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SCIENTIFIC REPORT

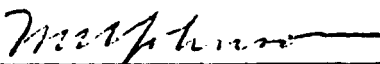
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ABSORPTION BY CO<sub>2</sub> BETWEEN 5400 AND 6600 cm<sup>-1</sup>  
(1.6 Micron Region)

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ABSTRACT

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The absorption by 28 different samples of  $\text{CO}_2$  and  $\text{CO}_2 + \text{N}_2$  in the  $5400\text{-}6600\text{ cm}^{-1}$  ( $1.6\ \mu$ ) region has been studied by the use of a spectrometer having a spectral resolution between approximately  $0.5$  and  $1.3\text{ cm}^{-1}$ . Samples were contained in two different absorption cells; one having a maximum path of 933 meters and used at a maximum pressure of 2.5 atm. The other was used at paths as long as 32.9 meters and at pressures as high as 14.6 atm. Photographs of the spectra of all the samples as well as a table of transmittance versus wavenumber are included. Also presented is a table of integrated absorptance  $\int_{\nu'}^{\nu} A(\nu) d\nu$  versus  $\nu$ , where approximately 380

values are tabulated for the largest samples.

*Author*

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## SECTION 1

### INTRODUCTION AND SUMMARY

Most of the absorption by  $\text{CO}_2$  in the  $5400\text{-}6600\text{ cm}^{-1}$  region is due to four summation bands ( $06^\circ 1$ ,  $14^\circ 1$ ,  $22^\circ 1$ , and  $30^\circ 1$ ) and their associated difference bands. Besides these bands, there are a few others which are extremely weak and are not observable except for very large samples. But, although they are very weak, they may produce most of the absorption over a few small intervals.

At present there is particular interest in these  $\text{CO}_2$  bands because a detailed knowledge of them is important in the investigation of the atmospheres of Mars and Venus. This wavenumber region is useful since it is relatively free of absorption by other gases which occur in the earth's atmosphere; therefore, spectra of the planets can be obtained from ground level. Furthermore, the  $\text{CO}_2$  bands are sufficiently weak that the absorption of the radiation as it passes through the earth's atmosphere is small and can be accounted for.

Howard, Burch and Williams<sup>1</sup> have made some quantitative measurements on the absorption in this region, but the use of their data is limited by the relatively low spectral resolution. Courtoy<sup>2</sup> has measured the positions of several hundred absorption lines with very good accuracy and has identified many bands which had not been observed previously; but only limited information about the amount of absorption by a given sample can be obtained from these results. Kuiper<sup>3</sup> has also investigated the absorption by large samples; but his measurements were made with only moderate resolution and with samples at pressures of several atmospheres.



Because of the limitations of the previous work, there was still need for data on samples covering wide ranges of pressure and absorber thickness and with resolution sufficiently good that at least some lines from most of the bands could be resolved. The present investigation was undertaken for the purpose of obtaining these data. A long absorption cell with possible paths as great as 933 meters enabled us to study samples having very large absorber thickness at pressures which are not so great as to smooth out the structure in the band. Because of the long paths, we were able to observe and identify five new CO<sub>2</sub> bands in this region which have not been reported previously.

A shorter cell was also used to investigate samples at higher pressures in order that band strengths could be measured easily. The strengths of the more important bands were determined and the results are tabulated in Section 3. The widths of many of the lines can also be determined from "curves of growth" of the average absorptance over relatively narrow intervals. Once the strengths and widths of the lines have been found, the absorptance at any wavenumber can be calculated for a great variety of samples, even though they may be non-uniform in temperature and pressure.

Spectra of 28 samples with pressures ranging from 0.02 to 14.6 atmospheres and with path lengths from 4 to 933 meters have been reproduced and digitized. The reproduced spectra are shown in Section 3, and a table of transmittance  $T(\nu)$  versus wavenumber  $\nu$  is presented in Section 4. Section 5 contains a table of  $\int_{\nu'}^{\nu} A(\nu) d\nu$ , the integrated absorptance, versus  $\nu$ .  $\nu'$  is on the low wavenumber side of the region considered for a given sample, and the tabulations are made for approximately 380 different values of  $\nu$  for the largest samples.

## SECTION 2

### EXPERIMENTAL METHODS

#### 2.1 GAS SAMPLING

Samples of  $\text{CO}_2$  and  $\text{CO}_2 + \text{N}_2$  were contained in two different absorption cells which have been described previously.<sup>4</sup> The longer cell has a base length of approximately 30 meters and was used at as many as 32 passes, giving a total path length of 933 meters. It is approximately 0.9 meters in diameter and can be evacuated to less than 1 micron of Hg or pressurized to as much as 2.5 atmospheres. The shorter cell has a base length of approximately 1 meter and was used at as many as 32 passes. It can be evacuated or pressurized to as much as 15 atmospheres.

The  $\text{CO}_2$  was drawn from the vapor in a dewar which contained both liquid and vapor maintained at a temperature less than about  $-20^\circ\text{C}$  by a relief valve which kept the pressure from exceeding 300 psig. We found that there was considerably less  $\text{H}_2\text{O}$  in samples drawn from the vapor over the liquid rather than from the liquid. The  $\text{H}_2\text{O}$  content was also much lower than in samples obtained from commercial cylinders at room temperature. The amount of  $\text{H}_2\text{O}$  in the  $\text{N}_2$  was much less than that in the  $\text{CO}_2$ , and it was not necessary to take extreme care to reduce the amount of  $\text{H}_2\text{O}$  put into the sample with the  $\text{N}_2$ . It was drawn off as a liquid into a heat exchanger where it evaporated and entered the cell.

$\text{CO}_2 + \text{N}_2$  mixtures were mixed in the cell.  $\text{CO}_2$  was introduced to the desired pressure;  $\text{N}_2$  was then added and mixed by fans inside the absorption cells. No attempt was made to change the relative abundances of the different isotopes of C or O in the samples studied. It is probably safe to assume that the natural abundances of these isotopes were present ( $\text{C}^{12}$ , 98.9%;  $\text{C}^{13}$ , 1.1%;  $\text{O}^{16}$ , 99.76%;  $\text{O}^{17}$ , 0.04%;  $\text{O}^{18}$ , 0.20%). Some results discussed in a previous report<sup>5</sup> indicate that the abundance of  $\text{C}^{13}$  was, in fact, about 1.1%. No check was made on the isotopes of O.

Sample pressures less than approximately 0.06 atm were measured with a U-tube oil manometer, and those in the range  $0.06 < P < 2$  atm with a U-tube Hg manometer. All pressures  $> 2$  atm were measured with a bourbon-type gauge. For all except the lowest pressures used, the errors arising from the uncertainty in the pressure measurements are probably negligible.

Since  $\text{CO}_2$  varies significantly from a perfect gas at some of the higher pressures used in this investigation, it was necessary to account for the Van der Waals' forces giving rise to the deviation from a perfect gas. In calculating the absorber thickness  $u$ , the following equation was used:

$$u = W p L \frac{273}{296} \text{ (atm cm)}_{\text{STP}} \quad (2-1)$$

$L$  is the geometrical path length in centimeters,  
 $p$  is the partial pressure of  $\text{CO}_2$  in atmospheres,  
 $273/296$  accounts for the difference in density between standard temperature and room temperature at which the measurements were made.

$W$  is a correction term which accounts for the Van der Waals' forces in  $\text{CO}_2$  and is given adequately for the pressures used in this investigation by

$$W = 1.00 + 0.0047 p. \quad (2-2)$$

In order to relate the pressure of a sample to the half-width of the absorption lines, it is necessary to account for the different broadening abilities of  $\text{CO}_2$  and  $\text{N}_2$  when dealing with mixtures of these two gases. Burch, Gryvnak and Williams<sup>6</sup> have used an equivalent pressure  $P_e$  given by

$$P_e = 1.3 p + (P - p), \quad (2-3)$$

where  $P$  is the total pressure. It is noted that the equivalent pressure approaches the total pressure for a very dilute mixture of  $\text{CO}_2$  in  $\text{N}_2$ , which is a good approximation to the earth's atmosphere.

Since the simple classical theory predicts that the half-width of a line is proportional to the density of molecules, Equation (2-3) should probably be modified to account for the non-linearity between the density of  $\text{CO}_2$  and its partial pressure. No correction is necessary for  $\text{N}_2$  since it behaves much more like a perfect gas. The adjustment was made in the following way:

$$P_e = 1.3 W p + (P-p). \quad (2-3')$$

The self-broadening factor 1.3 is not valid in all portions of the spectrum. But in a detailed study of the shapes of collision-broadened lines which will be described in a separate report,<sup>7</sup> we found that it is satisfactory in regions where most of the absorption is due to lines whose centers are a few tenths of a  $\text{cm}^{-1}$  away. Therefore, it probably can be used throughout most of the region covered by this report. However, it should be considerably greater in a region such as that between  $7100 \text{ cm}^{-1}$  and the head of the  $00^0_3$  band at approximately  $6990 \text{ cm}^{-1}$  where the absorption is due to the wings of lines whose centers are several  $\text{cm}^{-1}$  away.<sup>5</sup> The difference in the self-broadening factor arises from the fact that the shape of the extreme wings of a self-broadened line is quite different from that of a nitrogen-broadened line.

## 2.2 RECORDING AND CALIBRATION OF SPECTRA

The spectra were obtained with an Ebert-type spectrometer whose main mirror has a 75 cm focal length. It utilized a small grating having a ruled area  $64 \times 64$  mm with 600 lines/mm and blazed at 1.6 microns. The grating was used in the first order and a Si filter eliminated overlapping orders of shorter wavelength. A PbS cell cooled with liquid nitrogen was used as the detector. It was not necessary to cool the detector below dry ice temperature for operation in this wavelength region, but the dewar was designed to hold the liquid nitrogen for use at longer wavelengths. Cooling by liquid nitrogen was, therefore, more convenient and was used since the signal-to-noise ratio was approximately the same at both temperatures.

The spectrometer is "home made" and was contained in a tank which could be evacuated to essentially eliminate absorption due to atmospheric gases outside of the absorption cell. The spectrometer tank, as well as another tank containing the radiation source and chopper, were connected to the absorption cell by means of flexible bellows so that all of the optical path external to the absorption cell could be evacuated.

Three different resolution schedules were used in recording the spectra: the approximate spectral slitwidths for each schedule at three different wavenumbers are given in Table 2-1.

TABLE 2-1  
RESOLUTION SCHEDULES

$\nu$ ( $\text{cm}^{-1}$ )	Spectral Slitwidth ( $\text{cm}^{-1}$ )		
	Schedule A	Schedule B	Schedule C
5900	0.49	0.78	1.07
6200	0.55	0.88	1.22
6500	0.61	0.97	1.35

Resolution Schedule A was used in a few regions of the spectrum to resolve closely spaced lines; but because of the small signal available while using this schedule, considerable time was required to scan even a short spectrum. Therefore, B, which represents a compromise between resolution and scanning time, was used for the majority of the data. Schedule C was used for some spectra of samples at several (32) passes of the absorption cell for which the signal was low. The schedule used for each spectrum is listed in Table 3-2.

$\text{CO}_2$  and  $\text{CH}_4$  lines whose positions are well known, or could be calculated, were used for the wavenumber calibration of the spectra. The calibration lines are separated by an average of about  $10 \text{ cm}^{-1}$ , which is sufficiently close that the spectrum could be assumed to be linear between them. All the lines used for calibration between  $5800$  and  $6600 \text{ cm}^{-1}$  are listed in Table 3-3, and their positions are shown on the spectra in Section 3. The calibration lines used between  $5500$  and  $5700 \text{ cm}^{-1}$  are shown in Fig. 3-1.

Background curves were obtained with the absorption cell evacuated for each number of passes for which sample spectra were obtained. The background curves were different for different numbers of passes since the reflectivity of the mirrors in the multiple-pass optics varies with wavenumber. The appropriate background curve, which represents 100 percent transmittance, was then fitted to each spectrum and traced on it. All the sample spectra extended beyond the region of absorption on both ends of the band so that dependable "tie-points" between a spectrum and its background could be established. The transmittance was determined from the ratio of the deflection of the sample spectrum to that of the background curve at the same wavenumber.

Each spectrum was examined and compared with others as a check for consistency. Small changes were made to account for  $\text{H}_2\text{O}$  absorption. The corrections could be made reasonably accurately by comparing the

spectra with those of  $\text{H}_2\text{O} + \text{N}_2$  samples at the proper path lengths and pressures. The corrected spectra were then replotted and are shown in Section 3. As each spectrum was being replotted, pairs of values related to transmittance and wavenumber were punched on IBM cards which served as input for a computer program used to calculate transmittance and integrated absorptance as a function of wavenumber.

## SECTION 3

### DISCUSSION OF ABSORPTION BANDS

#### 3.1 IDENTIFICATION AND FEATURES OF THE ABSORPTION BANDS

All of the CO<sub>2</sub> bands which one might expect to produce appreciable absorption in the region from 5400 to 6600 cm<sup>-1</sup> are listed in Table 3-1. The positions of the band centers of most of the bands are taken from Courtoy,<sup>2</sup> while centers of the others were calculated from energy levels tabulated by Stull, Wyatt and Plass.<sup>8</sup> In the notation for the transitions the lower level is omitted when it is 00<sup>0</sup>0. There are probably other very weak bands in this region, particularly some from transitions from higher energy levels, which could be observed with better resolution and long paths. However, their contribution is certainly small at room temperature or below. The bands listed are limited to those observed by Courtoy<sup>2</sup> plus those we observed and were able to identify with reasonable certainty.

