

T H E S I S

ABSORPTION OF ATMOSPHERIC
OZONE IN THE .3 MICRON
REGION AT FORT COLLINS

Submitted by
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In partial fulfillment of the requirements
for the degree of Master of Science
in Physics

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR
SUPERVISION BY Neal David Wilsey
ENTITLED ABSORPTION OF ATMOSPHERIC OZONE IN THE
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DEGREE OF MASTER OF SCIENCE.

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must be obtained from the Dean of the Graduate School.

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Chapter I

INTRODUCTION

For many years there has been extensive interest in the presence of ozone in the earth's atmosphere, since one of the significant properties of ozone is its strong absorption band in the ultraviolet region. Below .30 microns practically all of the sun's radiation is absorbed by the atmosphere. Much of this absorption has been attributed by many investigators (4,6,10,21,29) to ozone. The heat liberated by this absorption and by exothermic decomposition of ozone is held to be a large factor in the establishment of thermal equilibrium in the atmosphere (3).

Frith (10) gives a brief outline of the development of knowledge about atmospheric ozone and methods for its detection. The most widely used methods for detection and measurement involve optical absorption. A discussion of these methods is given by Stair (29). In the region from .30 microns to .34 microns ozone is the only constituent of the atmosphere known to have a strong absorption band. This permits determination of total ozone by observations from a ground station through comparison of intensities of the sun's radiation over this wavelength range.

One of the difficulties that has been encountered is that of gathering a consistent set of data among the various stations. This has been attributed to differences in calibration of the photometric instruments and real or apparent discrepancies in the absorption coefficients (6). Although spectrophotometers have been in use for many years, there is still a need for improvement of calibration procedures. For this reason, it was decided to recalibrate the Dobson Ozone Spectrophotometer which is used at Fort Collins to study absorption of ozone. An improved calibration technique would insure more accurate data at each observation station as well as better agreement among the different stations.

The study of seasonal and daily variations in ozone content of the atmosphere may help to increase the information about the physics of the atmosphere. Several investigators (2,4,22) have noted a seasonal variation in ozone content and have given correlations with movements of air masses. Reed (26) has shown that day to day changes in total ozone can be attributed to vertical motions of air masses in the stratosphere and upper troposphere.

The problem was to study the seasonal and daily variations of ozone over Fort Collins utilizing absorption in the .3 micron region and to develop a technique for calibration of the spectrophotometer.

Chapter II

THE ABSORPTION PROCESS

The intensity of radiation passing through a uniform layer of an absorbing medium is given by

$$I = I_0 10^{-\alpha x} \quad 2.1$$

where I_0 is the initial intensity, α the decimal absorption coefficient, and x the thickness of the layer.

Figure 1 illustrates the path of a light ray through the earth's atmosphere. In addition to absorption by ozone, two other mechanisms account for the attenuation of intensity: molecular scattering by air and particulate scattering by haze (6). Taking this into consideration, equation 2.1 may be modified for any wavelength, λ , to give

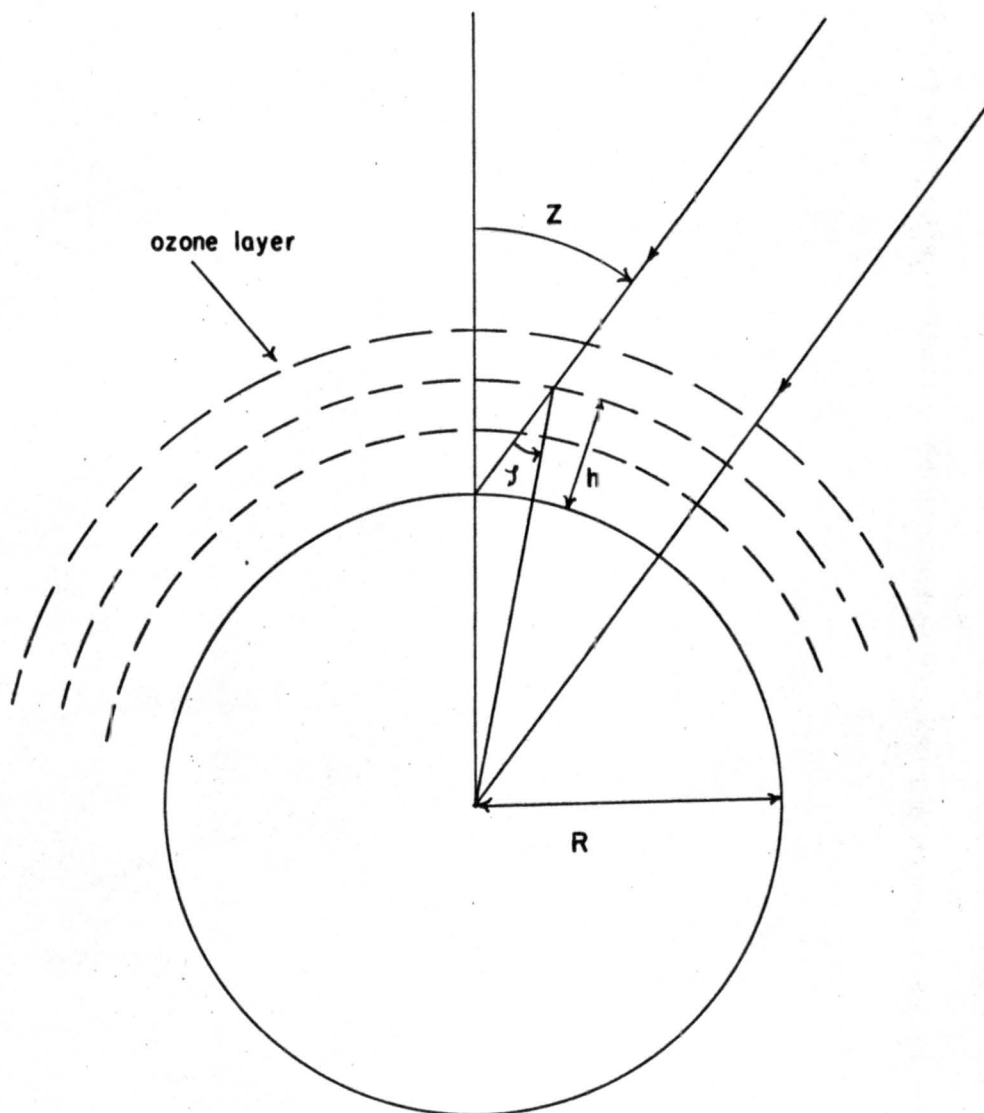
$$I_\lambda = I_{0\lambda} 10^{-\alpha x_\mu - \beta m - \delta \sec Z} \quad 2.2$$

where:

I_λ = intensity of radiation with wavelength λ at the surface of the earth.

$I_{0\lambda}$ = intensity of radiation with wavelength λ outside the earth's atmosphere.

α = absorption coefficient for wavelength λ .



LIGHT RAY PASSING THROUGH THE OZONE LAYER
(not to scale)

Figure 1.

β = scattering coefficient for air for wavelength λ .

δ = particulate scattering coefficient for wavelength λ .

m = relative path length through the atmosphere such that $m = 1$ when the sun is at zenith.

μ = normalizing factor relating the path length through the ozone layer to that when the sun is at zenith.

$\sec Z$ = normalized relative path length through the lower atmosphere.

The ozone in the atmosphere is not in a uniform layer. Therefore, x is defined as that thickness of pure ozone at standard temperature and pressure which would give an absorption equal to that of the total atmospheric ozone. Total ozone mentioned hereafter will, therefore, be in terms of x .

