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INFRARED ABSORPTION BY CH₄, H₂O AND CO₂

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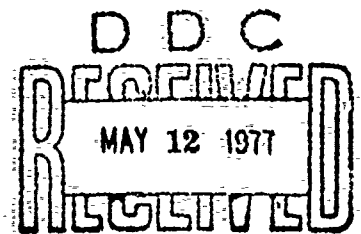
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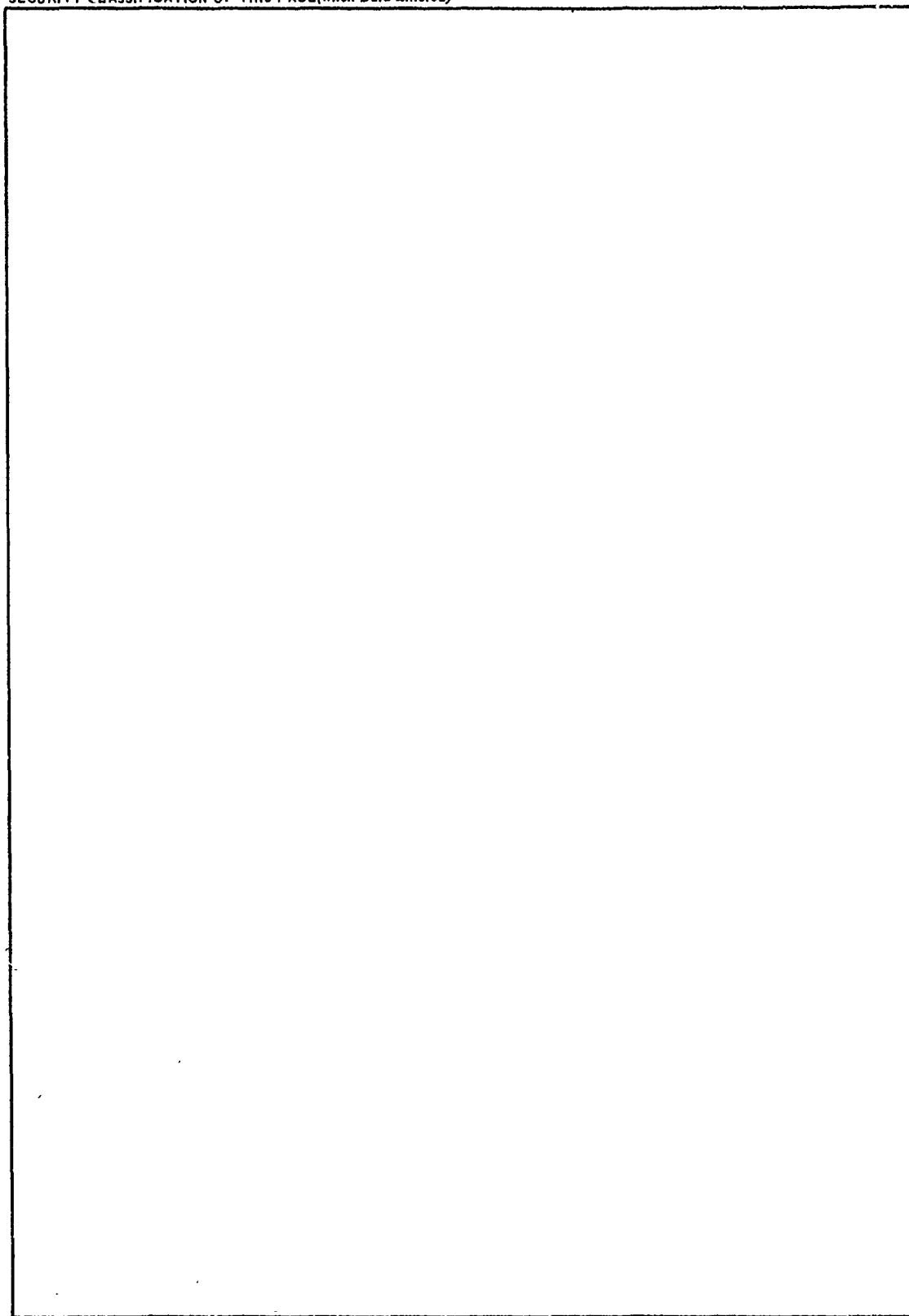
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SECTION 1

