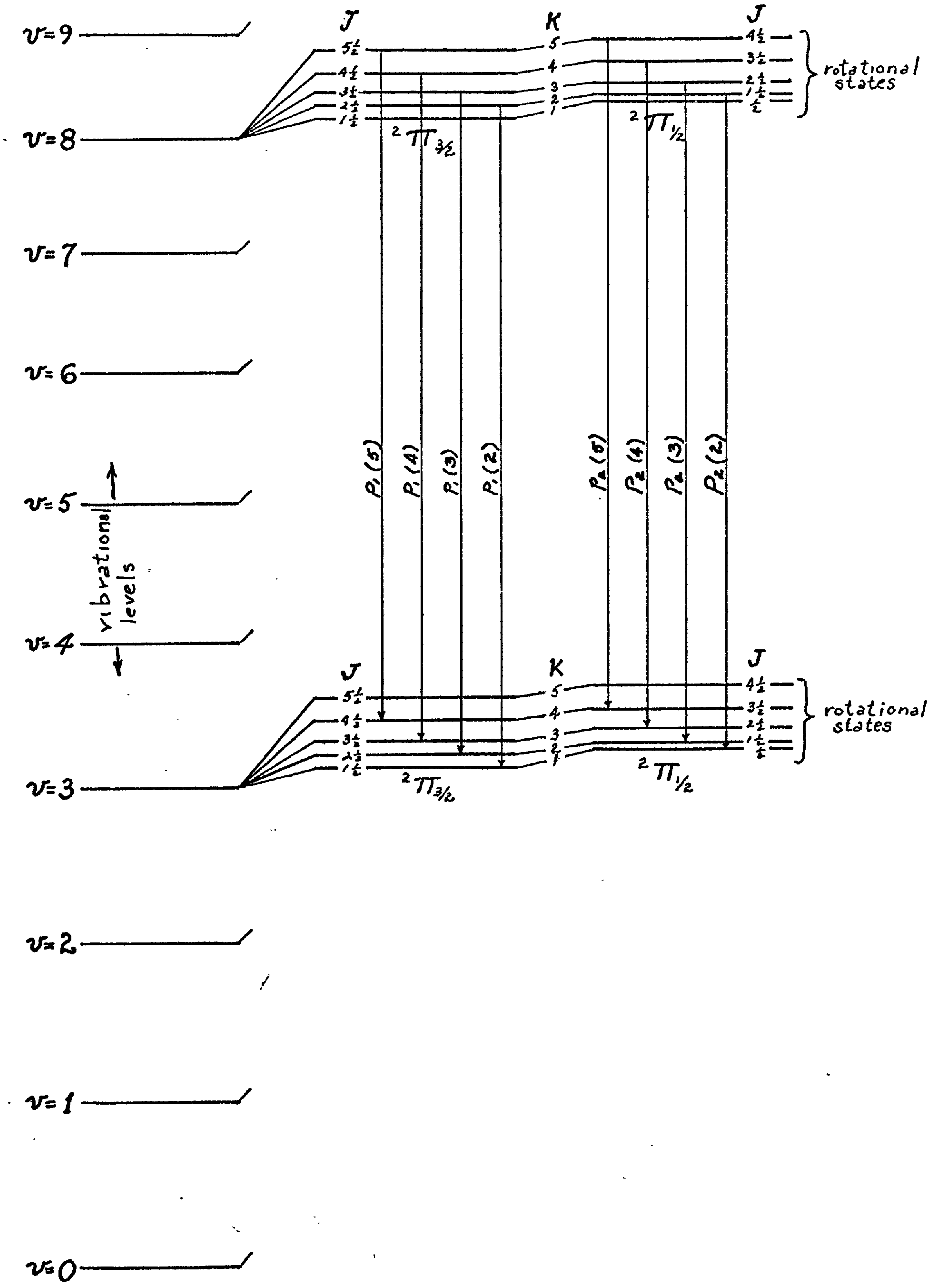

Figure 14
Energy Level Diagram for the (8,3) Sequence
Vibrational-rotational States of the OH Molecule

TABLE I

Wavelengths of the P_1 and P_2 Branches of the (8,3) Sequence of the Rotational-Vibrational Spectra of the OH Molecule in its Ground States

P_1 Branch		P_2 Branch	
$P_1(2)$	7316.5 Å	$P_2(2)$	7304.0 Å
$P_1(3)$	7341.5 Å	$P_2(3)$	7330.0 Å
$P_1(4)$	7368.0 Å	$P_2(4)$	7358.5 Å
$P_1(5)$	7401.5 Å	$P_2(5)$	7391.5 Å

the choice of vibrational bands to the (8,3) sequence.