With the exception of five of the weaker bands listed, all those in this region arise from transitions in which there is a change of one in  $\nu_3$ , the quantum number associated with  $\nu_3$  ( $\Delta\nu_3 = 1$ ). Since for CO<sub>2</sub>,  $\nu_1 \approx 2\nu_2$ , all bands for which  $2\Delta\nu_1 + \Delta\nu_2$  is constant occur close to each other if  $\Delta\nu_3$  is the same.  $2\Delta\nu_1 + \Delta\nu_2 = 6$  for all the bands listed in Table 3-1 having  $\Delta\nu_3 = 1$ . Since  $\nu_1$  is not exactly equal to  $2\nu_2$ , but slightly larger, the bands having the largest change in  $\nu_1$  occur at slightly higher frequencies.  $\nu_1 = 1388.2$  and  $\nu_2 = 667.4$  for C<sup>12</sup>O<sub>2</sub><sup>16</sup>.

TABLE 3-1

CO<sub>2</sub> BANDS BETWEEN 5500 and 6600 cm<sup>-1</sup>

Band Center cm <sup>-1</sup>	Transition	Species
5584.28 <sup>a</sup>	00 <sup>0</sup> 3←10 <sup>0</sup> 0	12, 16, 16 <sup>b</sup>
5687.05 <sup>a</sup>	00 <sup>0</sup> 3←02 <sup>0</sup> 0	12, 16, 16
5857.59 <sup>a</sup>	02 <sup>0</sup> 2	12, 16, 18
5951.53	06 <sup>0</sup> 1	13, 16, 16
5959.57 <sup>a</sup>	10 <sup>0</sup> 2	12, 16, 18
6020.75	07 <sup>1</sup> 1←01 <sup>1</sup> 0	12, 16, 16
6075.93	06 <sup>0</sup> 1	12, 16, 16
6088.16	15 <sup>1</sup> 1←01 <sup>1</sup> 0	13, 16, 16
6119.56	14 <sup>0</sup> 1	13, 16, 16
6196.12	15 <sup>1</sup> 1←01 <sup>1</sup> 0	12, 16, 16
6227.88	14 <sup>0</sup> 1	12, 16, 16
6241.93	22 <sup>0</sup> 1	13, 16, 16
6243.54	23 <sup>1</sup> 1←01 <sup>1</sup> 0	13, 16, 16
6308.15	24 <sup>0</sup> 1←02 <sup>0</sup> 0	12, 16, 16
6347.81	22 <sup>0</sup> 1	12, 16, 16
6356.25	23 <sup>1</sup> 1←01 <sup>1</sup> 0	12, 16, 16
6363.58	30 <sup>0</sup> 1	13, 16, 16
6397.51	31 <sup>1</sup> 1←01 <sup>1</sup> 0	13, 16, 16
6503.05	30 <sup>0</sup> 1	12, 16, 16
6536.43	31 <sup>1</sup> 1←01 <sup>1</sup> 0	12, 16, 16
6538.03 <sup>a</sup>	03 <sup>1</sup> 2	12, 16, 16

<sup>a</sup>To the knowledge of the authors, these bands have not been observed previously; band centers were calculated from energy levels tabulated by Stull, Wyatt and Plass.<sup>8</sup> Centers for all other bands are taken from Courtoy.<sup>2</sup>

<sup>b</sup>Numbers represent isotopes of C, O, and O, respectively.



Because of anharmonicity, a combination or fundamental band usually occurs at a slightly higher wavenumber than its associated difference band which arises from a transition from an excited state with the changes in all three quantum numbers the same. However, the displacement of the bands varies from one band to another, depending on Fermi resonance. It can be seen that the  $30^0_1$  and  $22^0_1$  bands occur at lower wavenumbers than their associated difference bands arising from transitions from the  $01^1_0$  state. However, as more frequently occurs, the opposite is true for the  $14^0_1$  and  $06^0_1$  bands.

The  $02^0_2$  and  $10^0_2$  bands of  $C^{12}O^{16}O^{18}$  are forbidden for  $C^{12}O_2^{16}$ ; but they appear because of the asymmetry of the  $C^{12}O^{16}O^{18}$  molecule. The  $00^0_3 \leftarrow 10^0_0$  and the  $00^0_3 \leftarrow 02^0_0$  bands occur near each other since the upper level is common and  $2\Delta v_1 + \Delta v_2$  is the same for both bands. A replotted spectrum of these bands<sup>1</sup> is shown in Figure 3-1; it was recorded for the largest sample studied.

A replotted spectrum of the region from approximately  $5800$  to  $6600\text{ cm}^{-1}$  is shown in Figure 3-2 for the same sample. The positions of the centers of many of the bands are indicated. Spectra of the remainder of the samples are shown in Figures 3-3 through 3-6 and 3-7 through 3-10 for the spectral regions  $5900$  to  $6275\text{ cm}^{-1}$  and  $6275$  to  $6600\text{ cm}^{-1}$ , respectively. The numbers appearing in rectangles are the numbers assigned to the samples which are described in Table 3-2, the table of sample parameters.

The other numbers appearing in some of the spectra refer to the lines used in the wavenumber calibration. The positions of these lines are given in Table 3-3.

Portions of the spectra of some of the samples for which the absorption  $A(\nu)$  was very small have been omitted. The spectra were "nested" in order to conserve space, and no attempt was made to put them in any particular order.

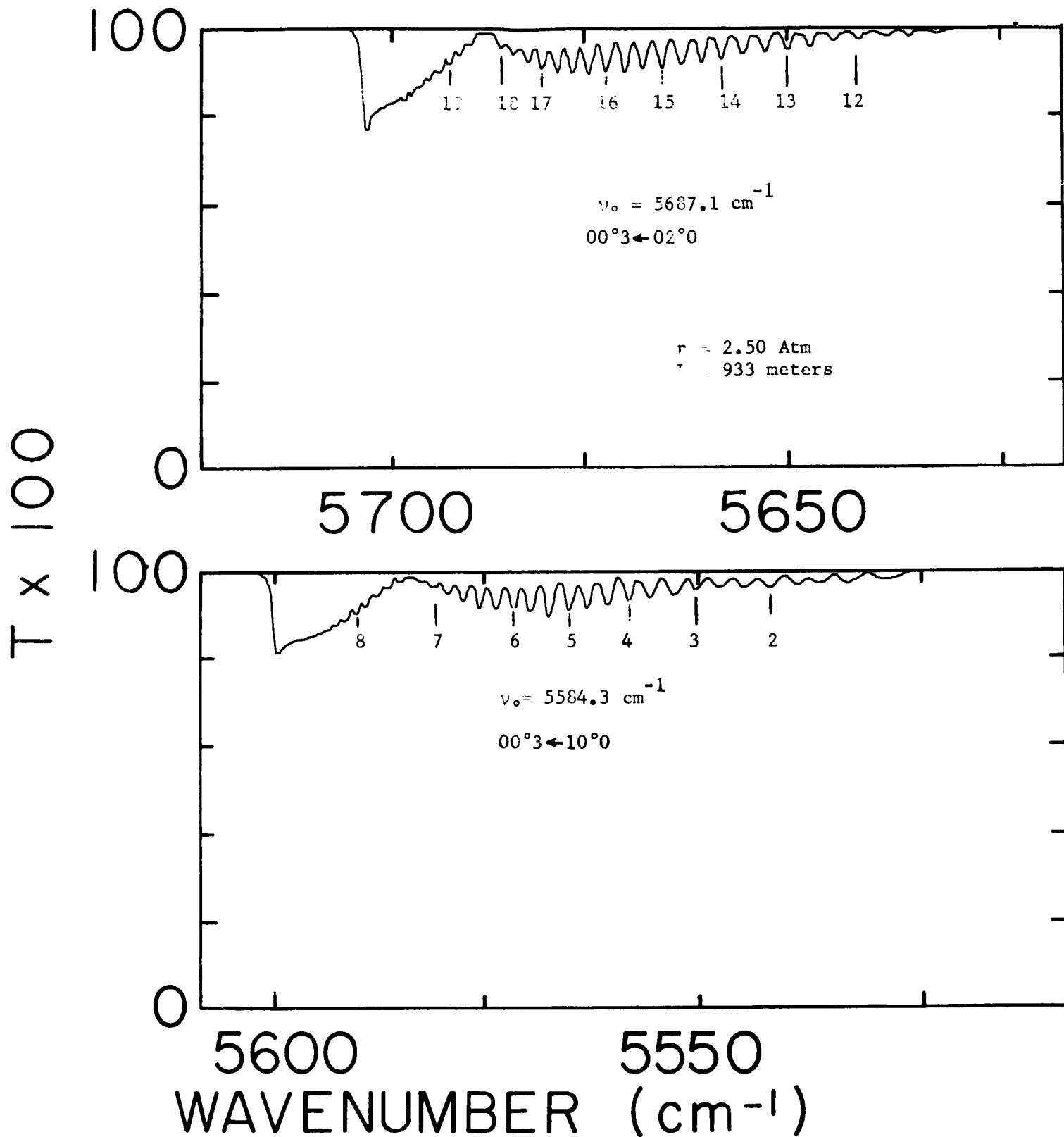


FIGURE 3-1 SPECTRUM OF THE  $00^\circ 3 \leftarrow 02^\circ 0$  AND  $00^\circ 3 \leftarrow 10^\circ 0$  BANDS FOR SAMPLE 1 IN THE REGION BETWEEN 5450 AND 5710  $\text{cm}^{-1}$ .

The lines that are numbered were used in calibration and their wavenumber positions ( $\text{cm}^{-1}$ ) are;

1 5507.8 ( $\text{H}_2\text{O}$ )	6 5571.7	11 5621.6 ( $\text{H}_2\text{O}$ )	16 5672.3
2 5541.8	7 5581.1	12 5641.1	17 5680.3
3 5550.2	8 5590.5	13 5649.8	18 5685.5
4 5558.1	9 5602.8 ( $\text{H}_2\text{O}$ )	14 5658.1	19 5692.0
5 5565.2	10 5614.0 ( $\text{H}_2\text{O}$ )	15 5665.5	

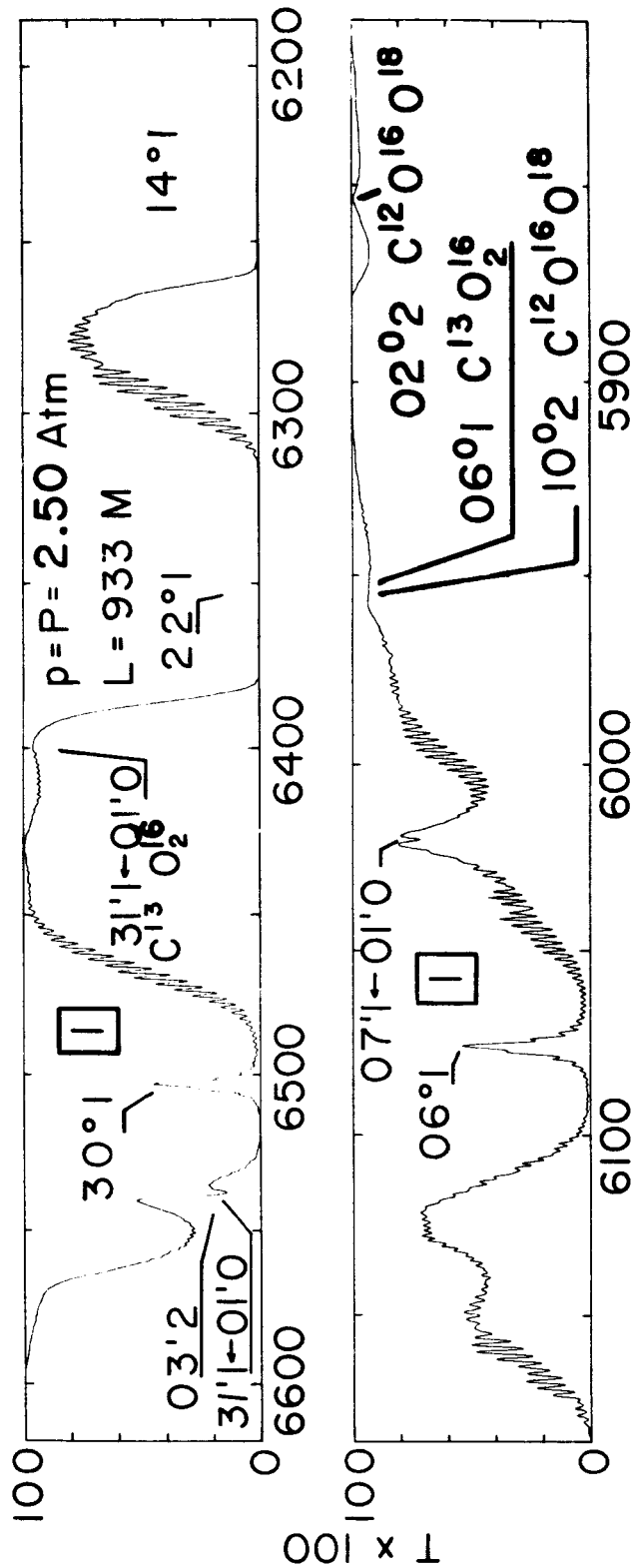


Fig. 3-2. WAVENUMBER (cm<sup>-1</sup>)

FIGURE 3-2 SPECTRUM OF THE 5800 - 6600 cm<sup>-1</sup> REGION

The centers of several of the bands are indicated.  
 The species is C<sup>12</sup>O<sup>16</sup>O<sup>18</sup> when it is not indicated.