INTRODUCTION

BACKGROUND

The primary purpose for the experimental work reported herein has been to provide absorption data to check the Air Force Geophysical Laboratories (AFGL) line-parameter listing¹ and to serve as a basis for possible modification to the listing. The particular absorption bands studied have been selected because of current applications that require that the absorption by these bands in known atmospheric paths be predictable as accurately as possible. Emphasis has been placed on data from which improved values of line intensities, line widths and continuum absorption coefficients can be determined. No new data are reported on line positions because reliable data on the center positions of most of the significant absorption lines are either already incorporated in the AFGL listing or are available elsewhere.

Section 2 provides spectral data on the absorption by CH_4 between 1150 and 1400 cm^{-1} . Absorption in the lower atmosphere by CH_4 is typically much less than that by H_2O in this same spectral region. However, in the less humid, upper atmosphere, CH_4 produces a large fraction of the absorption that occurs. Because of the complex nature of CH_4 absorption spectra, it is quite difficult to derive a set of CH_4 line parameters from which absorption spectra can be predicted accurately. Recent comparisons of calculated spectra with experimental data indicate that major revisions in the current listing of CH_4 lines are in order. Relative intensities of many of the individual lines can be checked with the detailed data provided in Section 2. The samples investigated cover wide ranges of absorber thickness and pressure with the temperature near 304K.

Some new and improved data are presented in Section 3 on the continuum absorption by pure H_2O between 600 and 1300 cm^{-1} . Some of these data are believed to be more accurate than similar data reported previously by us.² Impurities in the H_2O samples studied previously may have resulted in values of the continuum absorption coefficient that are too high by as much as 20 percent in some parts of this spectral region. The samples reported in Section 3 varied in temperature from 296K to 430K. The continuum absorption coefficient decreases rapidly with increasing temperatures.

Detailed spectral data are presented in Section 4 on the absorption by H_2O between 333 and 444 cm^{-1} . Calculating H_2O absorption in this spectral region from a list of line parameters is complicated by the apparent presence of some continuum absorption in addition to absorption by the lines centered within the region. The data in Section 4 represent samples that cover wide

¹R. A. McClatchey, W. S. Benedict, S. A. Clough, D. E. Burch, R. F. Calfee, K. Fox, L. S. Rothman, and J. S. Garing, "AFCRL Atmospheric Absorption Line Parameters Compilation", AFCRL-TR-73-0096, 26 January 1973. (Associated with this report is a magnetic tape listing the line parameters.)

²D. E. Burch, "Investigation of the Absorption of Infrared Radiation by Atmospheric Gases"; Semi-Annual Technical Report, Contract F19628-69-C-0263, 31 January 1970.

ranges of absorber thickness and pressure, making it possible to determine the relative contribution by the continuum and by nearby lines.

Absorption and emission by the well-known 15 μm bands of CO_2 forms the basis for experiments on the remote sensing of the atmospheric temperature profile from satellite-borne instruments. The many overlapping bands in this region make it difficult to calculate accurately the irradiance at the top of the atmosphere, or at a satellite, within any narrow spectral interval in the band system. The extensive data presented in Section 5 are intended to provide a means of checking the intensities, widths, and shapes of the CO_2 lines that are involved in the atmospheric calculations. The samples studied cover wide ranges of absorber thickness and pressures from approximately 0.002 atm to 1 atm. Three sample temperatures, approximately 245 K, 274 K and 310 K, were employed to represent most of the temperature range in the earth's atmosphere. Although temperatures somewhat lower than those employed occur in the atmosphere, the wide temperature range of the samples studied should provide a reliable check on the predicted temperature dependence. Thus, reliable extrapolation to lower temperatures should be possible after the best possible set of line parameters has been derived.