Since it is practical to measure the relative intensities of two wavelengths, λ and λ' , it is convenient to develop an expression for x in terms of these intensities. For wavelength λ' , equation 2.2 becomes

$$I_{\lambda'} = I_{0\lambda'} 10^{-\alpha'x\mu - \beta'm - \delta'\sec Z} \quad 2.3$$

Taking the logarithm of both sides of equations 2.2 and 2.3,

$$\text{Log } I_{\lambda} = \text{Log } I_{0\lambda} - \alpha\mu x - \beta m - \delta \sec Z \quad 2.4a$$

and

$$\text{Log } I_{\lambda'} = \text{Log } I_{0\lambda'} - \alpha'\mu x - \beta' m - \delta' \sec Z \quad 2.4b$$

Subtracting equation 2.4a from 2.4b and solving for x,

$$x = \left[1/(\alpha - \alpha')\mu \right] \left[N_{\lambda\lambda'} - (\beta - \beta')m - (\delta - \delta') \sec Z \right] \quad 2.5$$

where

$$N_{\lambda\lambda'} = \text{Log}(I_{0\lambda}/I_{0\lambda'}) - \text{Log}(I_{\lambda}/I_{\lambda'}) \quad 2.6$$

If $\sec Z$ is less than 3, m , μ , and $\sec Z$ are approximately equal. Equation 2.5 then reduces to

$$x = \left[1/(\alpha - \alpha') \right] \left[N_{\lambda\lambda'}/\mu - (\beta - \beta') - (\delta - \delta') \right] \quad 2.7$$

For clear days $(\delta - \delta')$ should approach zero and the last term of equation 2.7 can be neglected. If, however, much haze is present, neglecting this term results in an incorrect value for x. To compensate for this, two sets of wavelength pairs, "A" and "D", are chosen so that $(\delta - \delta')_A \approx (\delta - \delta')_D$. Then

$$x = \frac{1}{(\alpha - \alpha')_A - (\alpha - \alpha')_D} \left\{ \frac{N_A - N_D}{\mu} - [(\beta - \beta')_A - (\beta - \beta')_D] \right\} \quad 2.8$$

The ratio $I_{\lambda}/I_{\lambda'}$ is measured for each wavelength pair. x can then be calculated provided that $I_{0\lambda}/I_{0\lambda'}$, μ , the absorption coefficients, and the scattering coefficients

are known.

The intensity ratios outside the atmosphere are not well known so that $I_{0\lambda}/I_{0\lambda'}$ must be determined experimentally for each station. This will be discussed in more detail in chapter III.

From the definition of μ and Figure 1, it can be seen that $\mu = \sec \gamma$. Using the fact that $\sin (180^\circ - Z) = \sin Z$, and the law of sines, it can be shown that

$$\sin \gamma = \left[R/(R + h) \right] \sin Z \quad 2.9$$

R is the radius of the earth, h the assumed mean height of the ozone layer, and Z the observer's zenith angle with the sun. From the latitude and longitude of the observation station, the declination of the sun, and the time of observation, the angle Z can be calculated. Instructions for this are found in the Observers Handbook (6).

The Rayleigh scattering coefficients for air are used and assumed to be reliable (23). The absorption coefficients which are used as recommended by the International Ozone Commission are those measured by Vigroux at -44°C (6). Good correlation has been obtained by Inn and Tanaka (13) and by Hearn (12) using different techniques of measurement. The absorption coefficients were found to be independent of pressure and only slightly temperature dependent. Nevertheless, it has

been found that observations taken on different wavelength pairs lead to different values of total ozone. Whether this is due to errors in the absorption coefficients or the presence of some other absorbing medium is not presently known.

Chapter III

INSTRUMENTATION

The Dobson Ozone Spectrophotometer contains a double monochromator, a photomultiplier, a.c. amplifier, and two optical wedges used to control the absorption of one of the wavelengths. A diagram of the optical system is shown in Figure 2.

Optical System

After passing through a quartz window in the top of the instrument, sunlight is directed to the entrance slit (S_1) of the first monochromator by means of a right-angled prism. The desired wavelengths are brought into focus on the exit slits (S_2 , S_3 , S_4) after passing through a quartz lens, 60° prism, and mirror in a Littrow arrangement.

The instrument is provided with a shutter which can be positioned in front of either slit S_2 or S_4 . Thus, two wavelengths are allowed to pass into the second monochromator. A rotating sector wheel alternately blocks off the two "open" exit slits. This chopping mechanism permits one wavelength at a time to enter the second monochromator. The sector wheel is so designed that the slits are blocked off for an equal time period over each half revolution of the wheel. After passing through the exit slit (S_5) to the second monochromator,

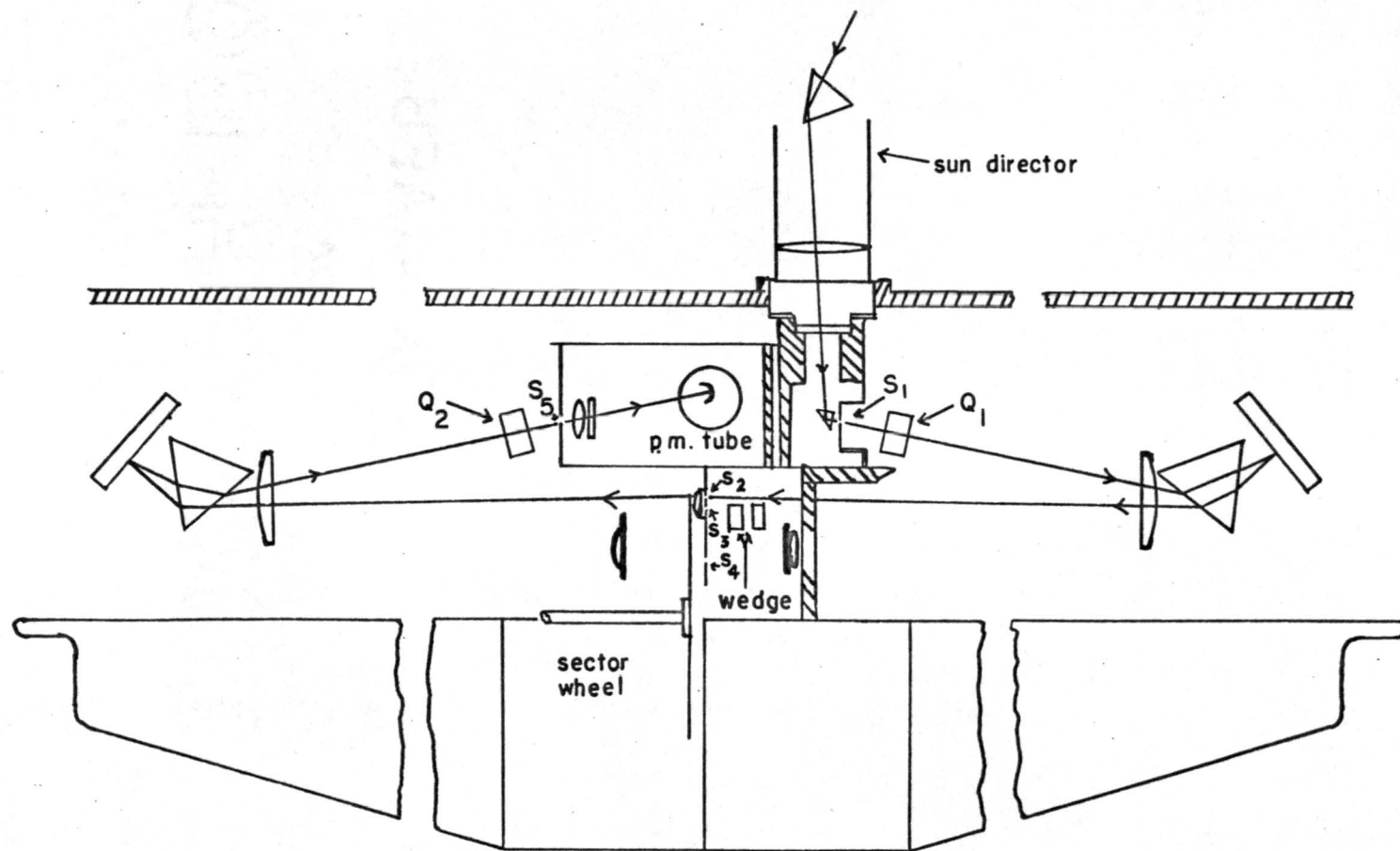


Figure 2.

OPTICAL SYSTEM

the light falls on a photomultiplier which is positioned as shown in Figure 2.

Two absorbing wedges are positioned in front of S_3 with their gradients in opposite directions. These wedges are moved along their lengths by a calibrated dial. Since for each position of the dial light intensity passing through the wedges is reduced by a definite ratio, the dial can be adjusted until the photomultiplier current is the same for each wavelength.

By rotating the thick flat quartz plates, Q_1 and Q_2 about a horizontal axis, the beam of light is displaced vertically. Thus, by rotating Q_1 and Q_2 , different wavelengths can be made to fall on the exit slits. The instrument is designed so that the wavelength falling on S_2 can be made any value between .305 microns and .325 microns. Light passing the other slits is changed accordingly. Slight changes to Q_1 settings are made to correct for changes in the index of refraction of quartz due to temperature changes.

Electrical System

A diagram of the electrical system is given in figure 3. The photomultiplier is supplied with 1000 volts d.c., with each dynode differing in potential from the adjacent one by about 100 volts. The anode is at approximately ground potential while the cathode has a potential of -1000 volts.