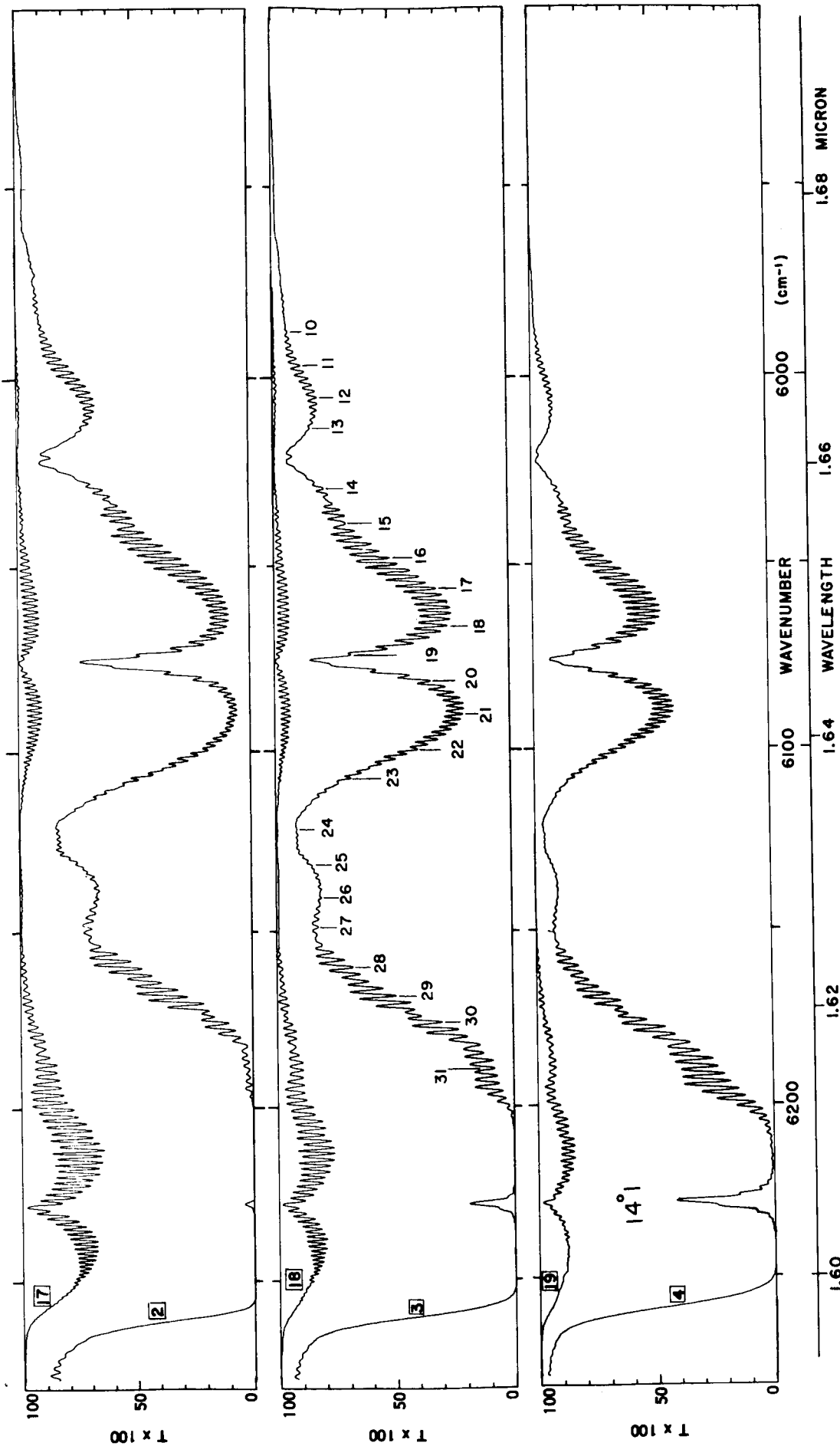


Fig. 3-3

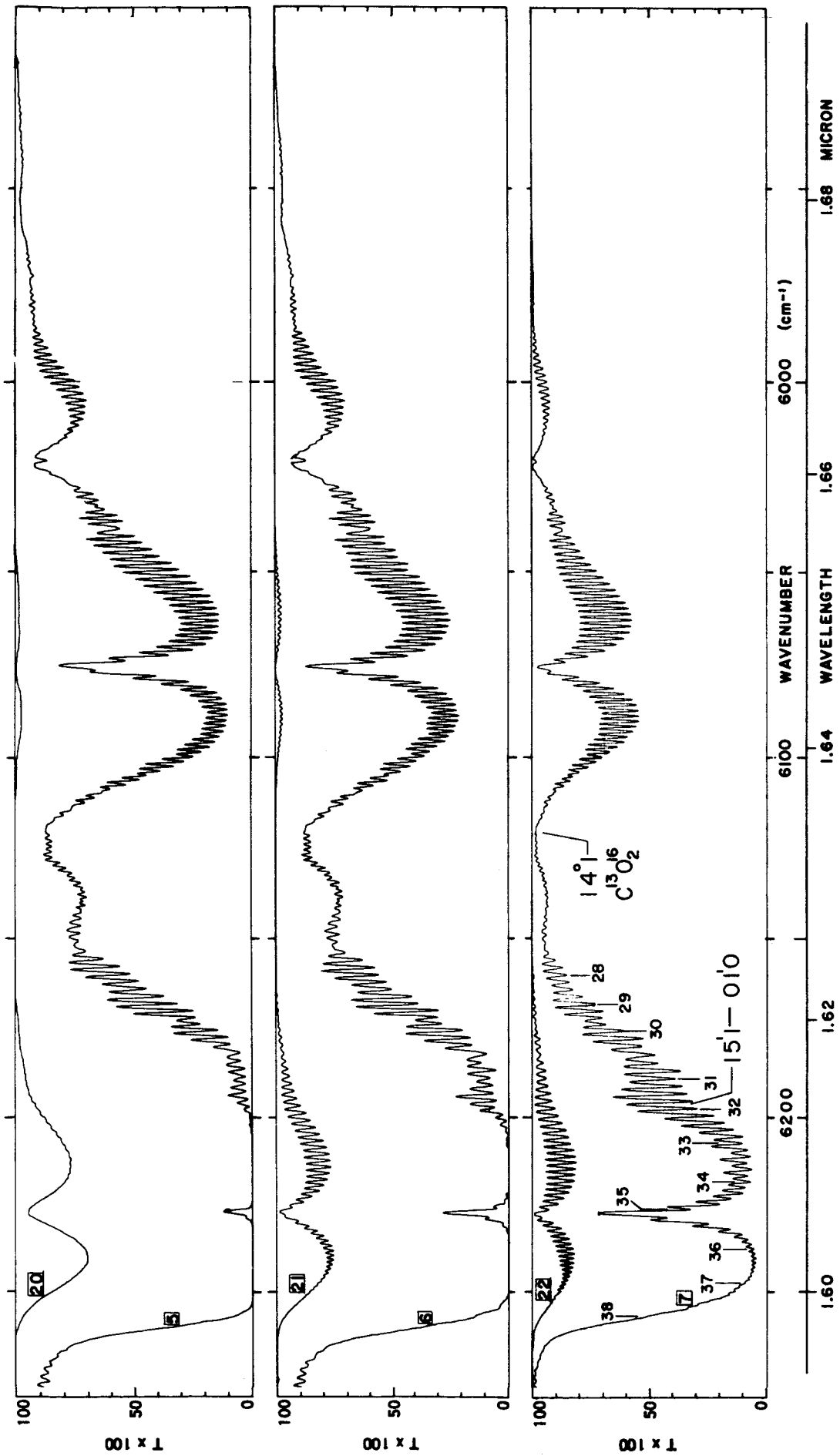


Fig. 3-4

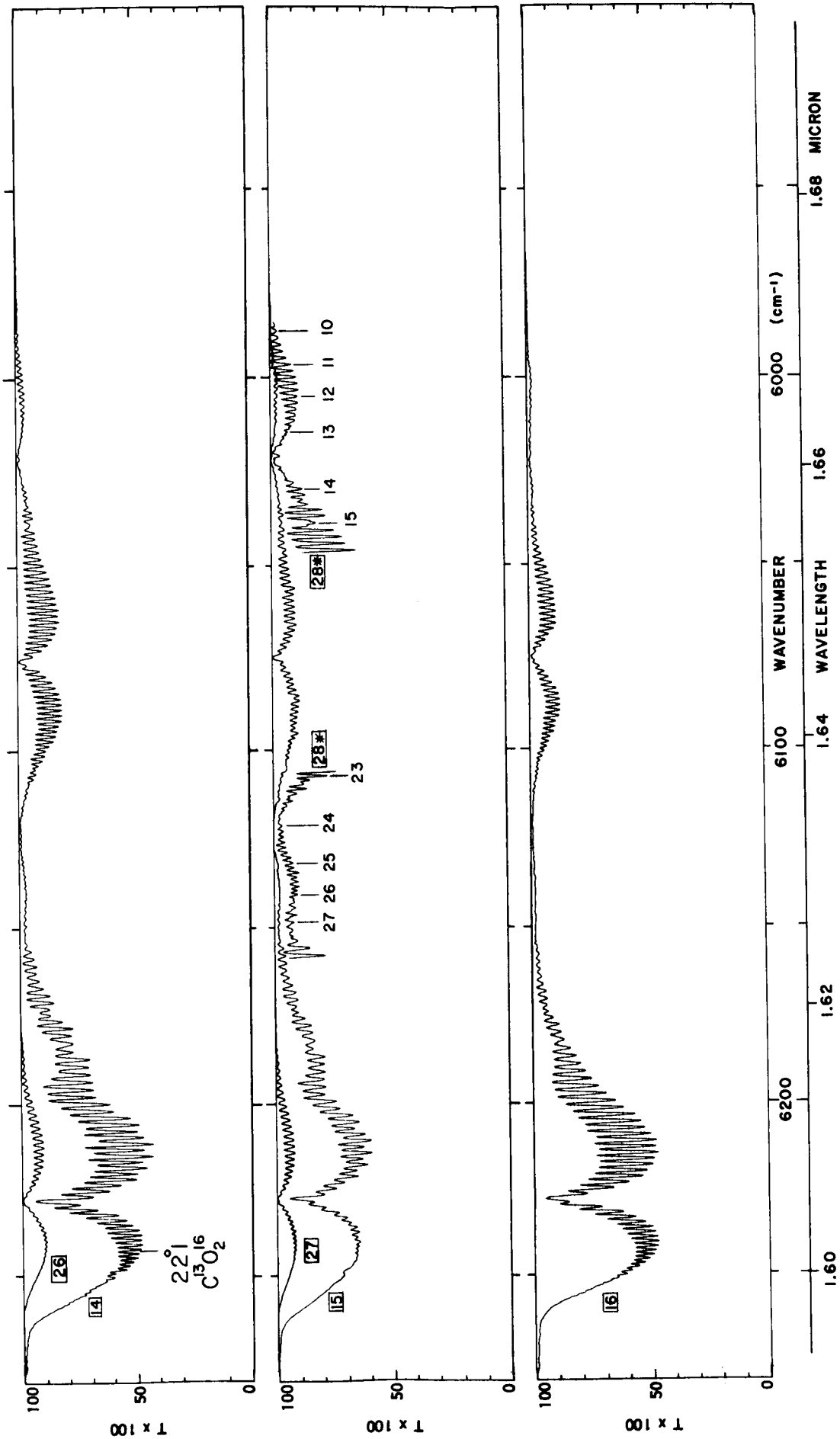


Fig. 3-5

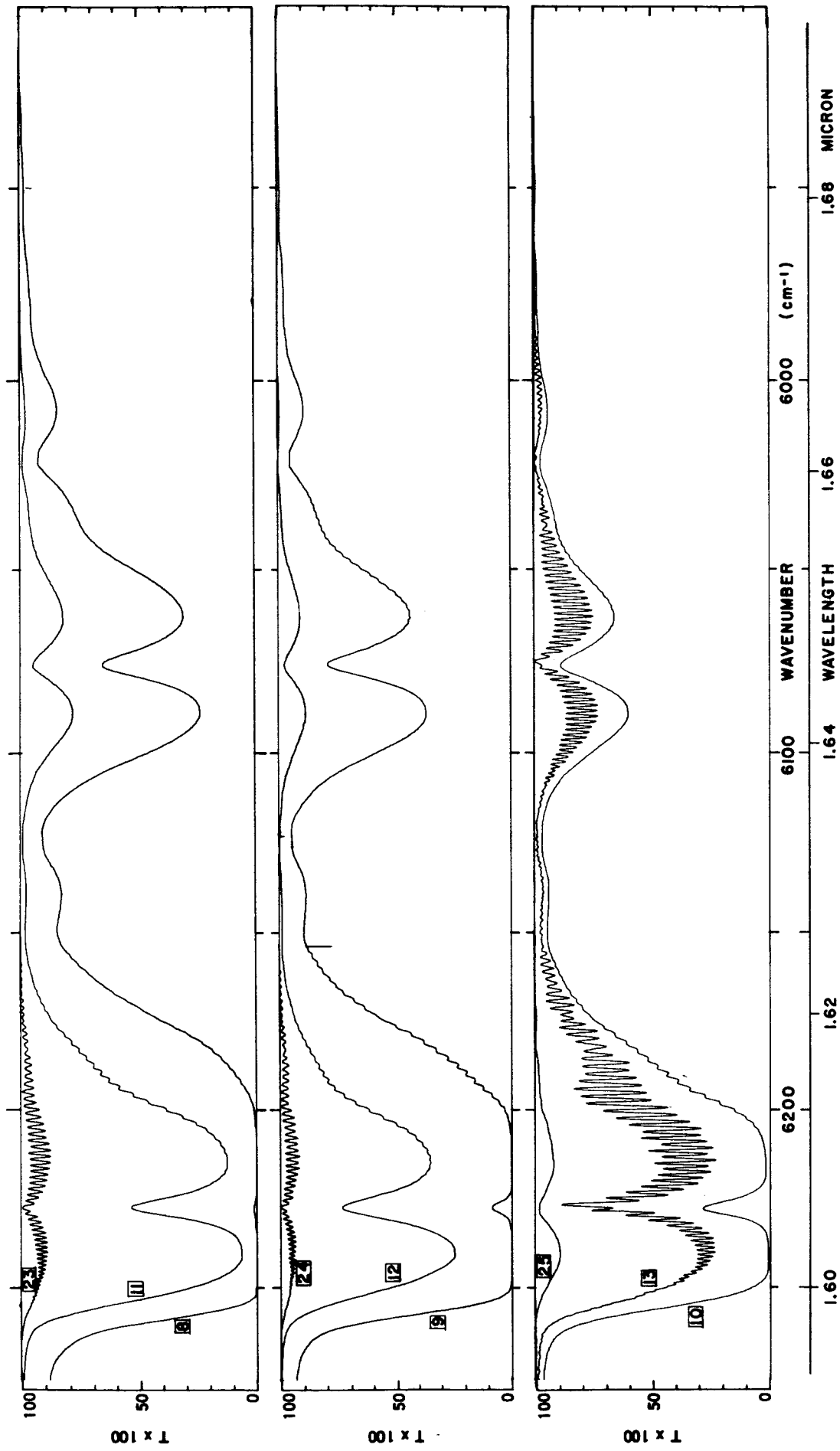


Fig. 3-6

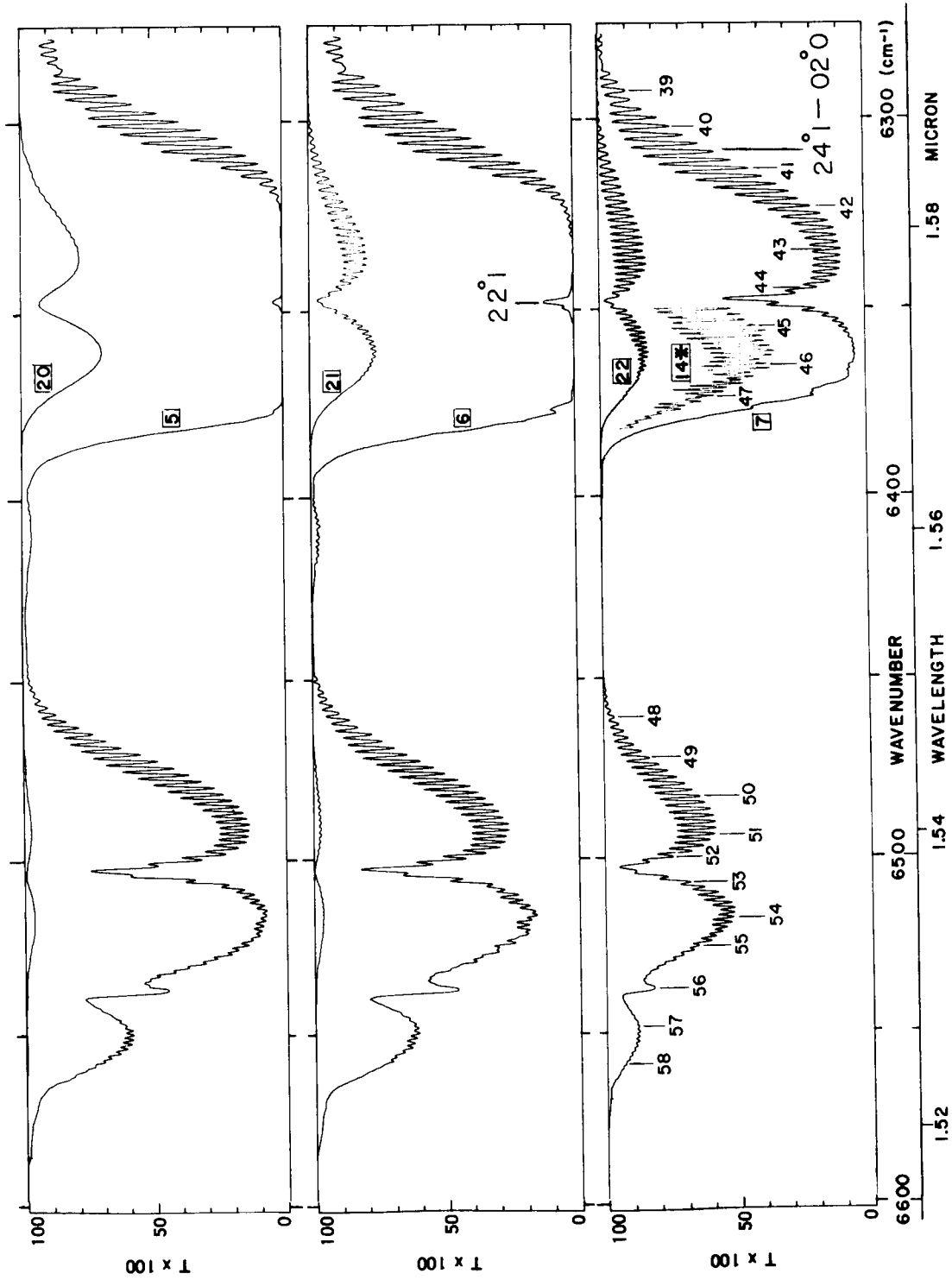


Fig. 3-7



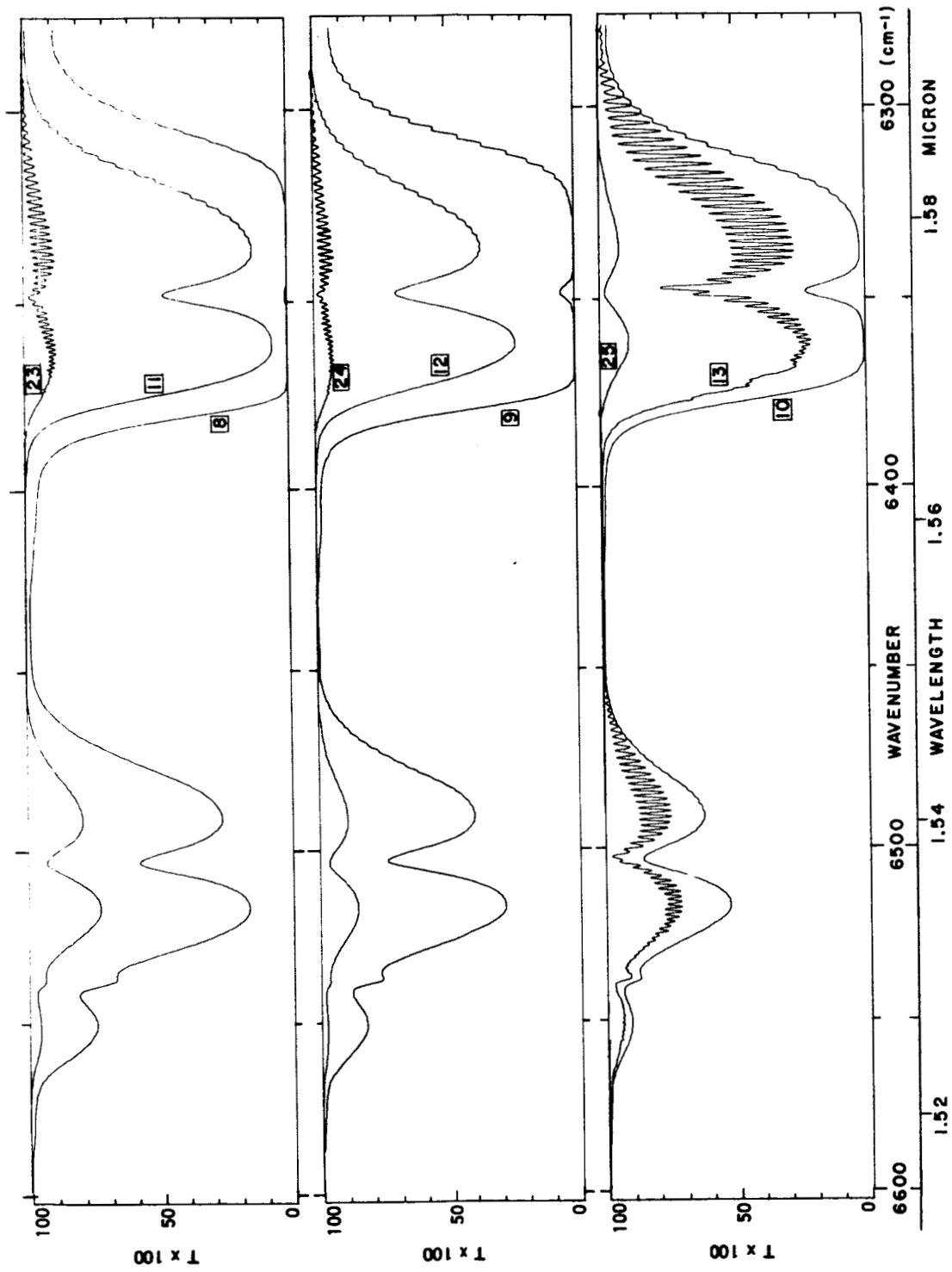


Fig. 3-8

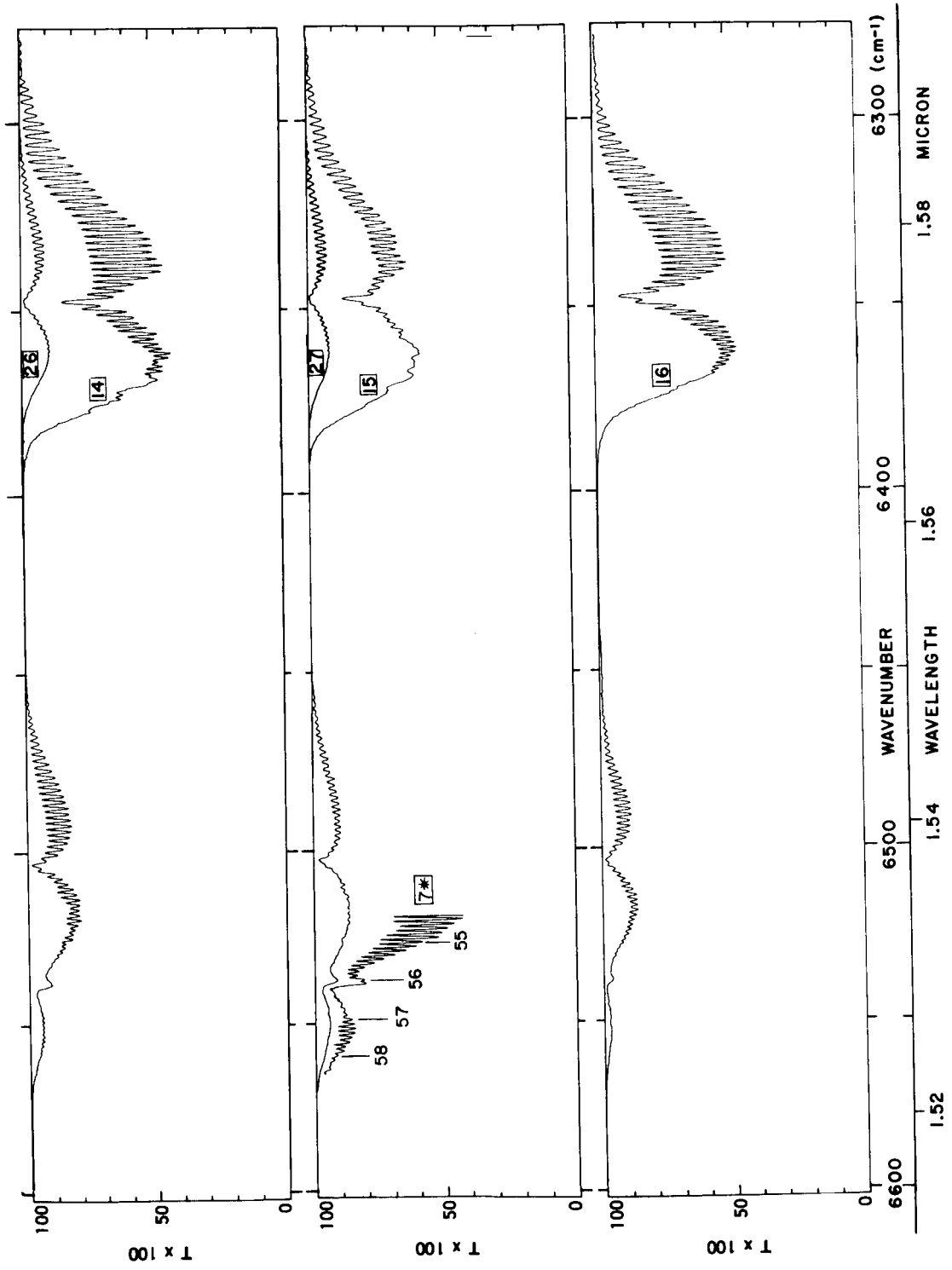


Fig. 3-9

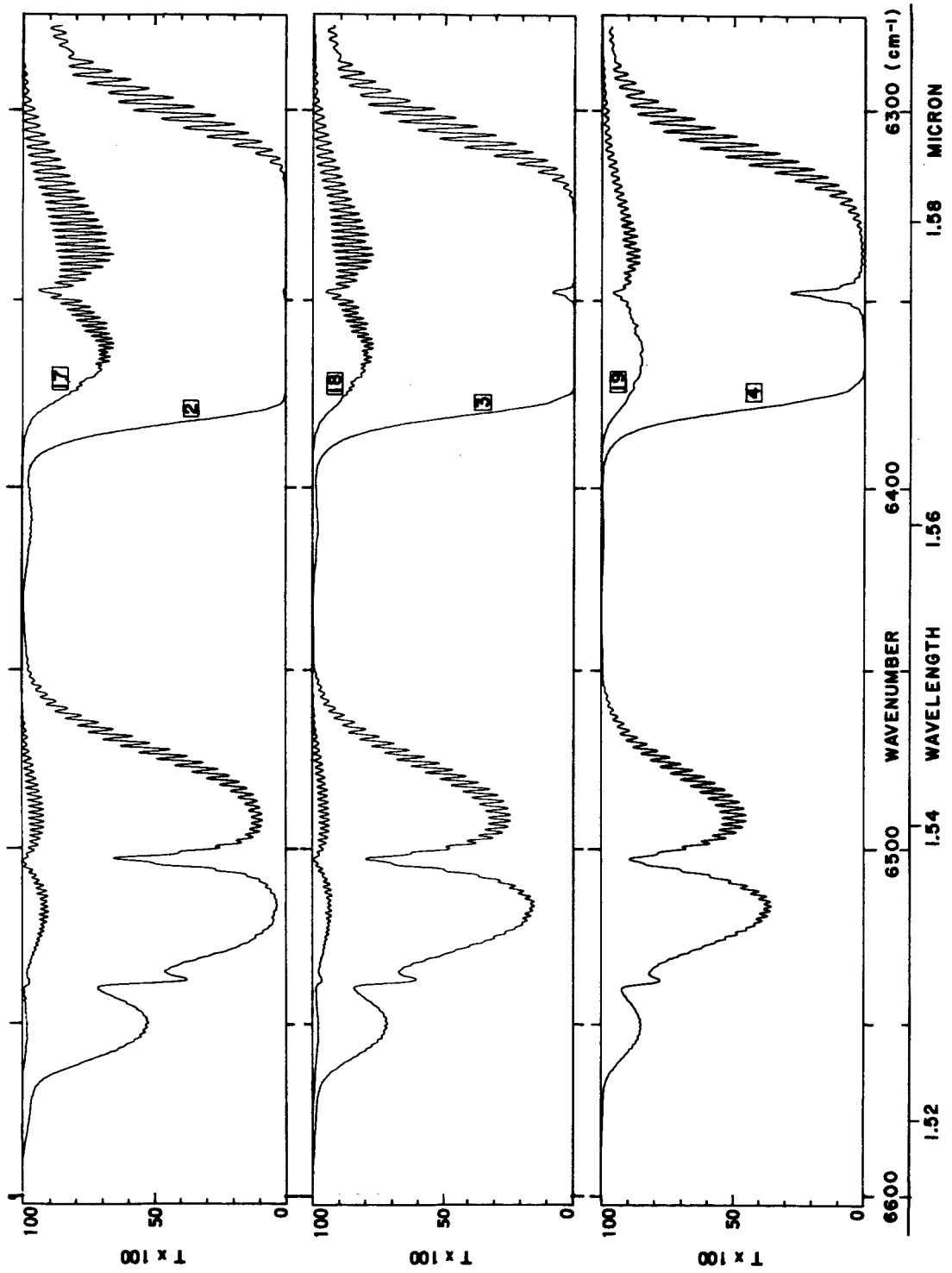


Fig. 3-10

Table 3-2

## SAMPLE PARAMETERS

Sam. No.	P	P	P <sub>e</sub>	p	P	P <sub>e</sub>
	torr	torr	torr	atm	atm	atm
1	1,900	1,900	2,500	2.50	2.50	3.29
2	1,920	1,920	2,520	2.53	2.53	3.32
3	1,920	1,920	2,520	2.53	2.53	3.32
4	1,900	1,900	2,500	2.50	2.50	3.29
5	1,522	1,522	1,995	2.00	2.00	2.62
6	760	760	992	1.000	1.000	1.31
7	760	760	992	1.000	1.000	1.31
7*	760	760	992	1.000	1.000	1.31
8	11,100	11,100	15,500	14.6	14.6	20.3
9	7,600	7,600	10,300	10.00	10.00	13.6
10	7,600	7,600	10,300	10.00	10.00	13.6
11	7,600	7,600	10,300	10.00	10.00	13.6
12	7,600	7,600	10,300	10.00	10.00	13.6
13	175	707	759	0.230	0.930	0.999
14	175	175	228	0.230	0.230	0.300
14*	175	175	228	0.230	0.230	0.300
15	88	88	114	0.116	0.116	0.150
16	58.5	743	761	0.0770	0.977	1.001
17	58.5	212	230	0.0770	0.279	0.303
18	58.5	58.5	76.1	0.0770	0.0770	0.1001
19	29.4	29.4	38.2	0.0387	0.0387	0.0503
20	506	9,800	9,960	0.665	12.9	13.1
21	506	506	659	0.665	0.665	0.865
22	17.8	223	228	0.0234	0.293	0.300
23	17.8	72	77.3	0.0234	0.0946	0.102
24	17.8	17.8	23.1	0.0234	0.0234	0.0304
25	165	9,800	9,850	0.217	12.9	13.0
26	165	710	760	0.217	0.934	1.000
27	165	165	214	0.217	0.217	0.283
28*	1,083	1,083	1,410	1.43	1.43	1.86

\*These spectra were obtained with higher resolution for calibration purposes. No calculations were made for the transmittance and integral tables.

Table 3-2 (Cont'd)

Sam. No.	L Path m	u atm cm STP	Res. Sch.	Pages on which spectra appear	
				6600-6275 -1 cm	6275-5900 -1 cm
1	933	217,000	B	3-5	3-5
2	469	110,000	B	3-13	3-6
3	237	55,700	B	3-13	3-6
4	121	28,000	B	3-13	3-6
5	469	87,100	B	3-10	3-7
6	933	86,200	B	3-10	3-7
7	237	21,900	B	3-10	3-7
7*	237	21,900	A	3-12	
8	32.9	47,300	B	3-11	3-9
9	32.9	31,600	B	3-11	3-9
10	16.5	15,900	B	3-11	3-9
11	8.26	7,930	B	3-11	3-9
12	4.16	3,990	B	3-11	3-9
13	469	9,940	B	3-11	3-9
14	469	9,940	B	3-12	3-8
14*	469	9,940	A	3-10	
15	933	9,940	C	3-12	3-8
16	469	3,320	B	3-12	3-8
17	469	3,320	B	3-13	3-6
18	469	3,320	B	3-13	3-6
19	933	3,320	C	3-13	3-6
20	16.5	1,010	B	3-10	3-7
21	16.5	1,010	B	3-10	3-7
22	469	1,010	B	3-10	3-7
23	469	1,010	B	3-11	3-9
24	469	1,010	B	3-11	3-9
25	16.5	330	B	3-11	3-9
26	16.5	330	B	3-12	3-8
27	16.5	330	B	3-12	3-8
28*	237	31,300	A		3-8

Table 3-3

CALIBRATION LINES BETWEEN 5800 AND 6600  $\text{cm}^{-1}$ .

Line No.	$\nu$ $\text{cm}^{-1}$	Line No.	$\nu$ $\text{cm}^{-1}$	Line No.	$\nu$ $\text{cm}^{-1}$
1	5891.3 M	21	6090.2	41	6313.0
2	5903.3 M	22	6100.1	42	6323.1
3	5915.1 M	23	6107.9	43	6334.4