TEMPERATURE The transitions between thermally populated states are known to have their number frequency distributed exponentially with energy. Assuming thermal equilibrium, the intensity, I(J), of a rotational line, relative to other rotational lines in the same branch of a given band, is given by:

$$I(J) = C\ \nu_J^4\ s_J\ \exp\left\{-F(J)hc/kT\right\}$$

where ν_J is the wavenumber of the line, s_J is the line strength, and F(J) is the rotational term value of the upper level with the rotational quantum number J. F(J) is approximated by BJ(J+1), where B is the rotational constant. s_J is given by (Hönl and London, 1925):

$$s_J = \begin{cases} \dfrac{(J+1)^2 - 9/4}{J+1} & ,\ P_1 \text{ Branch} \\ \dfrac{(J+1)^2 - 1/4}{J+1} & ,\ P_2 \text{ Branch} \end{cases}$$

The general approach to determining T, the rotational temperature, from the above formulae, knowing the relative distribution of I(J), the intensity of lines of the various rotational states, is to plot $\log_e\left\{I(J)/\nu_J^4\ s_J\right\}$ versus J(J+1) which results in a straight line if thermal equilibrium exists. The temperature is then:

$$T = \frac{Bhc}{k\alpha} = \frac{17.253}{\alpha}$$

where α is the negative slope of the line.

This plot of $\log_e\left\{I(J)/\nu_J^4\, s_J\right\}$ versus $J(J+1)$ was made hourly for a total of 13 hours over 3 nights for intensities in the P_1 branch, for a total of 9 hours of data from 2 nights for intensities in the P_1 and P_2 branch and for a total of 6 hours of data from a different night in the P_1 branch. The P_1 branch is about 3 to 4 times more intense than the P_2 branch; therefore, measurement of intensities in the P_2 branch were possible only with large amounts of data to increase the signal to noise ratio to a reasonable value.

DISCUSSION OF RESULTS

Shown in Figure 15 is a plot of $\log_e \{I(J)/\nu_J^4 s_J\}$ versus J(J+1) for a total of nine hours of data from 14-15 August and 15-16 August 1967. As was mentioned in regard to Figure 13, the data from which the plot was made, the noise here is almost negligible. It will be noticed, however, that the points do not fall on a straight line. Another set of points representing a total of six hours of data from 10-11 August 1967 is shown also in Figure 14 and results in a plot in which the points are distributed about a straight line in a similar manner to the first plot. These plots make the attempted fitting of a straight line meaningless. Three possible explanations of this anomalous behaviour are possible:

1. Assuming thermal equilibrium exists, there must be an error in the functional dependence of s_J or F(J) on J. A change in F(J) would have the effect of expanding and contracting different parts of the abcissa, J(J+1), of the above plot. There is no way this kind of change could reasonably effect the fitting of the four points to a straight line. To fit the points by altering s_J would require fourth order corrections to the approximation for s_J of 25% at some points; however, the approximation used for s_J (Hönl and London,