DEFINITIONS, SYMBOLS, AND NOMENCLATURE

The absorber thickness, u , of a gas sample is given by

$$\begin{aligned} u(\text{molecules/cm}^2) &= 2.69 \times 10^{19} p^* (\text{atm}) L(\text{cm}) (273/\theta) \\ &= 7.34 \times 10^{21} p^* L/\theta. \end{aligned} \tag{1}$$

The temperature θ is in degrees Kelvin, and L is the geometrical path length through the sample. The density-equivalent-pressure p^* of the absorbing gas may vary slightly from the partial pressure p at high pressures. The gas does not follow exactly the perfect gas law at the higher pressures for which the Van der Waals' equation of state is required. The deviation from the perfect gas law causes a non-linear relationship between the pressure and the density of the gas. At partial pressures less than 1 atm, p can be substituted for p^* without introducing significant error, but p^* may differ significantly from p at high pressures. For all of the pressures used in the present investigation, the following simple expression is sufficiently accurate:

$$p^* = p(1 + c p) \tag{2}$$

The pressures are in atm, and c depends on the gas species and temperature. Near room temperature, $c \approx 0.005$ for CO_2 , and 0.002 for CH_4 . When a sample consists of two or more gas species, the total pressure is represented by P .

The true transmittance that would be observed with infinite resolving power is given by

$$T' = \exp(-u\epsilon), \quad \text{or} \quad (-1/u) \ln T' = \epsilon, \quad (3)$$

where ϵ is the absorption coefficient. Because of the finite slitwidth of a spectrometer and variations in ϵ with wavenumber due to line structure, the observed transmittance T may differ from T' at the same wavenumber. The quantity T represents a weighted average of T' over the interval passed by the spectrometer.

The absorption coefficient due to a single collision-broadened absorption line at a point within a few cm^{-1} of the line centers, ν_0 , is given approximately by the Lorentz shape:

$$k_L = \frac{S_J}{\pi} \frac{\alpha}{(\nu - \nu_0)^2 + \alpha^2}. \quad (4)$$

The line intensity

$$S_J = \int k d\nu \quad (5)$$

is essentially independent of pressure for the conditions of the present study. It has been shown^{3, 4, 5} that for $|\nu - \nu_0|$ greater than a few cm^{-1} , the Lorentz equation may require modification. The equation can be modified by employing a correction factor χ , which is a function of $|\nu - \nu_0|$, so that

$$k = k_L \chi = \frac{S}{\pi} \frac{\alpha \chi}{(\nu - \nu_0)^2 + \alpha^2}, \quad (6)$$

where k_L denotes the value given by the Lorentz coefficient. The value of χ is approximately equal to unity for small $|\nu - \nu_0|$, but may be quite different for large $|\nu - \nu_0|$. For example, $\chi \ll 1$ for the extreme wings of CO_2 lines,

³D. E. Burch, D. A. Gryvnak, R. R. Patty, and C. E. Bartky; J. Opt. Soc. Am. 59, 267 (1969). Also Publication No. U-3203, Philco-Ford Corporation, Aeronutronic Division, Contract NOnr 3560(00), 31 August 1968.

⁴B. H. Winters, S. Silverman, and W. S. Benedict: Journal of Quantitative Spectroscopy and Radiative Transfer 4, 527 (1964).

⁵D. E. Burch, D. A. Gryvnak, and J. D. Pembroke; "The Absorption by H_2O Between 1630 and 2245 cm^{-1} ", Philco-Ford Report U-5090, Contract No. F19628-73-C-0011, January 1973.

but χ may be greater than 1 for H_2O lines. (Ref. 5). Most of the samples in the present study were at sufficiently high pressures for collision broadening to be dominant. Under this condition, the line half-width α is proportional to the collision frequency and thus to the gas pressure. At pressures less than approximately 0.01 atm, the more complex Voigt profile is appropriate.

In many reports and papers, including ones published previously by us, S_J is called line strength. In order to conform with the majority of the workers in the field, we now refer to S_J as the intensity, not the strength. The terms S_v refers to the intensity of a vibration-rotation band that contains many lines. The combined intensity of a system of bands is denoted by S_{sys} . If essentially all of the absorption in a given spectral region results from a system of overlapping bands, we see from Eq. (3) that

$$S_{sys} = \int K dv = (-1/u) \int \ln T' dv. \quad (7)$$

When the spectral slitwidth is only a few-tenths of a cm^{-1} wide and gas samples are pressurized to approximately 10 atm or more, the observed transmittance T is very nearly equal to the true, monochromatic transmittance T' . Under this condition, $\int \ln T' dv$ is approximately equal to the measurable quantity $\int \ln T dv$ so that S_{sys} can be determined experimentally. The intensity of the CH_4 band system reported in Section 2 has been measured by this suggested method from spectra of high-pressure samples of $CH_4 + N_2$.