4	5926.5 M	24	6121.9	44	6344.6
5	5938.1 M	25	6132.0	45	6354.5
6	5949.5 M	26	6141.1	46	6364.9
7	5960.8 M	27	6149.1	47	6373.4
8	5972.1 M	28	6160.2	48	6460.9
9	5983.1 M	29	6168.3	49	6472.3
10	5987.5	30	6175.8	50	6483.1
11	5996.4	31	6189.0	51	6493.4
12	6004.7	32	6197.4	52	6499.9
13	6014.4	33	6207.2	53	6506.9
14	6029.5	34	6218.1	54	6517.0
15	6038.9	35	6226.3	55	6525.1
16	6047.8	36	6237.4	56	6537.0
17	6056.5	37	6247.4	57	6547.9
18	6066.4	38	6256.4	58	6558.6
19	6074.4	39	6293.0		
20	6081.3	40	6302.1		

<sup>M</sup>The calibration lines designated with an M are  $\text{CH}_4$  lines whose wavenumbers are taken from Mohler.<sup>9</sup> The remaining lines are  $\text{CO}_2$  with wavenumbers taken from Courtoy.<sup>2</sup>

### 3.2 BAND STRENGTHS

The strength, or intensity, of an absorption band is given by

$$S_{\nu} = \int K(\nu) d\nu, \quad (3-1)$$

where the integration is performed over all  $\nu$  for which there is appreciable absorption.  $K(\nu)$ , the absorption coefficient, is defined in terms of  $T'(\nu)$ , the true transmittance which would be observed with infinite resolving power, by

$$T'(\nu) = \exp\left[-u K(\nu)\right], \text{ or } -\ln T'(\nu) = u K(\nu). \quad (3-2)$$

Of course, if more than one band contributes to the absorption at a given wavenumber,  $K(\nu)$  used in Equation (3-1) must include only the portion due to the band whose strength is being determined. The method used to estimate the contributions of each band in overlapping regions is described below.

The strengths of the bands included in this report are essentially independent of pressure over the range of pressures used. However, as the pressure is increased the lines are broadened until at 14.6 atm., the maximum pressure used, the half-widths are of the order of 1 to 1.5  $\text{cm}^{-1}$ , which is less than the spectral slitwidth used in obtaining most of the spectra. Consequently, the observed transmittance  $T(\nu)$  is very nearly the true transmittance  $T'(\nu)$ . By equating these two quantities and combining Equations (3-1) and (3-2), we obtain

$$S_{\nu} = -\frac{1}{u} \int \ln T(\nu) d\nu. \quad (3-3)$$

Equation (3-3) was used to determine the strengths of the stronger bands listed in Table 3-1 from spectra of samples at pressures greater than about 10 atmospheres. At these pressures,  $T(\nu) \approx T'(\nu)$  and Equation (3-3) can be used, provided  $T(\nu)$  is not too small, in which case the integral gets very large. Of course, the measurements cannot be made very accurately from spectra in which  $A(\nu) \equiv 1 - T(\nu)$  is too small because of the large uncertainty arising from noise or misplacement of the background curve. For small  $A(\nu)$ ,  $-\ln T(\nu) \approx A(\nu)$ . When possible, spectra were chosen so that  $0.3 \leq T(\nu) \leq 0.9$  over most of the band. It was not possible to use samples with sufficiently large absorber thickness in the shorter absorption cell to produce more than a few percent absorbance by the very weak bands. Therefore, the strengths of these bands were necessarily determined from spectra of samples contained in the longer absorption cell, although its maximum pressure is 2.5 atmospheres.