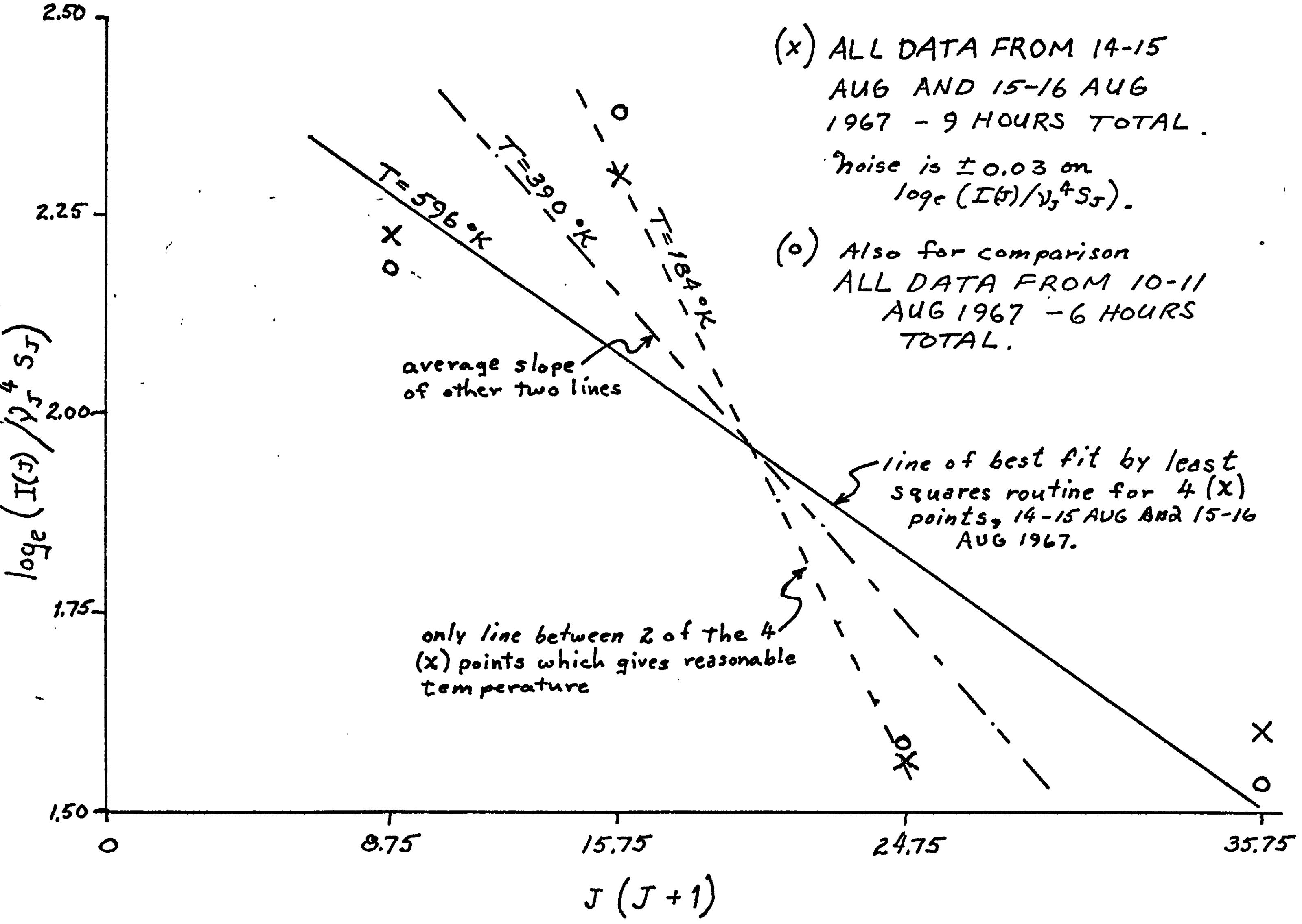

Figure 15. - $\log_e\left\{I(J)/\nu_J^4 s_J\right\}$ versus J(J+1) Assuming Thermal Equilibrium

1925), the line strength or transition probability, has been known to work very reliably in other OH bands, (Meinel, 1950b). It is unlikely that s_J or F(J) are in significant error and very large or impossible changes in them would be required to fit the points to a straight line.

2. Assuming the expressions for s_J and F(J) are adequately approximated by:

$$s_J = \begin{cases} \dfrac{(J+1)^2 - 9/4}{J+1} & , F_1 \text{ Branch} \\ \dfrac{(J+1)^2 - 1/4}{J+1} & , F_2 \text{ Branch} \end{cases}$$

and:

$$F(J) = BJ(J+1).$$

then thermal equilibrium among the rotational levels must not exist in the eighth vibrational level, but this is difficult to accept since lower vibrational levels have been found to be approximately thermally populated (Meinel, 1950b).