The output of the photomultiplier is led through

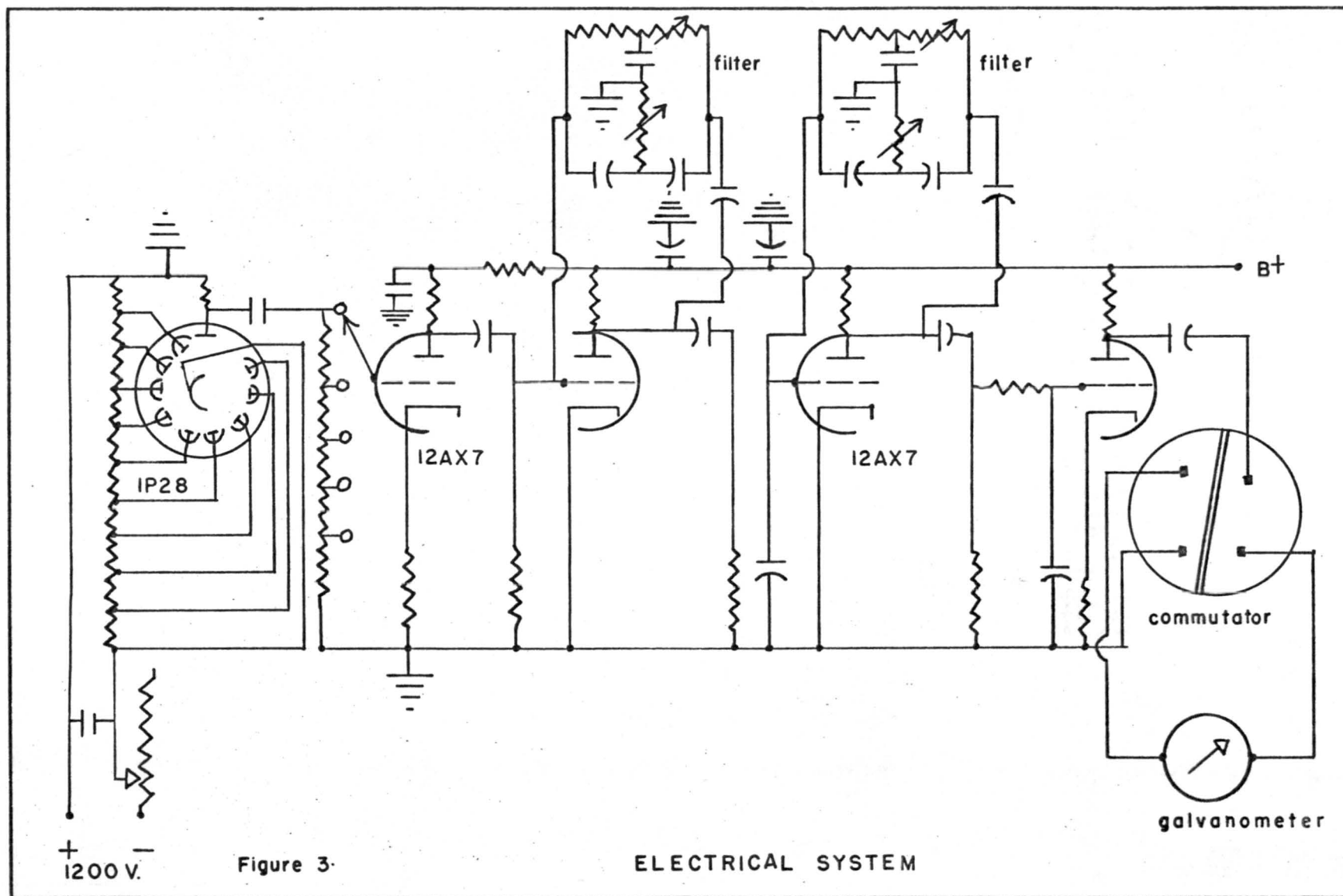


Figure 3.

ELECTRICAL SYSTEM

a capacitance to a four stage resistance-capacitance coupled amplifier. This amplifier is provided with two narrow band filters designed to pass the chopping frequency signal.

The output from the amplifier is led to a commutator fixed on the same shaft as the rotating sector wheel. The amplifier and galvanometer connections are made as shown so that proper adjustment of the commutator brushes provides rectification of the signal to a d.c. signal proportional to the difference between the currents of the photomultiplier due to the two wavelengths falling on it.

Calibration

The optical wedges were recalibrated using a modification of the two lamp method described in the Observer's Handbook (6). Two Sylvania DWY 625 watt "Sun Gun" lamps (x and y) were mounted as shown in Figure 4. A half-reflecting plate was placed at a 45° angle to each lamp and a shutter system constructed so that light from either lamp or both lamps could be made incident upon the sun director. A small lamp with a diffusing plate was placed behind slit S_4 .

Care was taken to insure that only light from the calibration lamps entered the spectrophotometer. Three inch diameter metal tubes eighteen inches in length were placed between the lamps and the half-reflecting plate to help to eliminate stray light in the room. These tubes

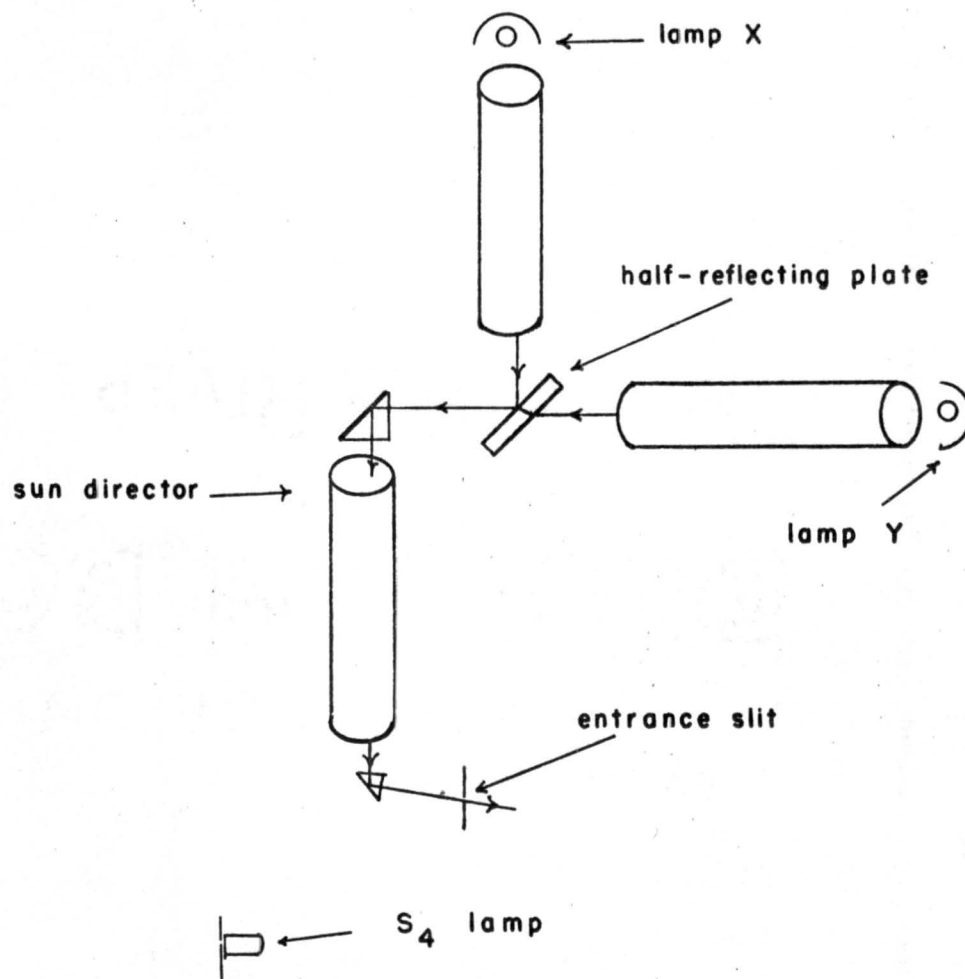


Figure 4.

CALIBRATION APPARATUS

were blackened inside and out with lamp black as were the shutters. This not only helped reduce reflections but also facilitated radiation of the considerable heat generated by the lamps. In addition, the room was kept free from other intense light.

For the calibration to be valid it is essential that light enter the instrument in the manner it would under normal operating conditions. For this reason the sun director was used and a ground quartz plate was placed over the entrance window to the instrument as it is when direct sun observations are taken. This not only insures filling the optics in the same manner as under operating conditions; it also takes into consideration the scattering and absorption by all the optical surfaces.

The procedure for obtaining calibration data was as listed below:

1. Lamps x, y, and S_4 were energized and allowed to come to an equilibrium temperature (about 10 minutes). The instrument shutter was adjusted to allow only light from S_3 and S_4 to reach the photomultiplier.