At this pressure  $T'(v)$  may be quite different from  $T(v)$ ; but Equation (3-3) can still be used, provided  $A(v)$  is small. A discussion of the limitations of Equation (3-3) when dealing with samples at relatively low pressures is given in Reference 5.

For  $\Sigma \leftarrow \Sigma$  bands (quantum number  $\ell = 0$ ) of  $\text{CO}_2$ , the strength  $S_m$  of a given line within a band is related to the band strength  $S_v$  by

$$S_m = S_v |m| \exp \left[ -\frac{B'' m(m-1)}{k\theta} \right] / Q_r \quad (3-4)$$

$m = J + 1$  for the R-branch and  $-J$  for the P-branch.  $B''$  is the rotational constant of the lower state,  $k$  is Boltzmann's constant,  $\theta$  is the temperature, and  $Q_r$  is the rotational partition function. The Q-branch is missing in  $\Sigma \leftarrow \Sigma$  bands, and contains only about one percent of the strength of  $\Pi \leftarrow \Pi$  bands ( $\ell = 1$  as in  $15^1 1 \leftarrow 01^1 0$ ). Equation (3-4) also gives the strengths of lines in the P- and R-branches of  $\Pi \leftarrow \Pi$  bands. Gray and Selvidge<sup>10</sup> have tabulated values of partition functions and relative line strengths for different types of  $\text{CO}_2$  bands at several temperatures.

According to quantum theory<sup>11</sup>, the relative strength of a difference band  $v_1, v_2^{+1}, v_3 \leftarrow 0, 1^1 0$  to its associated summation band  $v_1, v_2^0, v_3$  is given by

$$\begin{aligned} \frac{S_v(v_1, v_2^{+1}, v_3 \leftarrow 01^1 0)}{S_v(v_1, v_2^0, v_3)} &= 2 \exp(-hc 667.4/k\theta) \\ &= 0.078 \text{ for } \theta = 296^\circ\text{K}. \end{aligned} \quad (3-5)$$

$h$  is Planck's constant,  $c$  is the speed of light, and the factor 2 arises from the double degeneracy of the  $01^1 0$  state.  $667.4 \text{ cm}^{-1}$  is the difference between energy levels  $01^1 0$  and  $00^0 0$ .

Equation (3-5) also relates the strength of any difference band to its associated summation or fundamental band if the proper degeneracy factor is used and 667.4 is replaced by the difference between the energy level  $00^0 0$  and the lower level for the difference band.

The strengths of several of the bands in this region are given in Table 3-4. From Equations (2-1) and (3-3), we see that the units of band strength are  $\text{atm}^{-1} \text{cm}^{-1}$ , with the STP referring to the absorber thickness and not to the temperature at which the measurement was made. All measurements were at room temperature near  $296^\circ\text{K}$ .