3. Assuming the commonly used approximations for s_J and F(J) and thermal equilibrium, another way to explain the data is some hitherto un-noticed atmospheric absorption in this region, perhaps due to some other molecular resonance phenomena.

DIURNAL VARIATIONS An attempt has been made to assign temperatures to hourly sets of data for the purpose of studying diurnal variations of the temperature. The only line connecting any two of the four points in the $\log_e \{I(J)/\nu_J^4 s_J\}$ versus $J(J+1)$ plots which has a slope corresponding to a temperature similar to that measured by others is the line connecting the $P_1(3)$ and $P_1(4)$ points. In Figure 15 temperatures have been plotted using an average of the temperature derived from the $P_1(3)$ and the $P_1(4)$ points only and the temperature derived from the line fitted to all four points by a least squares routine. This is admittedly a completely arbitrary procedure, but it achieves the net result of a plausible value for the temperature and uses all of the data.

Due to the arbitrary procedures involved in their computation, the temperatures in Figure 16 have meaning relative to each other only. The rotational temperature is seen to rise until 02:00 hours and then decrease until dawn.

Also shown in Figure 16 is the total intensity of the

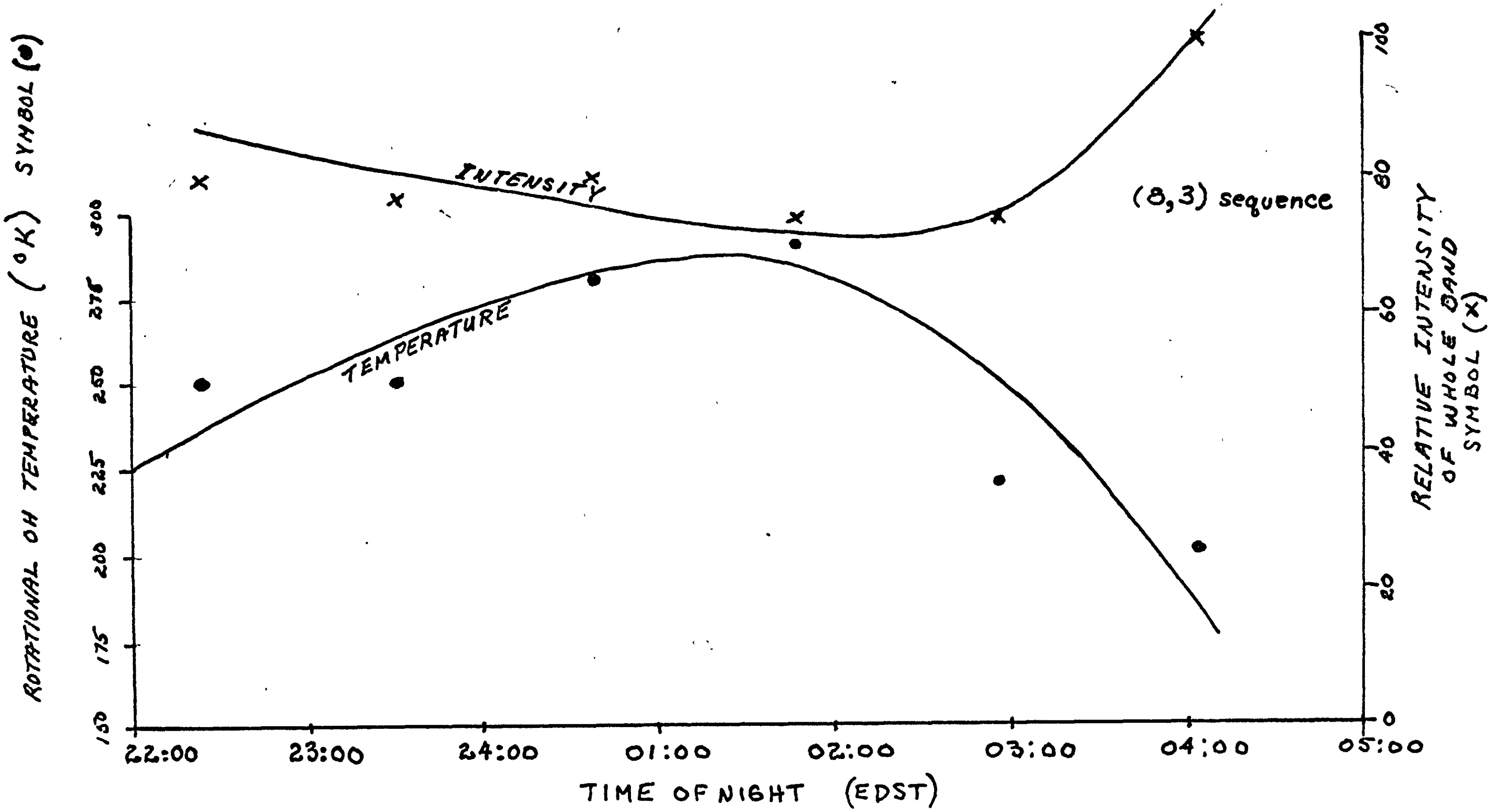

Figure 16 - Diurnal Variation of Temperature and Intensity

of the (8,3) band. This is the sum of the intensities of the four lines of the P_1 branch (after correction for the instrumental response and neglecting the weaker P_2 branch) versus time of night (local time in EDST). The intensity of the band is seen to decrease very slightly through the night and then rise rapidly two hours before dawn.