2. Lamp x only was allowed to radiate to the sun director and the S_4 lamp was adjusted until a null reading on the galvanometer was attained at a dial reading of about 5.

3. Lamp y only was allowed to radiate to the sun director and the voltage on this lamp was adjusted until

a null reading occurred.

4. A dial reading was obtained for lamp x, for lamps x and y together, and for lamp y.

5. The procedure was repeated at dial reading intervals of 5 through a dial reading of 225.

It was found that it took about five hours for the spectral characteristics of the lamps to stabilize initially. During the calibration it was found that five minutes between consecutive sets of readings was necessary for temperature stabilization. Constant voltage transformers were used to reduce fluctuations due to line variations.

The intensity falling on slit S_3 when both lamps are on should be exactly twice that for either lamp alone. Therefore, in order to obtain a null reading at the detector for the former case, the wedge density in front of S_3 (as shown in Figure 2) must increase by $\log 2 = 0.3010$. For each dial reading, R , the change in dial reading, ΔR , due to a doubling of intensity corresponds to an increase in wedge density of 0.3010. Figure 5 gives a plot of ΔR vs. R for $\lambda = .3398$ microns. The dotted line represents the curve inferred from the original calibration of the instrument by a different method.

It can be seen from the graph that there is a substantial difference in the two calibrations at the thin and thick ends of the wedges but good correlations over the central portion. Unfortunately, most of the

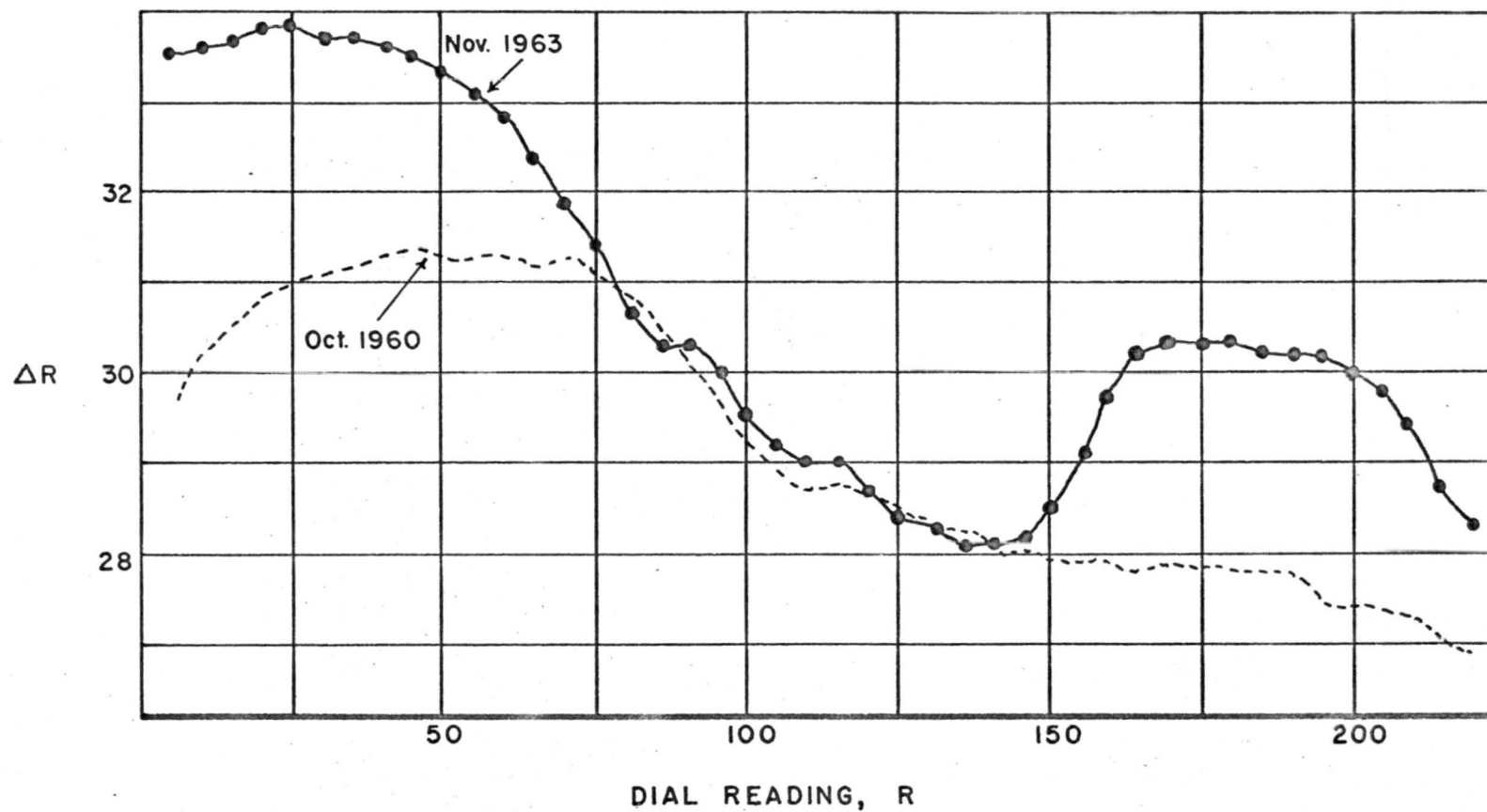


Figure 5.

WEDGE CALIBRATION

$\lambda = .3398 \mu$

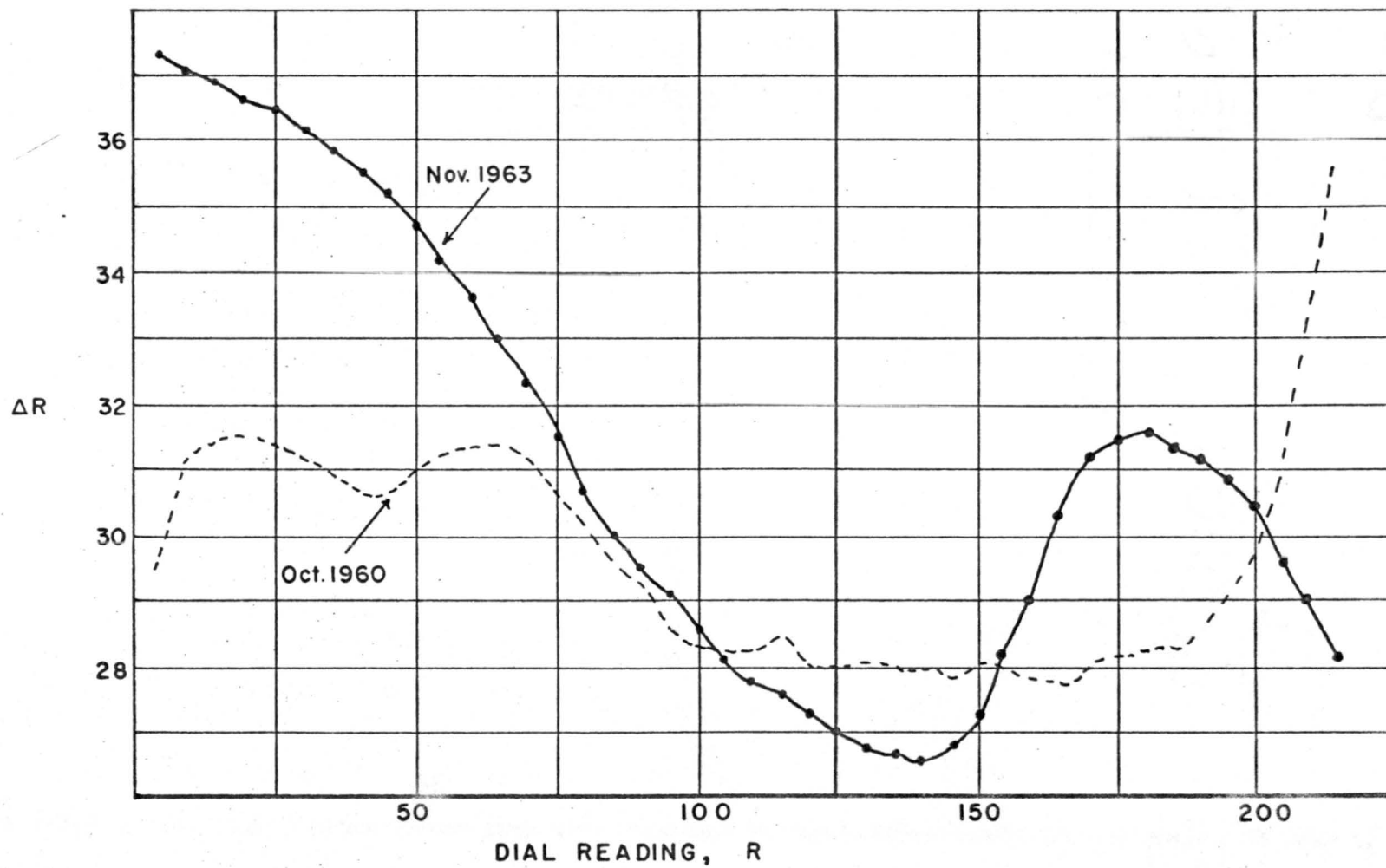


Figure 6

WEDGE CALIBRATION

$\lambda = .3254 \mu$

readings for this particular wavelength are taken for R less than 75. It can be seen that an error of as much as seven per cent could be made in the determination of N_D . Figure 6 gives a similar graph for $\lambda = .3254$ microns. It can be seen that the general shape of this calibration curve is nearly like that in Figure 5 but the inferred curves differ at the thick end of the wedges.