TABLE 3-4

## BAND STRENGTHS

Band Center cm <sup>-1</sup>	Transition	Species <sup>a</sup>	STRENGTH (atm <sup>-1</sup> cm <sup>-1</sup> STP cm <sup>-1</sup> )		
			P-Branch (Multiply all numbers below by 10 <sup>-4</sup> )	R-Branch	Entire Band
5584.28	00 <sup>0</sup> 3-10 <sup>0</sup> 0	12,16,16	0.10 ± 0.02	0.09 ± 0.01	0.19 ± 0.03
5687.05	00 <sup>0</sup> 3-02 <sup>0</sup> 0	12,16,16	0.10 ± 0.02	0.10 ± 0.01	0.20 ± 0.03
5857.59	02 <sup>0</sup> 2	12,16,18	0.046 ± 0.006	0.056 ± 0.006	0.102 ± 0.011
6075.93	06 <sup>0</sup> 1	12,16,16	6.3 ± 0.5	7.0 ± 0.5	13.3 ± 1.0
6227.88	14 <sup>0</sup> 1	12,16,16	56 ± 6	63 ± 3	119 ± 9
6347.81	22 <sup>0</sup> 1	12,16,16	55 ± 4	63 ± 4	118 ± 8
6503.05	30 <sup>0</sup> 1	12,16,16	6.5 ± 0.4	7.0 ± 0.4 <sup>b</sup>	13.5 ± 0.8 <sup>b</sup>

<sup>a</sup> Numbers denote isotopes of C, O, and O, respectively. The strengths are based on samples containing a mixture of all isotopic species, not just the one indicated.

<sup>b</sup> Strengths of R-branch and of entire band were calculated from measured strength of P-branch by assuming 48% of strength is in P-branch.

The strengths of the  $00^03 \leftarrow 10^00$  and  $00^03 \leftarrow 02^00$  bands were determined from the spectrum shown in Figure 3-1. There were a few  $H_2O$  lines in the region of the  $00^03 \leftarrow 10^00$  band in the original spectrum because of the trace of  $H_2O$  impurity in the sample. The spectrum was modified to account for the  $H_2O$  before it was replotted and digitized. Possible errors in accounting for the  $H_2O$  absorption increase the uncertainty in the measurement of the strengths by a few percent. Since the average absorptance in the P-branch of these bands is smaller than in the R-branch, and since it is more difficult to determine the wavenumber beyond which there is significant absorption, the uncertainty in the measurements of the P-branch is greater than in the R-branch.

The  $02^02$  band of  $C^{12}O^{16}O^{18}$  appears in a region which is free of absorption by other bands and its strength could be determined although it is much weaker than some of the other bands. The value given is based on the absorber thickness of the sample containing all the isotopes of C and O. If we assume that the sample contained the natural abundance (0.20%) of  $O^{18}$ , the strength should be multiplied by 500 to apply to a sample composed of  $C^{12}O^{16}O^{18}$  molecules only. As was the case for the two bands mentioned in the previous paragraph, the uncertainty in the measurement of the P-branch was greater than that in the R-branch. The uncertainty is also relatively high because of the small absorptance by even the largest samples.

By summing the strengths given by Equation (3-4) for all the lines in the P- and R-branches, we see that approximately 48% of the strength is in the P-branch and 52% in the R-branch. We see that this agrees, within experimental error, with the results listed in Table 3-4. Results of measurements given in previous reports<sup>4,5</sup> by us tend to confirm the validity of this ratio of strength between the two branches  $\Sigma \leftarrow \Sigma$  bands.

Portions of the  $06^01$  band of  $C^{12}O_2^{16}$  are overlapped by lines of its associated difference band  $07^11 \leftarrow 01^10$  as well as  $14^01$  and  $15^11 \leftarrow 01^10$  bands of  $C^{13}O_2^{16}$ ; therefore, it was not possible to determine the strength by merely integrating  $-\ln(Tv)$  over the region covered by the band. In order to account for the  $07^11 \leftarrow 01^10$  band, we assumed that its strength was related to that of its associated summation band by Equation (3-5). We further assumed that the strength of each of the lines within this band was given by Equation (3-4) and calculated the contribution of those within the region of integration. The contribution of the two bands of  $C^{13}O_2^{16}$  was small and was calculated by assuming that their strengths were related to the strengths of the same bands of  $C^{12}O_2^{16}$  band by the ratio of the relative abundances of  $C^{13}$  and  $C^{12}$  (1.1:100).

The R-branch of the  $14^01$  band is essentially isolated from other bands; thus its strength could be determined with relatively good accuracy. In order to calculate the strength of the P-branch, the same technique was used to account for the contribution of the  $15^11 \leftarrow 01^10$  band as was used

for the  $06^0_1$  band. The same technique was also used to account for the small amount of absorption by the weaker bands which overlap the  $22^0_1$  band.

Only a small correction was required to account for the absorption by weak bands overlapping the P-branch of the  $30^0_1$  band. However, the R-branch of this band is overlapped by the  $03^1_2$  and the  $31^1_1 \leftarrow 01^1_0$  bands. The contribution of the  $31^1_1 \leftarrow 01^1_0$  band could be calculated by the use of Equation (3-5); but without spectra in which the resolution was sufficiently good to resolve the lines of the  $03^1_2$  band, its contribution would be difficult to determine. Therefore, the strength of the R-branch of the  $30^0_1$  band which is given in Table 3-4 was not determined directly from the spectra. It was obtained by assuming that the ratio of the strength of the R-branch to the P-branch (52/48) mentioned above is valid.

By using more sophisticated techniques and by making use of spectra having considerably better resolution, it would be possible to determine the strengths of more of the bands in this region. However, we have determined the strengths of the more important ones which produce a very large percentage of the absorption in this region.

## SECTION 4

### TABLE OF TRANSMITTANCES

Table 4-1 consists of values of transmittance, in percent, recorded at intervals of  $0.2 \text{ cm}^{-1}$  in the region from  $5814$  to  $6604 \text{ cm}^{-1}$ . The interval is sufficiently small that an original spectrum could be approximated very closely by plotting the tabulated values and joining the points with straight lines. The first column gives the wavenumber in  $\text{cm}^{-1}$ , and the second gives the corresponding wavelength in microns. The tables were made by photographing a portion of the computer output which was obtained from the spectra by the technique described in Appendix C of reference 4.

The  $\text{CO}_2$  partial pressure  $p$ , the equivalent pressure  $P_e$  and the absorber thickness  $u$  are shown at the top of the column corresponding to each sample. The samples are designated by the same numbers as Table 3-2 and in the spectra in Section 3.

Values are not tabulated over regions of small, but observable, absorptance ( $T \approx 1$ ) for some of the samples. The transmittance is probably greater than 0.98 or 0.99 for even the largest sample (No. 1) at all wavenumbers between  $5400$  and  $6600 \text{ cm}^{-1}$  not showing absorption in either Figure 3-1 or 3-2.

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# Table 4-1 (cont'd)

Sam. No.	1	2	3	4	5	6	7	8	9	10	11	12
$P(\text{atm})$	$2.50 \times 10^0$	$2.53 \times 10^0$	$2.57 \times 10^0$	$2.60 \times 10^0$	$2.63 \times 10^0$	$2.66 \times 10^0$	$2.69 \times 10^0$	$2.72 \times 10^0$	$2.75 \times 10^0$	$2.78 \times 10^0$	$2.81 \times 10^0$	$2.84 \times 10^0$
$P_g(\text{atm})$	$3.29 \times 10^0$	$3.32 \times 10^0$	$3.35 \times 10^0$	$3.39 \times 10^0$	$3.42 \times 10^0$	$3.45 \times 10^0$	$3.48 \times 10^0$	$3.51 \times 10^0$	$3.54 \times 10^0$	$3.57 \times 10^0$	$3.60 \times 10^0$	$3.63 \times 10^0$
$u(\text{atm cm})$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$	$2.17 \times 10^5$
$\lambda$ (micron)	1.69482	1.69486	1.69490	1.69494	1.69498	1.69502	1.69506	1.69510	1.69514	1.69518	1.69522	1.69526
$\lambda$ (cm <sup>-1</sup> )	5924.2	5924.3	5924.4	5924.5	5924.6	5924.7	5924.8	5924.9	5925.0	5925.1	5925.2	5925.3
$\nu$ (cm <sup>-1</sup> )	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
$T$ (K)	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
$T \times 10^0$	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
$T \times 10^1$	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0	1000.0
$T \times 10^2$	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0	10000.0
$T \times 10^3$	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0	100000.0
$T \times 10^4$	1000000.0	1000000.0	1000000.0	1000000.0	1000000.0	1000000.0	1000000.0	1000000.0	1000000.0	1000000.0	1000000.0	1000000.0
$T \times 10^5$	10000000.0	10000000.0	10000000.0	10000000.0	10000000.0	10000000.0	10000000.0	10000000.0	10000000.0	10000000.0	10000000.0	10000000.0
$T \times 10^6$	100000000.0	100000000.0	100000000.0	100000000.0	100000000.0	100000000.0	100000000.0	100000000.0	100000000.0	100000000.0	100000000.0	100000000.0
$T \times 10^7$	1000000000.0	1000000000.0	1000000000.0	1000000000.0	1000000000.0	1000000000.0	1000000000.0	1000000000.0	1000000000.0	1000000000.0	1000000000.0	1000000000.0
$T \times 10^8$	10000000000.0	10000000000.0	10000000000.0	10000000000.0	10000000000.0	10000000000.0	10000000000.0	10000000000.0	10000000000.0	10000000000.0	10000000000.0	10000000000.0
$T \times 10^9$	100000000000.0	100000000000.0	100000000000.0	100000000000.0	100000000000.0	100000000000.0	100000000000.0	100000000000.0	100000000000.0	100000000000.0	100000000000.0	100000000000.0
$T \times 10^{10}$	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0	1000000000000.0
$T \times 10^{11}$	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0	10000000000000.0
$T \times 10^{12}$	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0	100000000000000.0





# Table 4-1 (cont'd)

Sam. No.	$\lambda$ (aircm)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
$\rho$ (atm)	$\times 10^0$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^1$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^2$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^3$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^4$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^5$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^6$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^7$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^8$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^9$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{10}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{11}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{12}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{13}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{14}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{15}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{16}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{17}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{18}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{19}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02
$\rho$ (atm)	$\times 10^{20}$	2.50	2.53	2.57	2.60	2.63	2.66	2.69	2.72	2.75	2.78	2.81	2.84	2.87	2.90	2.93	2.96	2.99	3.02



# Table 4-1 (cont'd)

Sam. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
$P(\text{atm})$	$2.50 \times 10^0$	$2.53 \times 10^0$	$2.57 \times 10^0$	$2.60 \times 10^0$	$2.63 \times 10^0$	$2.66 \times 10^0$	$2.69 \times 10^0$	$2.72 \times 10^0$	$2.75 \times 10^0$	$2.78 \times 10^0$	$2.81 \times 10^0$	$2.84 \times 10^0$	$2.87 \times 10^0$	$2.90 \times 10^0$	$2.93 \times 10^0$	$2.96 \times 10^0$	$2.99 \times 10^0$	$3.02 \times 10^0$
$P_g(\text{atm})$	$3.28 \times 10^0$	$3.32 \times 10^0$	$3.36 \times 10^0$	$3.39 \times 10^0$	$3.43 \times 10^0$	$3.46 \times 10^0$	$3.49 \times 10^0$	$3.52 \times 10^0$	$3.55 \times 10^0$	$3.58 \times 10^0$	$3.61 \times 10^0$	$3.64 \times 10^0$	$3.67 \times 10^0$	$3.70 \times 10^0$	$3.73 \times 10^0$	$3.76 \times 10^0$	$3.79 \times 10^0$	$3.82 \times 10^0$
$u$ (ft/min)	$2.17 \times 10^5$	$1.10 \times 10^5$	$5.57 \times 10^4$	$2.80 \times 10^4$	$8.71 \times 10^3$	$8.62 \times 10^3$	$2.19 \times 10^4$	$4.73 \times 10^4$	$3.16 \times 10^4$	$1.59 \times 10^4$	$7.93 \times 10^3$	$3.99 \times 10^3$	$9.96 \times 10^2$	$9.96 \times 10^2$	$3.32 \times 10^3$	$3.32 \times 10^3$	$3.32 \times 10^3$	$3.32 \times 10^3$
$\lambda$ (cm <sup>-1</sup> )	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$	$5987.0$
$\lambda$ (micron)	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$	$1.67029$
$\nu$ (cm <sup>-1</sup> )	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$	$16702.9$



# Table 4-1 (cont'd)

Wave No.	$\lambda$ ( $\mu\text{m}^{-1}$ )	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
$\tau(4\text{-}\tau)$	$\times 10^0$	2.53	2.53	2.53	2.50	2.60	1.66	1.00	1.00	1.00	1.00	1.00	1.00	2.10	2.30	1.16	7.70	7.70	3.87	6.65	6.65	$\times 10^{-1}$
$\rho(4\text{-}\rho)$	$\times 10^0$	3.32	3.32	3.32	3.32	2.62	1.51	1.31	1.36	1.36	1.36	1.36	1.36	9.89	3.00	1.50	1.00	1.00	3.03	1.00	1.00	$\times 10^{-1}$
$\eta(4\text{-}\eta)$	$\times 10^0$	1.10	5.57	2.80	2.71	2.62	2.19	4.73	3.16	1.59	7.93	3.99	3.99	9.94	9.94	9.94	3.32	3.32	3.32	3.32	3.32	$\times 10^3$
STP	$\times 10^5$	$\times 10^5$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^4$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$
$\tau$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$
$\rho$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$
$\eta$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$
STP	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$	$\times 100$