Ballif and Venkateswaran (1963) point out that diurnal variations of OH airglow intensity can be interpreted only as evidence that the ozone hypothesis of Bates and Nicolet (1950),

$$O_3 + H \rightarrow OH^* + O_2,$$

is valid. The definite diurnal variation in OH intensity observed in this experiment then indicates the existance of the ozone reaction of Bates and Nicolet (1950). However, Krassovsky's (O_2^*) hypothesis is not repudiated by this type of data.

Wallace (1962) presents summer temperatures at 42°N Latitude in the U. S. The minimum temperature, 175°K, is at 80 KM and increases to 240°K at 65 KM. After making allowances for the fact that the temperatures measured in this thesis are not absolute but relative to each other, it seems plausible that during the first part of the night the emitting layer moves from 80 KM down to 65 KM as ozone is depleted at higher altitudes, and then, initial illumination of the upper atmosphere by the sun increases the amount of ozone at higher altitudes and the emitting layer moves back up to 80 KM.

Further speculation regarding the OH emission mechanism would be enhanced by obtaining more temperature and intensity data with emphasis on diurnal, seasonal, and latitude variations. At this point in the study, however, it might be more fruitful to attempt to obtain more complete data on the altitude distribution of oxygen and hydrogen in its various molecular forms and compounds as a function of the above mentioned temporal parameters.