Because of differences in the efficiencies of collisions with molecules of different gas species, the half-width α of a collision-broadened line depends on the partial pressure of each of the gas species present in a sample. The equivalent pressure P_e given by the following equation is a convenient parameter when dealing with absorption by a mixture that contains non-absorbing N_2 in addition to the absorbing gas species:

$$P_e = Bp + p_{N_2} = (B-1)p + P, \quad (8)$$

where P is the total pressure, p_{N_2} is the partial pressure of N_2 , and p is the partial pressure of the absorbing gas species. The experimentally determined constant B is the ratio of the self-broadening ability to the broadening ability of N_2 . The equivalent pressure is therefore directly proportional to α , regardless of the relative concentrations of the absorbing gas and the N_2 . We note that P_e approximates P for dilute mixtures of the absorbing gas species in N_2 ($p \ll p_{N_2}$). The CO_2 samples discussed in Section 5 consisted of CO_2 plus dry air; the dry air consisted of 79% N_2 and 21% O_2 to closely approximate the atmosphere. The same symbol, P_e , represents the equivalent pressure of these samples with p_{air} replacing p_{N_2} in Eq. (8).

Because of the proportional relationship between α and pressure, k is also proportional to pressure in the extreme wings of a line where $|\nu - \nu_0| \gg \alpha$. It follows from Eq. (6) that the wing-absorption coefficient C due to the extreme wings of several lines is equal to the sum of all k 's due to the individual lines and is proportional to pressure. Because wing absorption changes slowly with wavenumber, it is frequently called continuum absorption. Continuum absorption may also arise from dimers, such as $\text{H}_2\text{O}:\text{H}_2\text{O}$, or from pressure-induced bands. These two types of continuum have the same pressure dependence as absorption by line wings; therefore, in some cases we cannot distinguish which is the source of the absorption being measured. The absorption coefficient due to local lines whose centers occur within a few cm^{-1} of the point of observation is denoted by $\mathcal{K}(\text{local})$. This quantity may vary rapidly with wavenumber and depends on pressure because of collision-broadening of the absorption lines. At a given wavenumber, there may be absorption by local lines as well as by continuum. Therefore, for a pure H_2O sample, the total absorption coefficient $\mathcal{K}$ in Eq. (3) is given by

$$\mathcal{K} = \mathcal{K}(\text{local}) + C_s^0 p. \quad (9)$$

The normalized continuum coefficient C_s^0 is the value of C_s at a given temperature when $p = 1$ atm. The subscript s denotes self-broadening of the lines. Since α^0 is proportional to p , and u is proportional to pL , it follows that $(-\ln T)$ for continuum due to the wings of lines is proportional to $p^2 L$.

For a mixture of $\text{H}_2\text{O} + \text{N}_2$, such as several of those used in the present study, Eq. (9) must be modified to account for broadening of the H_2O lines by N_2 .

$$\mathcal{K} = \mathcal{K}(\text{local}) + C_s^0 p + C_{\text{N}_2}^0 p_{\text{N}_2}. \quad (10)$$

Consider the continuum at a wavenumber where the absorption is due to the wings ($|\nu - \nu_0| \gg \alpha$) of several lines with the Lorentz shape given by Eq. (4). It follows from the above discussion that $C_s^0 / C_{\text{N}_2}^0$ is equal to the ratio $\alpha_s^0 / \alpha_{\text{N}_2}^0$ of the normalized half-widths for self-broadening and N_2 broadening. Previous results of measurements at wavenumbers where most of the absorption is due to H_2O lines centered between approximately 1 and 20 cm^{-1} away from the point of the measurement indicate that this ratio is approximately 5. However, at wavenumbers where much of the absorption is apparently due to more distant lines, the ratio $C_s^0 / C_{\text{N}_2}^0$ may be much greater than 5. These results indicate that the extreme wings of lines are non-Lorentzian and that the correction factor χ (Eq. (5)) is greater at large $|\nu - \nu_0|$ for self-broadened lines than for N_2 -broadened H_2O lines. Variations in the values of $C_s^0 / C_{\text{N}_2}^0$ are discussed in Sections 3 and 4 for H_2O .