The calibration curves in Figures 5 and 6 are an average of three calibration runs. Although there was some difficulty in controlling the voltage on the lamps due to their high wattage, the data for all three runs was very consistent. Three observers were used to control the lamps and take the data. For each position of the dial, lamp x and lamp y were initially adjusted to give the same reading. As was previously stated, the order of readings was "x", "x" + "y", "y". Any point at which the dial readings for lamp x and for lamp y were not in close agreement was considered to indicate a change in voltage. Therefore, the procedure was repeated whenever there was not close agreement.

Figures 5 and 6 show that the wedges increase in density fairly regularly along their lengths. Also, slit S_3 is placed with its length along the wedges so that a considerable portion of the wedges is averaged at each position of the dial. Therefore, if the dial readings are set down in intervals corresponding to density differences of 0.3010 and these intervals are in turn

broken up into smaller intervals, the density difference, f , for the central step in the larger interval bears to its change in R , δR , the same ratio as 0.3010 bears to ΔR . That is,

$$f = (0.3010)\delta R/\Delta R \quad 3.1$$

By setting the dial readings down in intervals described in the previous paragraph, it is possible to construct density tables for the entire range of the calibration. Table 1 gives an illustration of this method. G is an arbitrary density obtained by assigning the value of zero density to a dial reading of 5.

To convert G values to N values it is necessary to know what the dial readings for a given wavelength pair would be if the instrument were taken outside the atmosphere. One way of doing this is to plot G against μ on days of constant ozone and extrapolate to $\mu = 0$. The value obtained at $\mu = 0$ will be

$$G_0 = \text{Log} (I_{0\lambda}/I_{0\lambda}) + K \quad 3.2$$

where K is some constant of the instrument, a function of slit widths, absorption, reflection, and scattering at the optical surfaces and photomultiplier. Therefore

$$N = G - G_0 \quad 3.3$$

Table 1
CONSTRUCTION OF DENSITY TABLES

$$\lambda = .3398/\mu$$

							<u>f_i (avg.)</u>
G	0.0	30.10	60.20	90.30	120.40	150.50	180.60
R	5.0	38.5	72.1	103.8	133.0	161.2	191.0
ΔR	33.5	33.6	31.7	29.2	28.2	29.8	30.2
δR	4.8	4.9	4.7	4.6	4.4	4.3	4.7
f_1		4.36	4.29	4.58	4.61	4.54	4.67
G	4.51	34.61	64.71	94.81	124.91	155.01	185.11
R	9.8	43.4	76.9	108.4	137.4	165.5	195.7
ΔR	33.6	33.5	31.5	29.0	28.1	30.2	
δR	4.8	4.9	4.7	3.7	3.7	3.7	3.8
f_2		4.38	4.34	3.72	3.92	3.85	3.77
G	8.51	38.61	68.71	98.81	128.91	159.01	189.11
R	14.6	48.3	81.6	112.1	141.1	169.2	199.5
ΔR	33.7	33.3	30.5	29.0	28.1	30.3	
δR	4.8	4.9	4.8	4.5	4.4	4.6	4.6
f_3		4.38	4.49	4.58	4.68	4.71	4.58
G	13.08	43.18	73.28	103.38	133.48	163.58	193.68
R	19.4	53.2	86.4	116.6	145.5	173.8	204.1
ΔR	33.8	33.2	30.2	28.9	28.3	30.3	
δR	4.8	4.8	4.6	4.6	4.4	4.6	4.6
f_4	4.31	4.30	4.37	4.74	4.70	4.65	4.58
G	17.61	47.71	77.81	107.91	138.01	168.11	198.21
R	24.2	58.0	91.0	121.2	149.9	178.4	208.7
ΔR	33.8	33.0	30.2	28.7	28.5	30.3	
δR	4.8	4.7	4.3	4.0	3.7	4.1	
f_5	4.30	4.22	4.11	4.15	3.96	4.09	
G	21.75	51.85	81.95	112.05	142.15	172.25	202.35
R	29.0	62.7	95.3	125.2	153.6	182.5	212.8
ΔR	33.7	32.6	29.9	28.4	28.9	30.3	
δR	4.8	4.8	4.4	4.1	4.0	4.5	
f_6	4.29	4.34	4.34	4.26	4.28	4.47	
G	26.08	56.18	86.28	116.38	146.48	176.58	206.68
R	33.8	67.5	99.7	129.3	157.6	187.0	217.2
ΔR	33.7	32.2	29.6	28.3	29.4	30.2	
δR	4.7	4.6	4.1	3.7	3.6	4.0	
f_7	4.18	4.17	4.09	3.85	3.83	3.97	

$$\sum_{i=1}^7 f_i = \frac{4.02}{30.10}$$

The "N" tables constructed as described above are included in the appendix. To determine whether or not these tables give better accuracy than the original tables, a comparison was made as described below.

The spectrophotometer is provided with a rhodium-ized plate which can be placed in front of slit S_3 . Since this plate has a fixed optical density it was used to determine the accuracy of the tables. The procedure was the following:

1. Lamp x was positioned over the entrance slit and switched on and the circuit to lamp S_4 was closed.
2. The dial was set for a reading of about 70 and the S_4 lamp adjusted for a null reading on the galvanometer when the rhodiumized plate was out of the optical path.
3. The rhodiumized plate was moved into the optical path and the dial controlling the optical wedges was moved until a null reading was again obtained.
4. A set of five readings was taken in the order: "out", "in", "out", "in", "out".

The procedure was repeated in dial reading intervals of 10 through a dial reading of about 200.

The dial readings were converted to N values and the differences in N values, ΔN , with the plate in and out calculated. These values should all be constant and equal to the density of the rhodiumized plate. For $\lambda = .3398$ microns ΔN was found to be $.604 \pm .006$ using

the original tables and $.586 \pm .003$ using the newly compiled tables. For $\lambda = .3254$ microns the values were $.594 \pm .009$ and $.573 \pm .001$ respectively. The error indicated is the probable error of the mean.

Chapter IV

VARIATIONS OF TOTAL OZONE

Paetzold (22) and others (2,10) have noted a seasonal variation in the amount of ozone in the atmosphere. This has been attributed to photochemical production of ozone as a function of mean zenith distance of the sun and to motions of air masses. It has been observed (22) that a maximum generally occurs in April and a minimum is observed in October.

Figure 7 contains a graph of total ozone where monthly averages are plotted as a function of time. The solid line indicates a three year mean while the dotted line represents data for 1963. The maximum occurs in March or April while the minimum is in October. Lower values for 1963 can be attributed to an earlier establishment of summer weather patterns.