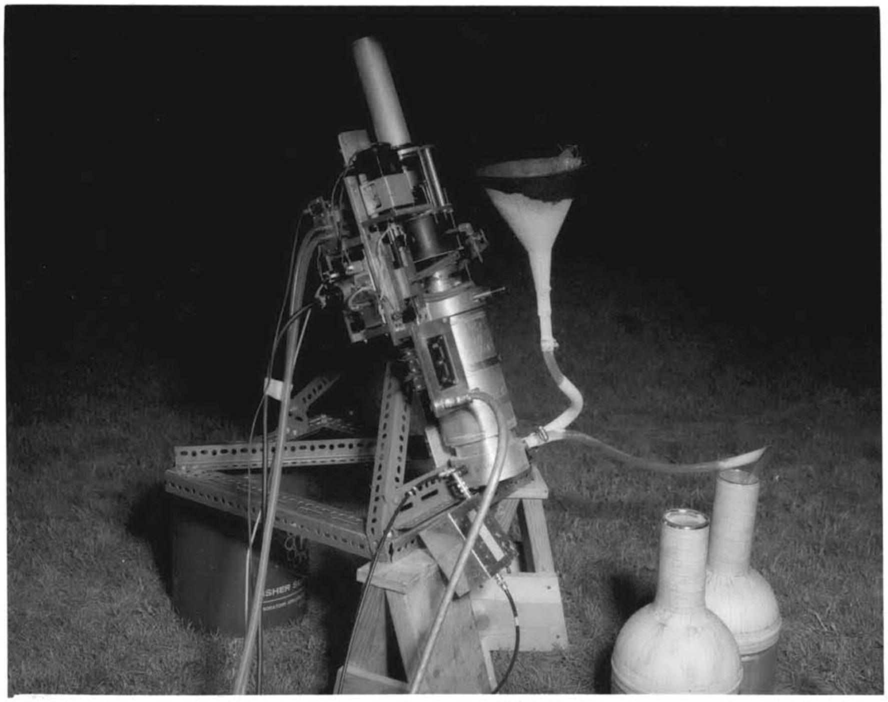

Figure 17

Photograph of OH Spectrometer

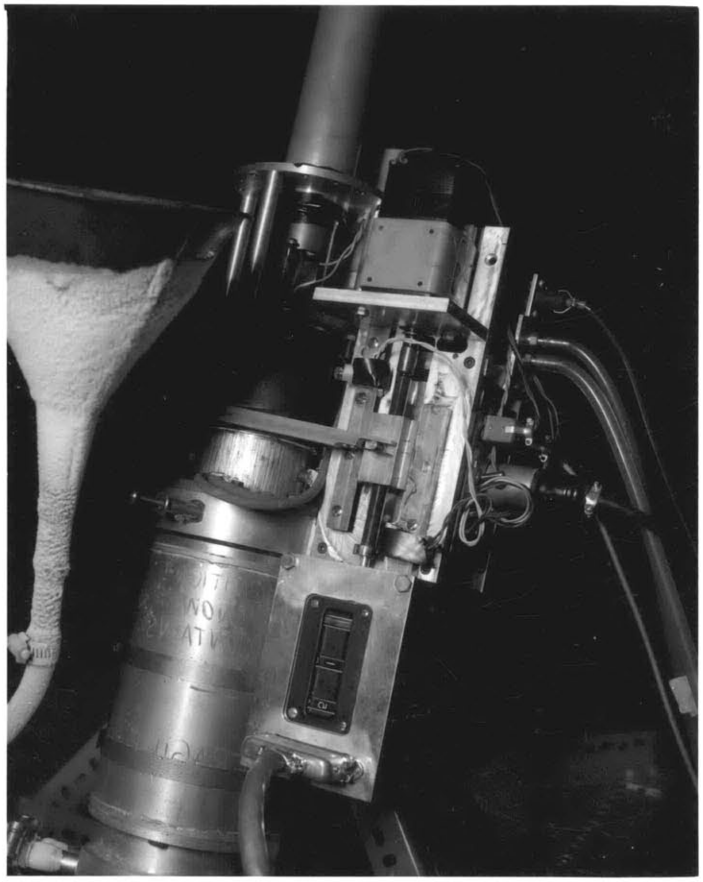

Figure 18

Photograph - Close-up of OH Spectrometer

Figure 19

Photograph of Support Electronics

APPENDIX I

Program for Reducing One Hour Samples of Data

```
*M4550-4182,FMS,DEBUG,1,3,1000,500
*       XEQ
*       LIST8
        DIMENSION B(1 00),X(1000),Y(1000) ,XX(2),YY(2)
        CALL PLOTS1 (B,1000)
        M=0
        N=0
        YY(2)=999.0
        YY(1)=401.0
        XX(1)=201.0
        XX(2) =899.0
   77 READ 88, X1,Y1,Y2,Y3,IDATE,TIME
   88 FORMAT (F3.0,1X,3F4.0,18X,I2,13X,F5.2,6X)
        IF(M) 100,104,100
  100 IF(IDATE-IDATE1) 99,101,99
  101 IF(TIME-TIME1) 99,102,99
   99 CALL SYMBL5 (-2.0,0.,.2,10HM4550-4182,90.,10)
        CALL NUMBR1 ( .,6.5,.2,IDATE1,0.,-1)
        CALL SYMBL5 (.4,6.5,-.2,MONTH1,0.,6)
        CALL SYMBL5 (1.4,6.5,-.2,MONTH2,0.,6)
        CALL NUMBR1 (3.0,6.5,.2,TIME1,0.,2)
        CALL SYMBL5 (3.9,6.5,-.2,REST,0.,6)
        CALL PICTUR (7.0,6.0,25HDIGITS (LAMDA INCREASING),25,
       133HAVERAGE COUNTS (10 SECOND PERIOD),33,X,Y,N,
       20.0,0,XX,YY,-2,0.0,0)
        N=0
        GO TO 102
  104 M=M+1
  102 IDATE1=IDATE
        TIME1=TIME
        X2=X1
        Y4=Y1
        Y5=Y2
        Y6=Y3
        IF (X2) 37,37,80
   80 READ 81,X1,Y13Y2,Y3,IDATE,MONTH1,MONTH2,TIME,REST
   81 FORMAT(F3.0,1X,3F4.0,18X,I2,2A6,1X,F5.2,1A6)
        N=N+1
        X(N)=(X1+X2-12.0)/2.0
        DIV=6.0
        IF(Y1-200.0)41,31,31
   31 IF(Y2-200.0)42,32,32
   32 IF(Y3-200.0)43,33,33
```

CONTINUED ON NEXT PAGE

```
   33 IF(Y4-200.0)44,34,34