# Table 4-1 (cont'd)

Sam. No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
$r$ (atm)	$2.50 \times 10^0$	$2.53 \times 10^0$	$2.56 \times 10^0$	$2.59 \times 10^0$	$2.62 \times 10^0$	$2.65 \times 10^0$	$2.68 \times 10^0$	$2.71 \times 10^0$	$2.74 \times 10^0$	$2.77 \times 10^0$	$2.80 \times 10^0$	$2.83 \times 10^0$	$2.86 \times 10^0$	$2.89 \times 10^0$	$2.92 \times 10^0$	$2.95 \times 10^0$	$2.98 \times 10^0$	$3.01 \times 10^0$	$3.04 \times 10^0$	$3.07 \times 10^0$	$3.10 \times 10^0$
$P_g$ (atm)	$3.29 \times 10^0$	$3.32 \times 10^0$	$3.35 \times 10^0$	$3.38 \times 10^0$	$3.41 \times 10^0$	$3.44 \times 10^0$	$3.47 \times 10^0$	$3.50 \times 10^0$	$3.53 \times 10^0$	$3.56 \times 10^0$	$3.59 \times 10^0$	$3.62 \times 10^0$	$3.65 \times 10^0$	$3.68 \times 10^0$	$3.71 \times 10^0$	$3.74 \times 10^0$	$3.77 \times 10^0$	$3.80 \times 10^0$	$3.83 \times 10^0$	$3.86 \times 10^0$	$3.89 \times 10^0$
$u$ (atm cm STP)	$2.17 \times 10^5$	$2.18 \times 10^5$	$2.19 \times 10^5$	$2.20 \times 10^5$	$2.21 \times 10^5$	$2.22 \times 10^5$	$2.23 \times 10^5$	$2.24 \times 10^5$	$2.25 \times 10^5$	$2.26 \times 10^5$	$2.27 \times 10^5$	$2.28 \times 10^5$	$2.29 \times 10^5$	$2.30 \times 10^5$	$2.31 \times 10^5$	$2.32 \times 10^5$	$2.33 \times 10^5$	$2.34 \times 10^5$	$2.35 \times 10^5$	$2.36 \times 10^5$	$2.37 \times 10^5$
$\lambda$ (atm cm)	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$
$\lambda$ (atm cm)	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$
$\lambda$ (atm cm)	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$	$1.45426$







Table with 10 columns of numerical data, containing various values ranging from 0.0 to 100.0 across multiple rows.

# Table 4-1 (cont'd)

Line No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
P (atm)	2.50 x 10 <sup>1</sup>	2.53 x 10 <sup>1</sup>	2.53 x 10 <sup>1</sup>	2.50 x 10 <sup>1</sup>	2.00 x 10 <sup>1</sup>	1.00 x 10 <sup>1</sup>	1.00 x 10 <sup>1</sup>	1.56 x 10 <sup>1</sup>	1.00 x 10 <sup>1</sup>	1.00 x 10 <sup>1</sup>	1.00 x 10 <sup>1</sup>	1.00 x 10 <sup>1</sup>	2.10 x 10 <sup>-1</sup>	2.10 x 10 <sup>-1</sup>	7.70 x 10 <sup>-2</sup>	7.70 x 10 <sup>-2</sup>	7.70 x 10 <sup>-2</sup>	7.70 x 10 <sup>-2</sup>	3.87 x 10 <sup>-2</sup>	6.65 x 10 <sup>-1</sup>	6.65 x 10 <sup>-1</sup>	
P <sub>e</sub> (atm)	3.29 x 10 <sup>1</sup>	3.32 x 10 <sup>1</sup>	3.32 x 10 <sup>1</sup>	3.29 x 10 <sup>1</sup>	2.62 x 10 <sup>1</sup>	1.31 x 10 <sup>1</sup>	1.31 x 10 <sup>1</sup>	2.03 x 10 <sup>1</sup>	1.36 x 10 <sup>1</sup>	1.36 x 10 <sup>1</sup>	1.36 x 10 <sup>1</sup>	1.36 x 10 <sup>1</sup>	9.99 x 10 <sup>-1</sup>	9.99 x 10 <sup>-1</sup>	1.00 x 10 <sup>1</sup>	1.00 x 10 <sup>1</sup>	3.03 x 10 <sup>1</sup>	3.03 x 10 <sup>1</sup>	5.03 x 10 <sup>1</sup>	1.31 x 10 <sup>1</sup>	8.65 x 10 <sup>-1</sup>	
u (atm cm) STP	2.17 x 10 <sup>5</sup>	5.57 x 10 <sup>5</sup>	5.57 x 10 <sup>5</sup>	2.60 x 10 <sup>4</sup>	8.71 x 10 <sup>4</sup>	8.62 x 10 <sup>4</sup>	2.19 x 10 <sup>4</sup>	4.73 x 10 <sup>4</sup>	3.16 x 10 <sup>4</sup>	1.59 x 10 <sup>4</sup>	7.93 x 10 <sup>3</sup>	3.99 x 10 <sup>3</sup>	9.96 x 10 <sup>2</sup>	9.96 x 10 <sup>2</sup>	9.96 x 10 <sup>2</sup>	3.32 x 10 <sup>3</sup>	3.32 x 10 <sup>3</sup>	3.32 x 10 <sup>3</sup>	3.32 x 10 <sup>3</sup>	3.32 x 10 <sup>3</sup>	1.01 x 10 <sup>3</sup>	1.01 x 10 <sup>3</sup>
λ (electron)	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954	1.53954
ν (cm <sup>-1</sup> )	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0
1000·ν	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0	6192.0
100·ν	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2	619.2
10·ν	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92	61.92
1·ν	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192	6.192







# Table 4-1 (cont'd)

Wave- length (micron)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27					
$\tau$ (atm)	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$				
$P_e$ (atm)	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$			
$w$ (atm-cm)	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$		
STP	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	$1.1 \times 10^0$	
$\nu$ (cm <sup>-1</sup> )	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000





# Table 4-1 (cont'd)

Series No.	λ (microns)	1		2		3		4		5		6		7		8		9		10		11		12		13		14		15		16		17		18		19		20		21		22		23		24		25		26		27	
		T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ	T	τ		
1-11551	1.41551	2.1	2.3	3.3	3.4	4.3	4.4	5.3	5.4	6.3	6.4	7.3	7.4	8.3	8.4	9.3	9.4	10.3	10.4	11.3	11.4	12.3	12.4	13.3	13.4	14.3	14.4	15.3	15.4	16.3	16.4	17.3	17.4	18.3	18.4	19.3	19.4	20.3	20.4	21.3	21.4	22.3	22.4	23.3	23.4	24.3	24.4	25.3	25.4	26.3	26.4	27.3	27.4		
1-11552	1.41552	2.1	2.3	3.3	3.4	4.3	4.4	5.3	5.4	6.3	6.4	7.3	7.4	8.3	8.4	9.3	9.4	10.3	10.4	11.3	11.4	12.3	12.4	13.3	13.4	14.3	14.4	15.3	15.4	16.3	16.4	17.3	17.4	18.3	18.4	19.3	19.4	20.3	20.4	21.3	21.4	22.3	22.4	23.3	23.4	24.3	24.4	25.3	25.4	26.3	26.4	27.3	27.4		

















# Table 4-1 (cont'd)

Wavelength (microns)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27		
1.58072	14.7	19.3	45.1	59.5	37.0	37.0	59.5	17.7	51.1	12.3	92.4	92.4	92.4	12.3	51.1	37.0	59.5	17.7	51.1	37.0	59.5	17.7	51.1	37.0	59.5	17.7	51.1	37.0	59.5

Table with 10 columns and 1000 rows. Columns contain numerical data points. Rows are labeled with alphanumeric codes such as A1122, A1123, A1124, etc., up to A1298.



Table with multiple columns containing numerical data and alphanumeric identifiers. The data is organized in rows and columns, with some cells containing values like '0.0', '1.5', '2.1', etc., and others containing alphanumeric strings like 'A551.1', 'B123.4', etc.













6435-1	1-55460	98-4	99-1	99-2	99-3	99-4	99-5	99-6	99-7	99-8	99-9	99-10	99-11	99-12	99-13	99-14	99-15	99-16	99-17	99-18	99-19	99-20	99-21	99-22	99-23	99-24	99-25	99-26	99-27	99-28	99-29	99-30	99-31	99-32	99-33	99-34	99-35	99-36	99-37	99-38	99-39	99-40	99-41	99-42	99-43	99-44	99-45	99-46	99-47	99-48	99-49	99-50	99-51	99-52	99-53	99-54	99-55	99-56	99-57	99-58	99-59	99-60	99-61	99-62	99-63	99-64	99-65	99-66	99-67	99-68	99-69	99-70	99-71	99-72	99-73	99-74	99-75	99-76	99-77	99-78	99-79	99-80	99-81	99-82	99-83	99-84	99-85	99-86	99-87	99-88	99-89	99-90	99-91	99-92	99-93	99-94	99-95	99-96	99-97	99-98	99-99	100-0	100-1	100-2	100-3	100-4	100-5	100-6	100-7	100-8	100-9	100-10	100-11	100-12	100-13	100-14	100-15	100-16	100-17	100-18	100-19	100-20	100-21	100-22	100-23	100-24	100-25	100-26	100-27	100-28	100-29	100-30	100-31	100-32	100-33	100-34	100-35	100-36	100-37	100-38	100-39	100-40	100-41	100-42	100-43	100-44	100-45	100-46	100-47	100-48	100-49	100-50	100-51	100-52	100-53	100-54	100-55	100-56	100-57	100-58	100-59	100-60	100-61	100-62	100-63	100-64	100-65	100-66	100-67	100-68	100-69	100-70	100-71	100-72	100-73	100-74	100-75	100-76	100-77	100-78	100-79	100-80	100-81	100-82	100-83	100-84	100-85	100-86	100-87	100-88	100-89	100-90	100-91	100-92	100-93	100-94	100-95	100-96	100-97	100-98	100-99	100-100
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# Table 4-1 (cont'd)

λ (micron)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	
(cm <sup>-1</sup> )	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100	T × 100
6504.0	1.53303	10.0	25.4	51.7	88.7	130.0	182.0	242.0	312.0	392.0	480.0	580.0	690.0	810.0	950.0	1100.0	1280.0	1480.0	1700.0	1950.0	2250.0	2600.0
6504.2	1.53304	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6504.4	1.53305	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6504.6	1.53306	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6504.8	1.53307	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6505.0	1.53308	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6505.2	1.53309	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6505.4	1.53310	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6505.6	1.53311	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6505.8	1.53312	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6506.0	1.53313	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6506.2	1.53314	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6506.4	1.53315	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6506.6	1.53316	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6506.8	1.53317	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6507.0	1.53318	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6507.2	1.53319	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6507.4	1.53320	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6507.6	1.53321	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6507.8	1.53322	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0
6508.0	1.53323	1.7	4.3	9.1	15.5	23.8	34.5	48.5	66.0	88.0	116.0	152.0	198.0	255.0	325.0	410.0	515.0	645.0	800.0	985.0	1210.0	1480.0







Table with multiple columns containing numerical data, organized in a grid-like structure. The columns contain various numerical values, possibly representing measurements or statistical data points.







## SECTION 5

### TABLE OF INTEGRATED ABSORPTANCE

Values of the integrated absorptance over the region from 5814 to 6582  $\text{cm}^{-1}$  are presented in Table 5-1 for the samples listed in Table 3-2. The integrals were calculated from the transmittance tables in Section 4 by assuming a spectrum could be constructed by plotting the transmittance values and joining them with straight lines. The important sample parameters are listed at the top of each column corresponding to a given sample.

The lower limit of integration  $\nu'$ , which is shown at the top of each column, was chosen at a point where there was very little, if any, absorption.  $\nu'$  is different for some samples than for others, since the integration was not performed over some of the regions of small absorption. The absorption by small samples is negligible in some regions where it is important for large samples.

In regions where the structure in the spectra is regular, the integrated absorptance was calculated at wavenumbers midway between the line centers. Thus, in the case of no overlapping, the difference between two successive tabulated values is the equivalent width of the absorption line in the interval. In some other regions where the structure was not particularly regular, the integrated absorptance was calculated at wavenumbers corresponding to absorptance minima. In still other regions where there was but little structure or where the absorptance minima would shift as the pressure or absorber thickness was changed, the values were calculated at integral wavenumbers, or possibly at integral half-wavenumbers, depending on the amount of information one might expect to obtain from closer readings.