The winter months are characterized by large day to day changes whereas these are quite small in summer. Figure 8 gives the daily changes in total ozone for the months of February and July 1963. The day to day changes are very large for the month of February. The range is even greater than the seasonal range. A check of lower atmosphere temperatures reveals that the days of maximum ozone concentration were also days of minimum

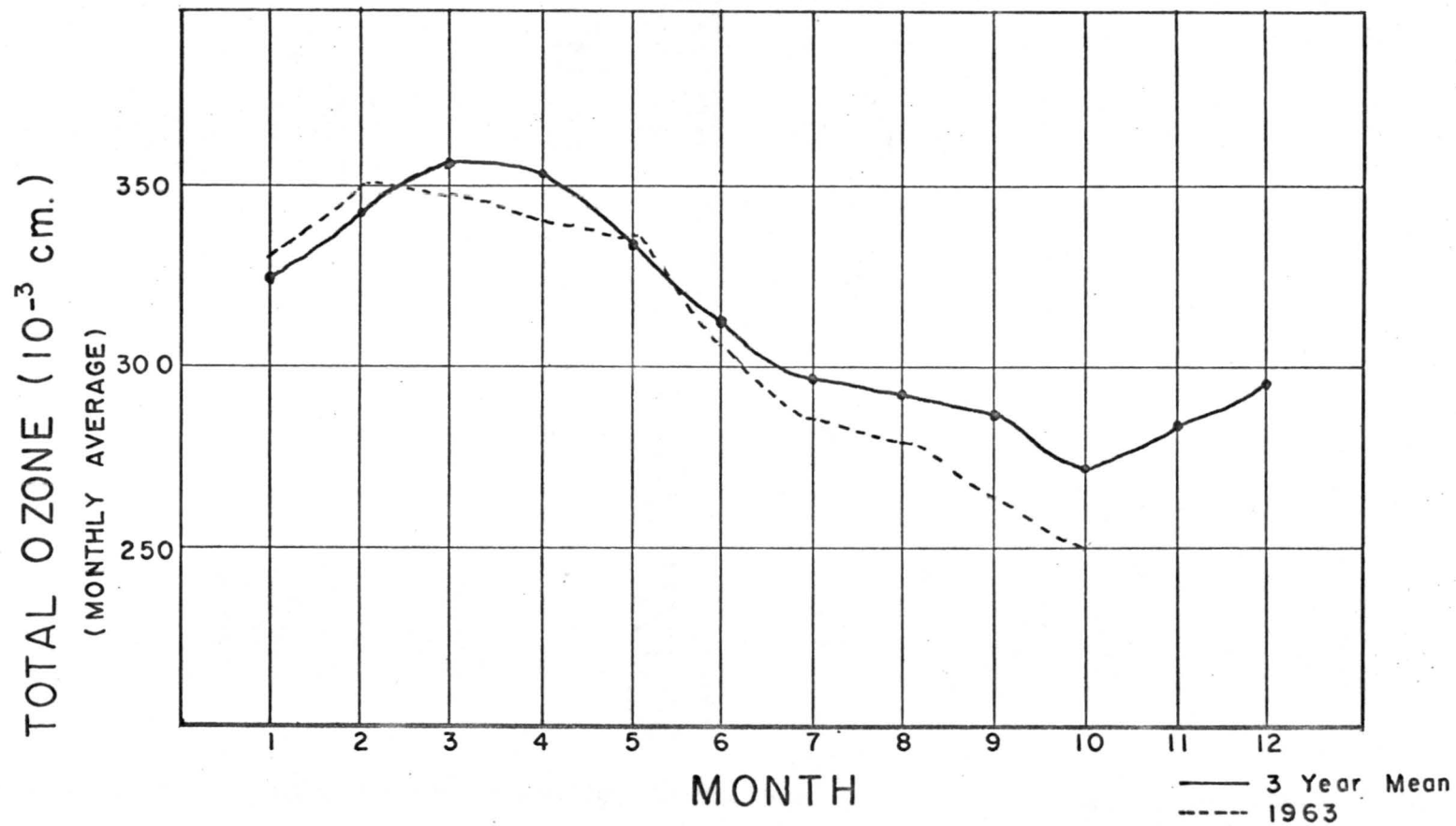
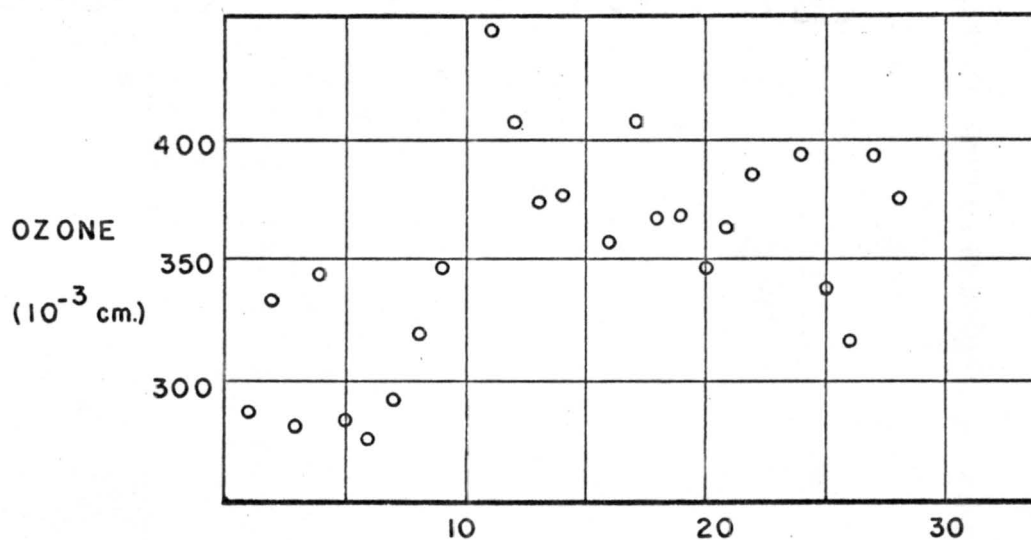
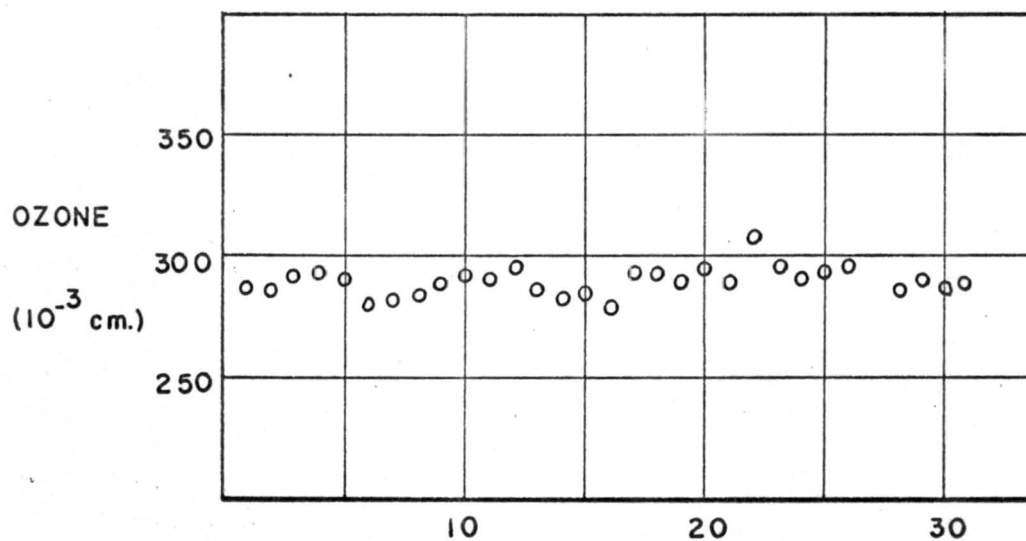


Figure 7.

SEASONAL VARIATION OF TOTAL OZONE



FEBRUARY 1963



JULY 1963

Figure 8.

DAILY OZONE VARIATIONS

temperature while minimum ozone concentration was found on days of high temperature. This would indicate increases in ozone due to an influx of cold polar air and decreases due to an influx of air from warmer regions. As a contrast to February, July was characterized by very little change. There was also very little day to day change in the temperature.

Figure 9 gives the vertical ozone distribution over Fort Collins obtained from balloon data for April 29 and July 3, 1963. The ozone distribution was determined using Regener's chemiluminescent sonde (27). The logarithm of the barometric pressure is plotted on the ordinate and the partial pressure of ozone is plotted on the abscissa. Since the barometric pressure varies exponentially with altitude, this is equivalent to plotting the amount of ozone as a function of height.

Aside from the obvious difference in total ozone, it can be also seen that on April 29 there was a much larger per cent of the total between 200 and 100 mb. Since there is no appreciable radiation available at this height which could account for the photochemical production of ozone, it is assumed (20) that this large quantity of ozone at the lower level is transported by air currents. Some of this ozone transportation has been attributed to the influx of air from ozone-rich polar regions while some can be due to a vertical mixing process (22).