   34 IF(Y5-200.0)45,35,35
   35 IF(Y6-200.0)46,36,36
   41 DIV=DIV-1.0
      GO TO 31
   42 DIV=DIV-1.0
      GO TO 32
   43 DIV=DIV-1.0
      GO TO 33
   44 DIV=DIV-1.0
      GO TO 34
   45 DIV=DIV-1.0
      GO TO 35
   46 DIV=DIV-1.0
   36 Y(N)=(Y1+Y2+Y3+Y4+Y5+Y6)/DIV
      GO TO 77
   37 END FILE 10
      CALL EXIT
      END
*     DATA
```

APPENDIX II

Program for Reducing Nine Hour Samples of Data

```
*M4550-4182,FMS,DEEJG,1,3,1000,500
*      XEQ
*      LIST8
       DIMENSION B(1000),X(1000),Y(1000) ,XX(2),YY(2)
       CALL PLOTS1 (B,1000)
       N=0
       FNCREA=6HINCREA
       XX(1)=201.0
       YY(1)=401.0
       XX(2) =899.0
       YY(2)=999.0
    59 XT=0.0
       YT=0.0
       R=0.0
       S=0.0
    19 READ 20,X1,Y1,Y2,Y3,DIRECT,IDATE
    20 FORMAT(F3.0,1X,3F4.0,7X,A6,5X,I2,24X)
       IF(X1)  49,49,11
    11 IF (IDATE) 28,29,28
    28 IF (Y1-200.0) 30,30,31
    31 R=R+1.0
    30 IF(Y2-200.0)32,32,33
    33 R=R+1.0
    32 IF (Y3-200.0) 34,34,35
    35 R=R+1.0
    34 S=S+1.0
       XT=XT+X1
       YT=YT+Y1+Y2+Y3
       IF (DIRECT-FNCREA) 37,36,37
    37 XT=XT-12.0
    36 IF(S-1000.0)19,19,29
    29 N=N+1
       X(N)=XT/S
       Y(N)=YT/R
       GO TO 59
    49 CALL SYMBL5 ( 2.0,0.,.2,10HM4550-4182,90.,10)
       CALL SYMBL5 (0.,6.5,.2,
      142HALL DATA FROM 14-15 AUG AND 15-16 AUG 1967,
      20.,42)
       CALL PICTUR (7.0,6.0,25HDIGITS (LAMDA INCREASING),25,
      133HAVERAGE COUNTS (10 SECOND PERIOD),33,X,Y,N,
      20.0,0,XX,YY,-2,0.0,0)
       END FILE 10
       CALL EXIT
       END
*      DATA
```

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