SECTION 2

ABSORPTION BY CH_4 BETWEEN 1100 cm^{-1} AND 1400 cm^{-1}

SAMPLING

The mixtures of $\text{CH}_4 + \text{N}_2$ were mixed in a 50-liter, glass-lined mixing tank. The CH_4 was first added to the evacuated tank, and the pressure was measured after the gas in the tank had stabilized. The N_2 was then added, and the resulting mixture was stirred by an internal mixer. The internal blade of the mixer was driven through a rotary seal by a hand-held drill motor. The gases were mixed for approximately 30 seconds, and the mixture was allowed to stabilize before the final pressure was measured. Total pressures of the mixtures were typically 10 atm. The concentration of the mixture was calculated by dividing the pressure of the CH_4 by the total pressure of the mixture with a small correction made for the non-linearity in the relationship between the molecular density and the pressure (see Eq. (2)). Two or three separate batches were mixed for each concentration, and the absorption by a few samples from each batch was measured. The results were compared as a check for the consistency of the mixing procedure.

All of the CH_4 samples for which data are reported were contained in one of two sample cells. The cell lengths are 10.2 cm and 0.574 cm. Each cell had two gas lines attached to it. The gas inlet line was attached to the gas-handling manifold; the other line went to the vacuum pump. The valves and manifold system were arranged so that it was convenient to fill the cell and flush it at nearly constant pressure with a pre-mixed sample of gas. The cell could also be evacuated quickly. The sample cells used for the majority of the data were contained in a vacuum tank that was connected directly to the vacuum tank containing the grating monochromator. The optical path external to the sample cell was evacuated to eliminate interference due to absorption by H_2O in the atmosphere. A few of the data were obtained a few years ago with the sample cell in an enclosure that was flushed with dry nitrogen.

A typical sampling procedure consisted of filling the evacuated sample cell from a previously mixed batch to a pressure slightly above the desired final pressure. The gas mixture was then allowed to flush slowly through the cell at a nearly constant pressure for several seconds in order to flush out any small amount of air that might have leaked into the gas-handling system. After the cell was flushed adequately, a portion of the mixture was pumped from the sample cell, leaving the desired final pressure for study. Several checks were made for possible errors introduced by leaks or by adsorption of some of the sample gas on the walls of the sample cell or gas lines. The total pressures and absorber thicknesses listed below for the samples are believed to be accurate to less than $\pm 1\%$ and $\pm 2\%$, respectively.

The temperature of the sample cell was measured by a thermometer mounted in good thermal contact with it. The thermometer was read visually through a plexiglass cover on the vacuum tank. Sample cell temperatures varied between

approximately 303 K and 310 K. The cells were not intentionally heated above room temperature; heat from the radiation source and the motor in the vacuum tank increased the internal temperature.

SPECTRAL DATA

All of the CH_4 data except for those in Table 2 are based on spectral curves obtained with the grating spectrometer described previously.⁶ The grating used for the CH_4 data contains 75 grooves/mm and is blazed for maximum efficiency at 12 μm . Overlapping orders of shorter wavelength energy were eliminated by an NaCl prism in the beam just ahead of the grating monochromator. The CH_4 data in Table 2 were obtained earlier to determine the intensity of the band by employing a commercial grating monochromator (Perkin-Elmer Model E-1) with the optical path flushed with dry nitrogen. The radiant energy from a Nernst glower in either instrument was chopped at 450 Hz to permit amplification and synchronous demodulation of the signal from the detector, which contains a Ge:Cu element cooled by liquid helium. The dc output of the synchronous demodulator was proportional to the amount of chopped energy incident on the detector and was displayed on a strip-chart recorder. A "background" curve was scanned with the sample cell evacuated, either immediately before or after the sample spectrum was scanned. The spectral curve of transmittance for a sample was obtained by comparing the original curve to the corresponding background curve.

Wavenumber calibration was provided from eleven CH_4 lines and seven H_2O lines of known wavenumber.⁷ The CH_4 lines chosen are either unblended, or only slightly blended, so that the positions could be determined with the required accuracy. The H_2O lines were observed by allowing a small amount of air to enter the vacuum tank that contained the sample cell. It was assumed that each spectrum is linear in wavenumber between each two adjacent calibration lines. Throughout most of the spectral region covered in Figs. 1 and 2, the estimated uncertainty in the wavenumber calibration is less than 0.3 cm^{-1} . The spectral slitwidth for the data in these two figures varies from approximately 0.75 cm^{-1} at 1170 cm^{-1} to 1.05 cm^{-1} at 1400 cm^{-1} . This slitwidth is based on a "triangular" slit function and is equal to the width of the triangle at half-maximum transmission.