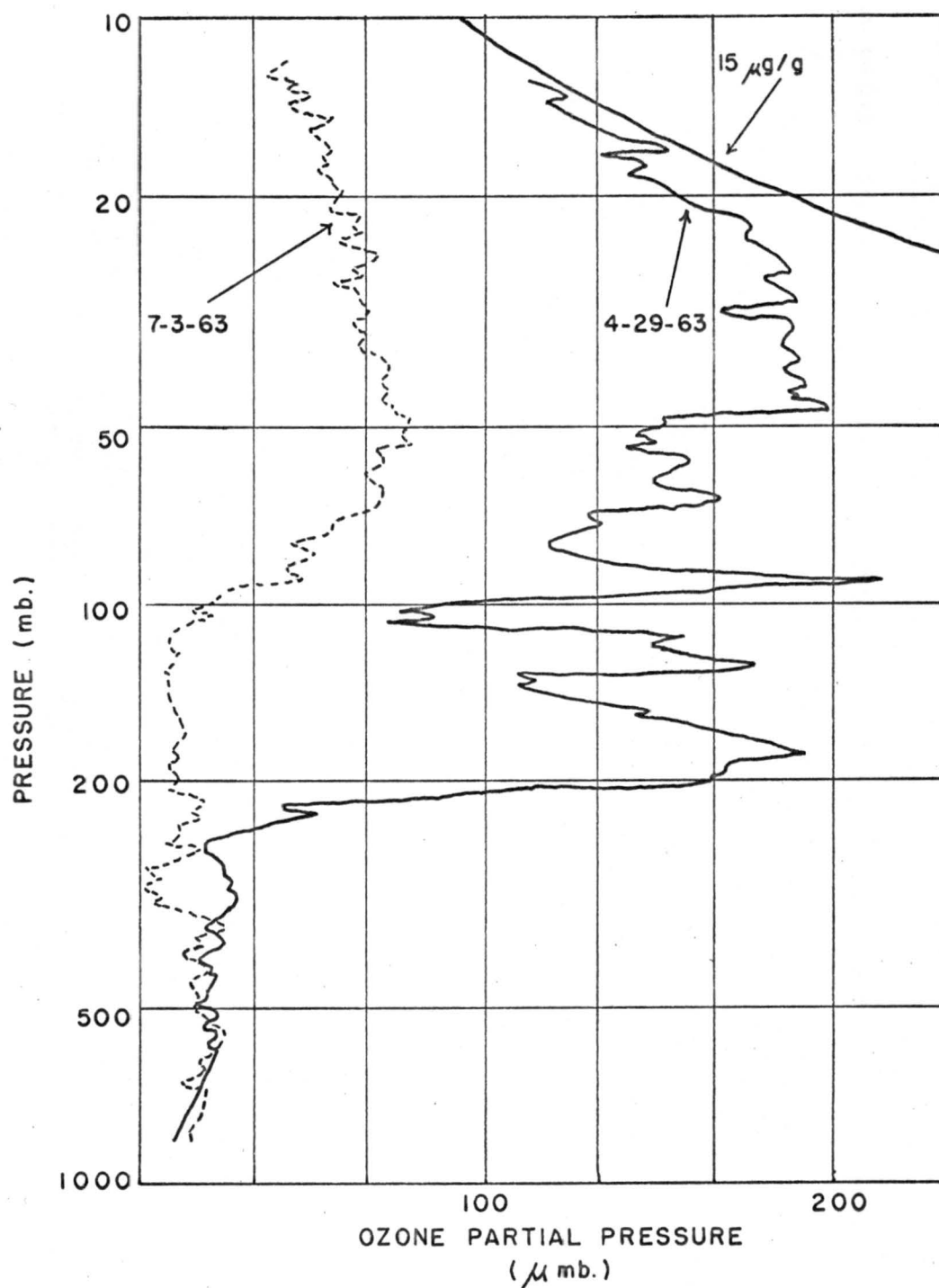


Figure 9.

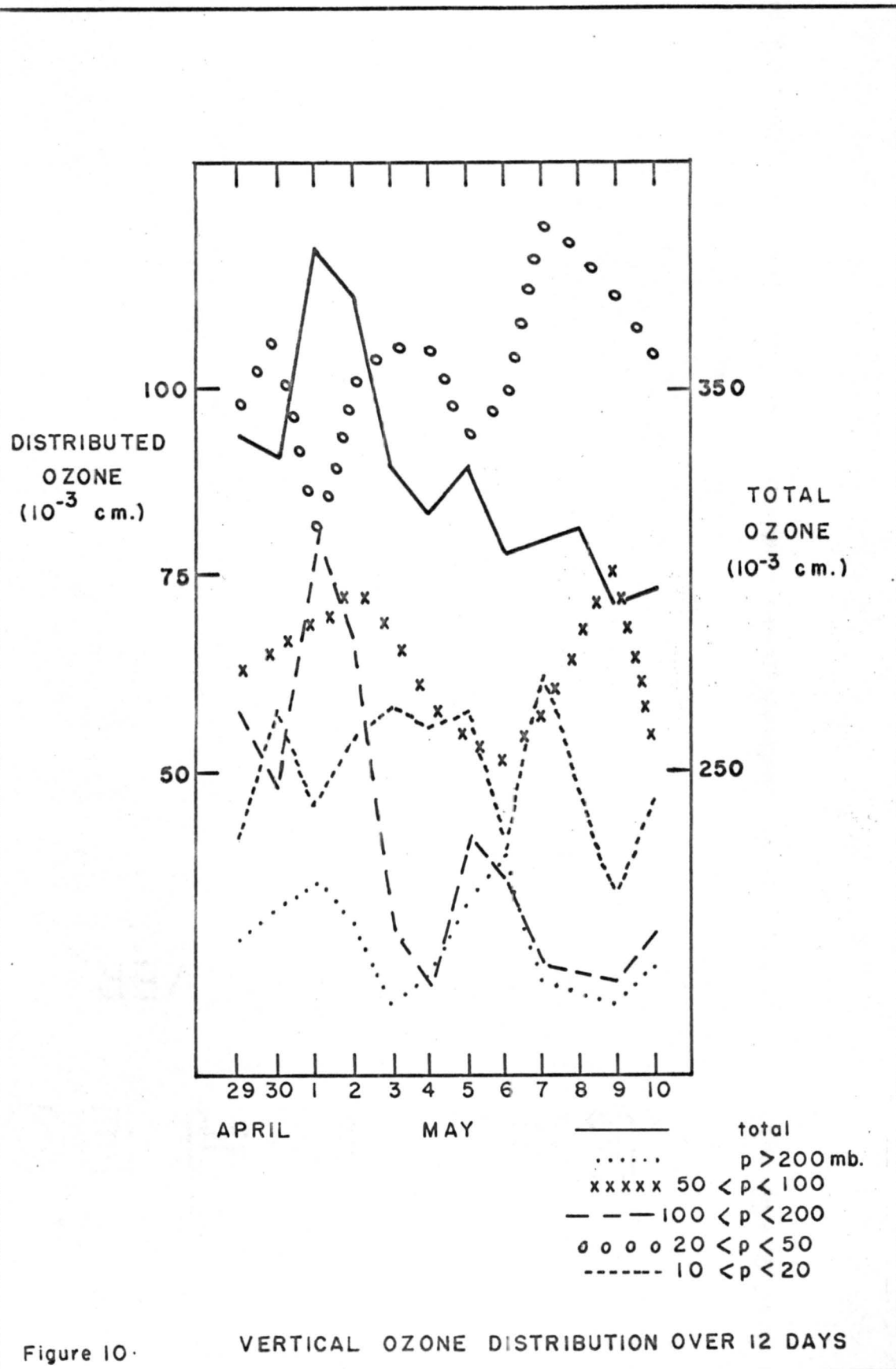
VERTICAL OZONE DISTRIBUTION

Daily balloon launches were made at Fort Collins over a twelve day period commencing April 29, 1963. This provided an excellent opportunity to test the effects of vertical changes in ozone distribution upon the total ozone. To obtain the total ozone, the graphs similar to Figure 9 were integrated using a polar planimeter and assuming that at lower pressure levels the mixing ratio of ozone to air was constant. The mixing ratio, r , is defined as

$$r = (\rho_o/\rho_a)(p_o/p_a) \quad 4.1$$

where ρ_o and ρ_a are the densities of ozone and air respectively, and p_o and p_a the pressures. One of the lines of constant mixing ($15 \mu\text{g/g}$) is shown in Figure 9. The totals obtained by this method were adjusted to totals calculated from spectrophotometer data.

Figure 10 gives the ozone distribution over this twelve day period for the pressure ranges indicated. The pressure regions chosen represent layers about five kilometers in thickness except for the pressure larger than 200 mb. which represents about 11.5 kilometers. On May 1, there was actually a decrease at larger heights. The subsequent decrease in total ozone is accompanied by increases at upper atmospheric levels with a decrease in the lower layers. In general, the change in ozone content in the upper layers is about 180° out of phase with changes in the lower layers.