# Table 5-1 $\int_{v_1}^{v_2} A(v)dv$ (cont'd.)

Wavenumber	13	14	15	16	17	18	19	20	21
$v_1$ ( $\text{cm}^{-1}$ )	5955	5955	5955	5955	5955	5955	6011.7	6021.9	6021.9
$v_2$ ( $\text{cm}^{-1}$ )	5955	5955	5955	5955	5955	5955	6011.7	6021.9	6021.9
$A(v)$	2.10 $\times 10^{-1}$	2.30 $\times 10^{-1}$	1.16 $\times 10^{-1}$	7.70 $\times 10^{-2}$	7.76 $\times 10^{-2}$	7.76 $\times 10^{-2}$	1.95 $\times 10^{-2}$	6.65 $\times 10^{-1}$	6.65 $\times 10^{-1}$
$\int_{v_1}^{v_2} A(v)dv$	9.99 $\times 10^{-1}$	3.00 $\times 10^{-1}$	1.50 $\times 10^{-1}$	1.00 $\times 10^{-1}$	3.03 $\times 10^{-1}$	1.00 $\times 10^{-1}$	5.03 $\times 10^{-2}$	2.31 $\times 10^{-1}$	8.65 $\times 10^{-1}$
$A(v)$ STP	9.99 $\times 10^3$	9.99 $\times 10^3$	9.99 $\times 10^3$	3.32 $\times 10^3$	3.32 $\times 10^3$	3.32 $\times 10^3$	3.32 $\times 10^3$	1.01 $\times 10^3$	1.01 $\times 10^3$

5995.0	0.	0.	0.	0.	0.	0.			
5999.6	0.	0.	0.	0.	0.	0.			
5995.0	0.039	0.001	0.	0.000	0.	0.			
5970.0	0.027	0.003	0.	0.000	0.000	0.			
5975.0	0.054	0.023	0.009	0.007	0.004	0.002			
5990.0	0.093	0.045	0.008	0.023	0.015	0.011			
5995.0	0.129	0.073	0.026	0.040	0.033	0.026			
5996.7	0.142	0.092	0.035	0.054	0.043	0.032			
5998.4	0.156	0.114	0.045	0.069	0.053	0.041			
5990.2	0.176	0.113	0.057	0.083	0.065	0.050			
5992.1	0.198	0.134	0.072	0.094	0.077	0.060			
5993.8	0.219	0.153	0.089	0.113	0.092	0.076			
5995.5	0.243	0.175	0.111	0.128	0.101	0.075			
5997.2	0.266	0.199	0.137	0.146	0.113	0.085			
5998.9	0.296	0.223	0.164	0.172	0.133	0.099			
5992.2	0.332	0.261	0.200	0.202	0.149	0.114			
5993.9	0.375	0.295	0.251	0.233	0.174	0.133			
5995.6	0.421	0.337	0.294	0.264	0.202	0.154			
5997.3	0.471	0.382	0.342	0.288	0.225	0.176			
5999.0	0.527	0.437	0.392	0.317	0.243	0.187			
5993.5	0.569	0.479	0.443	0.345	0.275	0.210			
5995.2	0.616	0.521	0.463	0.368	0.297	0.221			
5996.9	0.667	0.565	0.504	0.391	0.320	0.234			
5998.6	0.720	0.607	0.537	0.415	0.333	0.250			
5999.3	0.774	0.644	0.564	0.480	0.392	0.280			
5991.7	0.831	0.729	0.631	0.520	0.414	0.293			
5993.4	0.894	0.777	0.679	0.569	0.447	0.310			
5995.1	0.927	0.824	0.730	0.601	0.492	0.324			
5996.8	0.995	0.845	0.764	0.643	0.535	0.342			
5998.5	1.068	0.901	0.844	0.681	0.563	0.354			
5993.1	1.132	1.033	0.912	0.716	0.602	0.380			
5994.8	1.226	1.127	0.990	0.753	0.645	0.418			
5996.5	1.315	1.215	1.068	0.791	0.689	0.445			
5998.2	1.408	1.304	1.147	0.833	0.735	0.478			
5999.9	1.512	1.397	1.232	0.880	0.779	0.511			
5993.4	1.621	1.487	1.309	0.930	0.825	0.545			
5995.1	1.743	1.592	1.388	0.982	0.877	0.583			
5996.8	1.870	1.712	1.477	1.044	0.934	0.626			
5998.5	2.027	1.818	1.568	1.112	1.001	0.669			
5999.2	2.197	1.945	1.655	1.193	1.073	0.713			
5993.2	2.380	2.082	1.755	1.284	1.144	0.761			
5994.9	2.584	2.224	1.867	1.386	1.221	0.814			
5996.6	2.805	2.381	1.985	1.498	1.307	0.874			
5998.3	3.040	2.543	2.097	1.618	1.403	0.934			
5999.0	3.314	2.715	2.224	1.745	1.498	1.000			
5993.7	3.591	2.911	2.337	1.875	1.610	1.064			
5995.4	3.864	3.079	2.478	2.001	1.703	1.131			
5997.1	4.162	3.220	2.600	2.138	1.806	1.194			
5998.8	4.436	3.444	2.731	2.270	1.919	1.269			
5999.5	4.706	3.645	2.885	2.402	2.003	1.343			
5993.9	4.981	3.810	2.994	2.524	2.115	1.383			
5995.6	5.192	3.973	3.107	2.622	2.143	1.439			
5997.3	5.380	4.110	3.266	2.701	2.244	1.484			
5999.0	5.523	4.224	3.295	2.756	2.326	1.529			
5999.7	5.610	4.295	3.331	2.801	2.359	1.569			
5994.1	5.649	4.333	3.392	2.828	2.392	1.581			
5995.8	5.757	4.424	3.467	2.877	2.447	1.621			
5997.5	5.925	4.555	3.597	2.955	2.523	1.663			
5999.2	6.141	4.709	3.675	3.051	2.615	1.707			
5999.9	6.402	4.873	3.807	3.163	2.704	1.754			
5994.3	6.683	5.047	3.926	3.292	2.802	1.814			
5996.0	6.923	5.263	4.082	3.433	2.921	1.884			
5997.7	7.278	5.453	4.227	3.572	3.023	1.958			
5999.4	7.591	5.654	4.377	3.718	3.142	2.022			
5999.1	7.907	5.853	4.517	3.864	3.254	2.093			
5992.4	8.200	6.049	4.644	3.998	3.344	2.159			
5994.1	8.480	6.233	4.765	4.117	3.443	2.222			
5995.8	8.745	6.414	4.889	4.234	3.544	2.271			
5997.5	8.996	6.582	4.927	4.344	3.643	2.347			
5999.2	9.229	6.744	5.146	4.444	3.741	2.424			













# Table 5-1 $\int_{\nu_1}^{\nu_2} A_{ul} \omega d\nu$ (cont'd)

Ser. No.	13	14	15	16	17	18	19	20	21
$\mu(\text{atm})$	$2.40 \times 10^{-1}$	$2.30 \times 10^{-1}$	$1.16 \times 10^{-1}$	$7.70 \times 10^{-2}$	$7.70 \times 10^{-2}$	$7.70 \times 10^{-2}$	$3.87 \times 10^{-2}$	$6.65 \times 10^{-1}$	$6.65 \times 10^{-1}$
$P_c(\text{atm})$	$9.99 \times 10^{-1}$	$3.00 \times 10^{-1}$	$1.50 \times 10^{-1}$	$1.00 \times 10^{-1}$	$3.03 \times 10^{-1}$	$1.00 \times 10^{-1}$	$5.03 \times 10^{-2}$	$1.31 \times 10^1$	$8.65 \times 10^{-1}$
$\omega(\text{atm} \cdot \text{cm})$	$9.96 \times 10^2$	$9.94 \times 10^2$	$9.96 \times 10^2$	$3.32 \times 10^2$	$3.32 \times 10^2$	$3.32 \times 10^2$	$3.32 \times 10^2$	$1.01 \times 10^3$	$1.01 \times 10^3$
STP									
$\nu$ ( $\text{cm}^{-1}$ )	$\nu^1=5955$ $\text{cm}^{-1}$	$\nu^1=5955$ $\text{cm}^{-1}$	$\nu^1=5955$ $\text{cm}^{-1}$	$\nu^1=5965$ $\text{cm}^{-1}$	$\nu^1=5965$ $\text{cm}^{-1}$	$\nu^1=5965$ $\text{cm}^{-1}$	$\nu^1=6141.7$ $\text{cm}^{-1}$	$\nu^1=6021.9$ $\text{cm}^{-1}$	$\nu^1=6021.9$ $\text{cm}^{-1}$
5471.5	94.045	92.955	46.504	51.477	35.064	27.753		24.144	19.409
5473.2	94.178	93.077	46.571	51.524	35.097	27.787		24.157	19.921
5475.0	94.317	93.174	46.657	51.583	35.133	27.826		24.172	19.935
5476.8	94.482	93.283	46.750	51.649	35.187	27.869		24.186	19.953
5478.7	94.682	93.423	46.852	51.732	35.243	27.920		24.202	19.975
5480.5	94.897	93.587	46.969	51.826	35.307	27.976		24.221	20.000
5482.2	95.128	93.715	47.086	51.925	35.372	28.033		24.243	20.027
5484.0	95.402	93.892	47.221	52.043	35.441	28.102		24.268	20.063
5485.7	95.675	94.071	47.361	52.169	35.513	28.170		24.299	20.097
5487.5	95.987	94.263	47.513	52.307	35.647	28.241		24.338	20.137
5489.2	96.296	94.454	47.650	52.444	35.753	28.312		24.379	20.173
5490.9	96.613	94.651	47.813	52.582	35.851	28.387		24.423	20.221
5492.6	96.931	94.864	47.969	52.723	35.951	28.467		24.468	20.264
5494.2	97.234	95.053	50.118	52.852	36.043	28.544		24.511	20.304
5495.9	97.543	95.263	50.276	52.981	36.145	28.618		24.554	20.342
5497.5	97.819	95.443	50.421	53.099	36.232	28.684		24.591	20.375
5499.1	98.059	95.621	50.554	53.190	36.313	28.745		24.623	20.402
5500.7	98.242	95.763	50.687	53.256	36.369	28.797		24.650	20.427
5502.3	98.374	95.882	50.754	53.309	36.407	28.830		24.677	20.437
5504.6	98.451	95.937	50.819	53.342	36.427	28.859		24.689	20.441
5506.1	98.611	96.043	50.925	53.406	36.473	28.904		24.700	20.452
5507.6	98.836	96.202	51.001	53.487	36.537	28.952		24.714	20.473
5509.1	99.113	96.391	51.216	53.611	36.622	29.021		24.739	20.504
5510.6	99.426	96.602	51.387	53.746	36.724	29.106		24.773	20.541
5512.1	99.768	96.833	51.557	53.897	36.835	29.182		24.816	20.585
5513.5	100.114	97.061	51.733	54.050	36.954	29.267		24.860	20.630
5514.9	100.471	97.301	51.925	54.212	37.073	29.351		24.908	20.677
5516.3	100.832	97.543	52.111	54.375	37.191	29.437		24.960	20.725
5517.7	101.188	97.785	52.298	54.535	37.313	29.524		25.012	20.774
5519.1	101.537	98.027	52.486	54.692	37.427	29.608		25.063	20.821
5520.5	101.881	98.262	52.672	54.838	37.543	29.696		25.114	20.865
5521.8	102.188	98.474	52.837	54.967	37.641	29.767		25.162	20.907
5523.1	102.475	98.673	52.994	55.088	37.733	29.841		25.205	20.945
5524.4	102.745	98.873	53.149	55.199	37.823	29.916		25.244	20.973
5525.7	102.985	99.042	53.286	55.297	37.905	29.973		25.277	21.003
5527.0	103.204	99.202	53.424	55.383	37.993	29.993		25.305	21.035
5528.3	103.395	99.363	53.549	55.457	38.049	29.987		25.329	21.063
5529.5	103.549	99.491	53.656	55.512	38.102	29.934		25.348	21.077
5530.7	103.681	99.603	53.751	55.567	38.145	29.917		25.366	21.094
5531.9	103.796	99.705	53.838	55.601	38.185	29.921		25.380	21.105
5533.1	103.890	99.795	53.913	55.635	38.218	29.926		25.390	21.114
5534.3	103.975	99.873	53.982	55.665	38.244	29.927		25.399	21.122
5535.8	104.255	70.137	54.246	55.768	38.332	29.975		25.421	21.141
5539.0	104.288	70.183	54.282	55.777	38.345	29.994		25.427	21.145
5541.5	104.361	70.247	54.357	55.805	38.373	29.926		25.442	21.155
5543.1	104.419	70.294	54.415	55.827	38.393	29.946		25.449	21.157
5544.3	104.480	70.347	54.473	55.846	38.402	29.964		25.453	21.158
5545.8	104.559	70.413	54.547	55.872	38.431	29.967		25.457	21.159
5547.2	104.636	70.477	54.617	55.899	38.455	29.910		25.462	21.161
5548.2	104.694	70.525	54.671	55.920	38.475	29.952		25.465	21.162
5550.0	104.794	70.612	54.771	55.957	38.513	29.965		25.470	21.167
5551.3	104.867	70.675	54.841	55.988	38.534	29.991		25.474	21.168
5552.6	104.936	70.743	54.918	56.021	38.563	29.916		25.480	21.173
5554.0	105.007	70.807	54.975	56.053	38.587	29.943		25.487	21.173
5555.4	105.073	70.869	55.037	56.081	38.613	29.970		25.494	21.175
5556.7	105.125	70.923	55.090	56.103	38.627	29.992		25.500	21.179
5557.8	105.167	70.962	55.130	56.119	38.644	29.970		25.506	21.180
5559.0	105.209	71.001	55.172	56.136	38.662	29.978		25.511	21.182
5560.0	105.240	71.023	55.203	56.148	38.669	29.973		25.515	21.183
5562.0	105.296	71.072	55.252	56.167	38.685	29.978		25.521	21.184
5564.0	105.325	71.105	55.285	56.181	38.693	29.972		25.526	21.185
5566.0	105.347	71.122	55.307	56.193	38.700	29.978		25.528	21.185
5568.0	105.385	71.129	55.319	56.201	38.705	29.899		25.529	21.185
5570.0	105.388	71.131	55.326	56.207	38.703	29.816		25.520	21.185
5572.0	105.391	71.132	55.326	56.209	38.702	29.819		25.520	21.185
5574.0	105.399	71.132	55.325	56.210	38.702	29.819		25.520	21.185
5576.0	105.404	71.132	55.325	56.210	38.702	29.819		25.520	21.185
5578.0	105.405	71.132	55.325	56.210	38.702	29.819		25.520	21.185
5580.0	105.405	71.132	55.325	56.210	38.702	29.819		25.520	21.185
5582.0	105.405	71.132	55.325	56.210	38.702	29.819		25.520	21.185

## SECTION 6

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