Figures 1 and 2 show computer-plotted curves of transmittance for eleven representative samples of $\text{CH}_4 + \text{N}_2$. The important parameters for each sample are given in the figures. Samples 3 and 4 produce the most absorption, and the corresponding curves cover the widest spectral region. The sample pressures have been varied over a wide range up to 1 atm to provide information on the effect of collision broadening.

At the time the data were obtained, the detector noise was greater than normal. As a result, the rms noise on the recorder tracings corresponded to

⁶D. E. Burch, D. A. Gryvnak, and R. R. Patty. J. Opt. Soc. Am. 57, 885 (1967).

⁷NBS Monograph No. 16 (1959).

between 1% and 2% of the signal observed with the sample cell evacuated. The one-second electronic time constant used to reduce the noise necessitated scanning the spectra slowly to avoid errors in regions of rapidly changing recorder deflection. In addition to uncertainties introduced by the noise, the relatively long time required to scan a spectrum increased the possibility of errors due to slow drift that resulted from variations in the source emittance or in the optical alignment. By carefully comparing a complete spectrum with short regions scanned at separate times for an identical sample, we were able to detect and account for most of the significant errors due to drift. Complete spectra of the different samples were also compared for consistency. Areas of inconsistency were re-checked with new samples, and the appropriate changes were made to each spectrum before it was digitized. The digitizing process smoothed-out some of the noise that appeared on the original records.

One apparent discrepancy that was not found until the data were reduced occurs in the spectrum of Sample 3 in Fig. 2. The transmittance values indicated in the figure between approximately 1310 cm^{-1} and 1365 cm^{-1} would be more accurate if they were multiplied by 0.98. The values at lower wavenumbers, between 1250 cm^{-1} and 1310 cm^{-1} , may also be too high by a slightly smaller amount. This error probably resulted from placing the background curve too low on the sample spectrum. Some of the small structures in the spectra of the extreme wings of the band are uncertain and may be due to impurities in the sample. Except for the errors noted, the values of transmittance indicated by Figs. 1 and 2 are believed to be accurate to ± 0.02 .

Table 1 shows values of the cumulative integrated absorptance for the samples represented in Figs. 1 and 2. Each column corresponds to the sample indicated at the top of the column. The lower and upper limits of integration depend on the amount of absorption by the sample.

In accordance with Eq. (7), the value of $(-1/u) \int \ln T' dv$ over the spectral region including an entire band system is equal to the intensity of the band system. As discussed in Section 1, immediately below Eq. (7), the value of the integral $\int \ln T' dv$ is equal to the experimentally measurable quantity $\int \ln T dv$ when the spectral structure is sufficiently wide relative to the spectral slitwidth. A widely used method of measuring band intensities involves measuring the transmittance T for a sample at high pressures so that the individual absorption lines are collision broadened to a width comparable to the spectral slitwidth. Table 2 summarizes the results of such a measurement on a $\text{CH}_4 + \text{N}_2$ sample at a total pressure of 10 atm and the absorber thickness equal to 6.93×10^{18} molecules/cm². At this high sample pressure, the lines are broadened so that the transmittance T observed with a 0.8 cm^{-1} spectral slitwidth is approximately equal to the true transmittance T' that would be observed with infinite resolving power. The value of absorber thickness is sufficiently large to produce measurable absorption throughout most of the band while not producing too much absorption in the strongest portions to be measured accurately. If the transmittance is too low, $-\ln T$ can not be measured accurately. The results in Table 2 are consistent with results not included that were obtained for other high-pressure samples with different absorber thicknesses.

The combined intensity of all of the lines within a spectral interval is approximately equal to the difference between the two values of the cumulative integral listed in Table 2 for the two wavenumbers bounding the interval. Some allowance must be made for the finite slitwidth and for the contributions by wings of lines. For example, all of the contribution by a line may not be included if its center occurs in the spectral interval of interest but its wings extend outside the interval. The opposite effect results from the extreme wings of lines centered just outside of the interval.