The increases in total ozone accompanied by increases at lower altitudes but decreases at higher altitudes gives a definite indication of the vertical transport of ozone. Were it not for the decrease in the ozone content of the upper layers, the increase in the lower layers could be entirely explained by an influx of polar air. The temperature level in the lower troposphere (about 1.6 kilometers) at the time of the balloon launch was at a minimum on May 1 and was seen to increase steadily on subsequent days. This would indicate that the changes in total ozone during this period were a combination of advection and vertical movements.

By using only the total ozone calculated from spectrophotometer data, changes due to vertical movements could not be detected. To obtain a complete picture of daily ozone variations, vertical soundings are essential.

Chapter V

CONCLUSIONS

The method for calibrating the optical wedges as described in chapter III has several advantages over previous methods described in the Observer's Handbook (6). The first advantage is that light enters the spectrophotometer in nearly the same manner as when the instrument is used for routine observations. The ground quartz plate and sun director are both used. This was not the case with previous calibration techniques.

Another advantage is that the two lamp method permits the density increment to be a known value. Before such powerful lamps became available, the rhodiumized plate was used for a large portion of the wedges. The density of the rhodiumized plate then had to be deduced from the partial calibration with the two lamp method.

The most obvious test of a calibration method is its accuracy. The test of accuracy of "N" tables as described in Chapter III indicates a deviation of 1% using the original tables and .5% using the tables in the Appendix for $\lambda = .3398$ microns while the deviations were 1.5% and .2% respectively for $\lambda = .3254$ microns. This would indicate an increased accuracy, assuming that

the wedge characteristics have not changed since the original calibration.

Another indication of the accuracy of the calibration is how well the experiment can be repeated with close results. As was previously stated, all three calibration runs were remarkably consistent.

In accordance with instructions given in the Handbook (6), monthly tests have been run on the wedges using the rhodiumized plate method for two portions of the wedges. This practice has given a false appearance of accuracy. No large differences in calculated densities have been observed in these monthly tests due to compensating errors. It is suggested that in the future, several portions of the wedges be checked monthly.

The data presented in chapter IV help to confirm some of the existing theories which try to explain changes in atmospheric ozone content. The seasonal variation can be seen to be a combination of several phenomena. The early spring maximum in total ozone is seen to be a consequence of polar air motion and vertical displacements due to turbulence.

Day to day changes in total ozone are definitely linked to vertical displacements of ozone. These vertical displacements would be intimately connected with turbulence in the troposphere and lower stratosphere. Increases in total ozone are associated with lowering of the mean height of the ozone layer.

While total ozone calculated from spectrophotometer data can be very useful in following motion of air masses from station to station, local disturbances such as turbulence require knowledge about the vertical distribution. Therefore, it is important to correlate spectrophotometer data with data obtained from vertical soundings.

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APPENDIX

APPENDIX

Table 2

PROVISIONAL WEDGE DENSITY AS A FUNCTION OF DIAL READING, R

$$\lambda = .3398 \mu$$

R	0	1	2	3	4	5	6	7	8	9
0	-5.4	-4.5	-3.6	-1.8	-0.9	0	0.9	1.9	2.8	3.8
10	4.7	5.5	6.3	7.2	8.0	8.9	9.9	10.8	11.8	12.7
20	13.7	14.6	15.6	16.5	17.5	18.3	19.2	20.0	20.8	21.8
30	22.7	23.6	24.5	25.4	26.3	27.2	28.0	28.9	29.7	30.6
40	31.5	32.4	33.4	34.3	35.2	36.0	36.8	37.6	38.5	39.3
50	40.2	41.1	42.0	43.0	43.9	44.9	45.8	46.8	47.7	48.6
60	49.5	50.4	51.2	52.1	53.0	53.9	54.8	55.7	56.6	57.5
70	58.3	59.2	60.1	61.0	62.0	62.9	63.9	64.8	65.7	66.5
80	67.4	68.2	69.1	70.1	71.0	71.9	72.9	73.9	74.9	75.9
90	76.9	77.8	78.8	79.8	80.8	81.8	82.7	83.7	84.7	85.7
100	86.7	87.6	88.6	89.6	90.6	91.5	92.5	93.4	94.4	95.4
110	96.5	97.6	98.6	99.6	100.6	101.6	102.6	103.6	104.6	105.6
120	106.6	107.7	108.7	109.7	110.7	111.8	112.8	113.9	114.9	116.0
130	117.1	118.2	119.3	120.4	121.4	122.4	123.5	124.5	125.6	126.7
140	127.8	128.9	129.9	130.9	131.9	133.0	134.0	135.0	136.0	137.0
150	138.1	139.2	140.3	141.4	142.5	143.6	144.7	145.8	146.8	147.9
160	149.0	150.1	151.1	152.2	153.2	154.3	155.4	156.5	157.6	158.6
170	159.7	160.8	161.9	163.0	164.0	165.0	166.0	167.0	168.0	168.9
180	169.8	170.8	171.8	172.7	173.7	174.7	175.7	176.6	177.6	178.6
190	179.6	180.6	181.5	182.5	183.4	184.4	185.4	186.5	187.5	188.6
200	189.6	190.6	191.6	192.6	193.6	194.5	195.4	196.4	197.4	198.4
210	199.4	200.4	201.3	202.3	203.3	204.3	205.3	206.3		

APPENDIX

Table 3

PROVISIONAL WEDGE DENSITY AS A FUNCTION OF DIAL READING, R

$$\lambda = .3254 \mu$$

R	0	1	2	3	4	5	6	7	8	9
0	-4.0	-3.2	-2.4	-1.6	-.8	0	.8	1.6	2.3	3.1
10	3.9	4.7	5.5	6.3	7.0	7.8	8.6	9.5	10.3	11.2
20	12.0	12.9	13.7	14.5	15.3	16.1	17.0	17.8	18.6	19.4
30	20.2	20.9	21.7	22.6	23.4	24.2	25.0	25.8	26.6	27.4
40	28.3	29.1	29.9	30.7	31.5	32.3	33.1	33.9	34.7	35.6
50	36.4	37.2	38.1	38.9	39.8	40.7	41.6	42.5	43.3	44.2
60	45.0	45.9	46.8	47.6	48.5	49.3	50.2	51.0	51.8	52.7
70	53.6	54.4	55.3	56.2	57.1	57.9	58.8	59.7	60.6	61.4
80	62.3	63.2	64.1	65.0	65.9	66.8	67.8	68.7	69.7	70.7
90	71.6	72.6	73.6	74.6	75.5	76.5	77.5	78.5	79.4	80.4
100	81.4	82.4	83.4	84.4	85.4	86.5	87.5	88.5	89.6	90.6
110	91.6	92.6	93.7	94.7	95.8	96.8	97.9	98.9	100.0	101.0
120	102.1	103.1	104.2	105.3	106.4	107.5	108.6	109.7	110.8	111.9
130	113.0	114.1	115.2	116.3	117.4	118.5	119.7	120.8	121.9	123.1
140	124.3	125.5	126.6	127.7	128.9	130.0	131.1	132.3	133.4	134.5
150	135.6	136.8	138.0	139.2	140.4	141.5	142.6	143.7	144.9	146.0
160	147.1	148.2	149.4	150.6	151.7	152.8	153.9	155.0	156.1	157.2
170	158.2	159.3	160.3	161.3	162.3	163.4	164.4	165.4	166.4	167.4
180	168.4	169.4	170.4	171.4	172.4	173.3	174.3	175.2	176.1	177.0
190	177.9	178.8	179.8	180.8	181.8	182.7	183.6	184.5	185.5	186.5
200	187.4	188.4	189.3	190.2	191.1	192.0	193.0	194.0	195.0	196.0
210	196.9	197.9	198.9	199.9	200.9	201.9	202.9	203.9	204.9	205.9
220	206.9	207.9	208.9	209.9	210.9	211.9				

Abstract of Thesis
ABSORPTION OF ATMOSPHERIC
OZONE IN THE .3 MICRON
REGION AT FORT COLLINS

A study of the seasonal and daily variations of atmospheric ozone is made utilizing absorption in the .3 micron region.

A modified technique for calibrating the optical wedges of the Dobson Ozone Spectrophotometer is described. An analysis of the accuracy of this method indicates a probable error of .5% and .2% for wavelengths .3398 microns and .3254 microns respectively. This compares favorably with previous errors of 1% and 1.5%.

A correlation with balloon data gives evidence that daily and seasonal variations in the ozone content of the atmosphere are due to a combination of vertical and horizontal movements of air masses. It was found that over a twelve day period beginning April 29, 1963, increases in total ozone were accompanied by decreases at large altitudes and increases at lower altitudes. The opposite was true for decreases in total atmospheric ozone.

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