The intensity measured for the entire band system is $574 \pm 25 \times 10^{-20}$ molecules⁻¹ cm² cm⁻¹. This value compares favorably with the previously published values listed in Table 3 below.

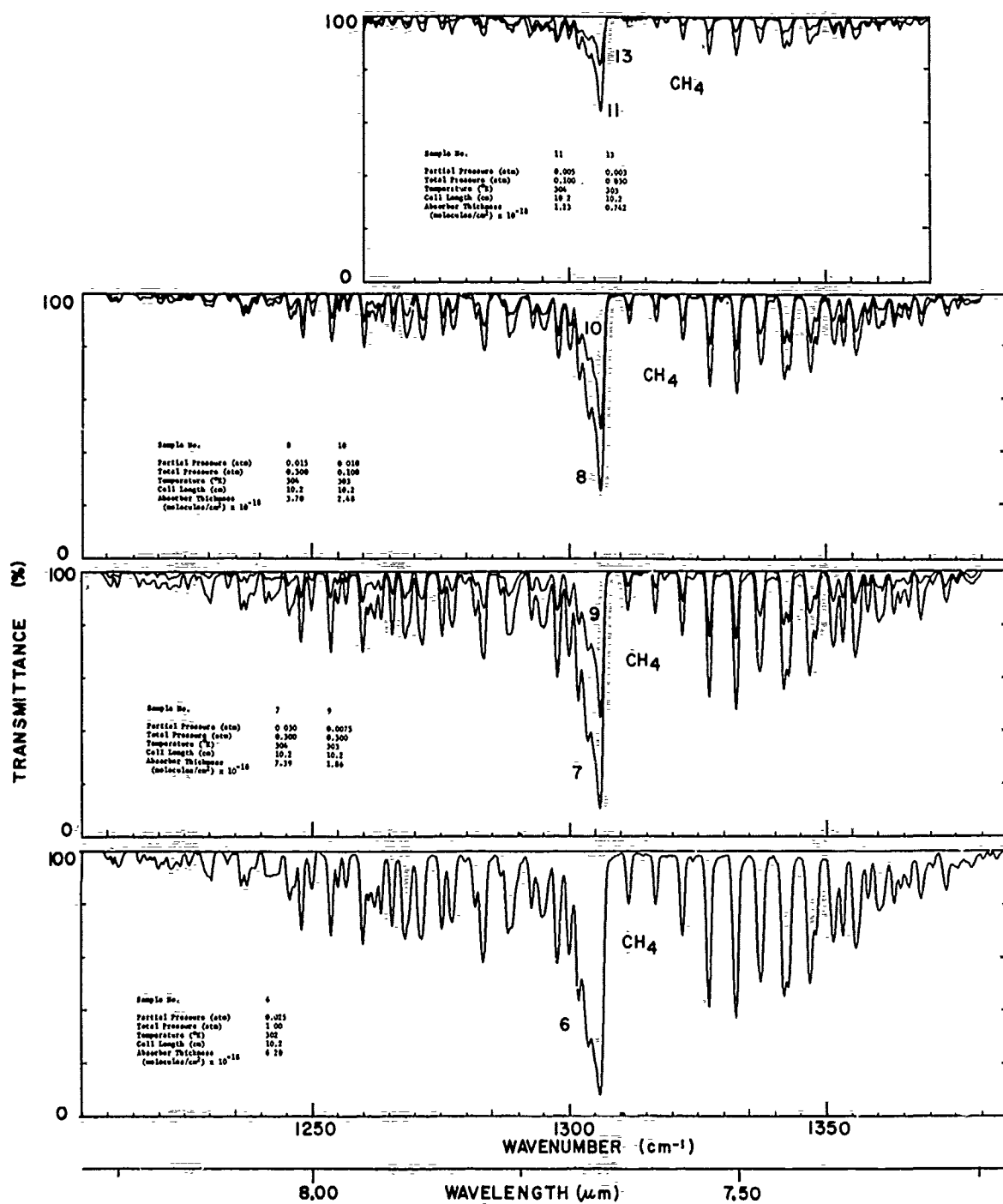


Figure 1. Spectral curves of transmittance of seven CH₄ samples.

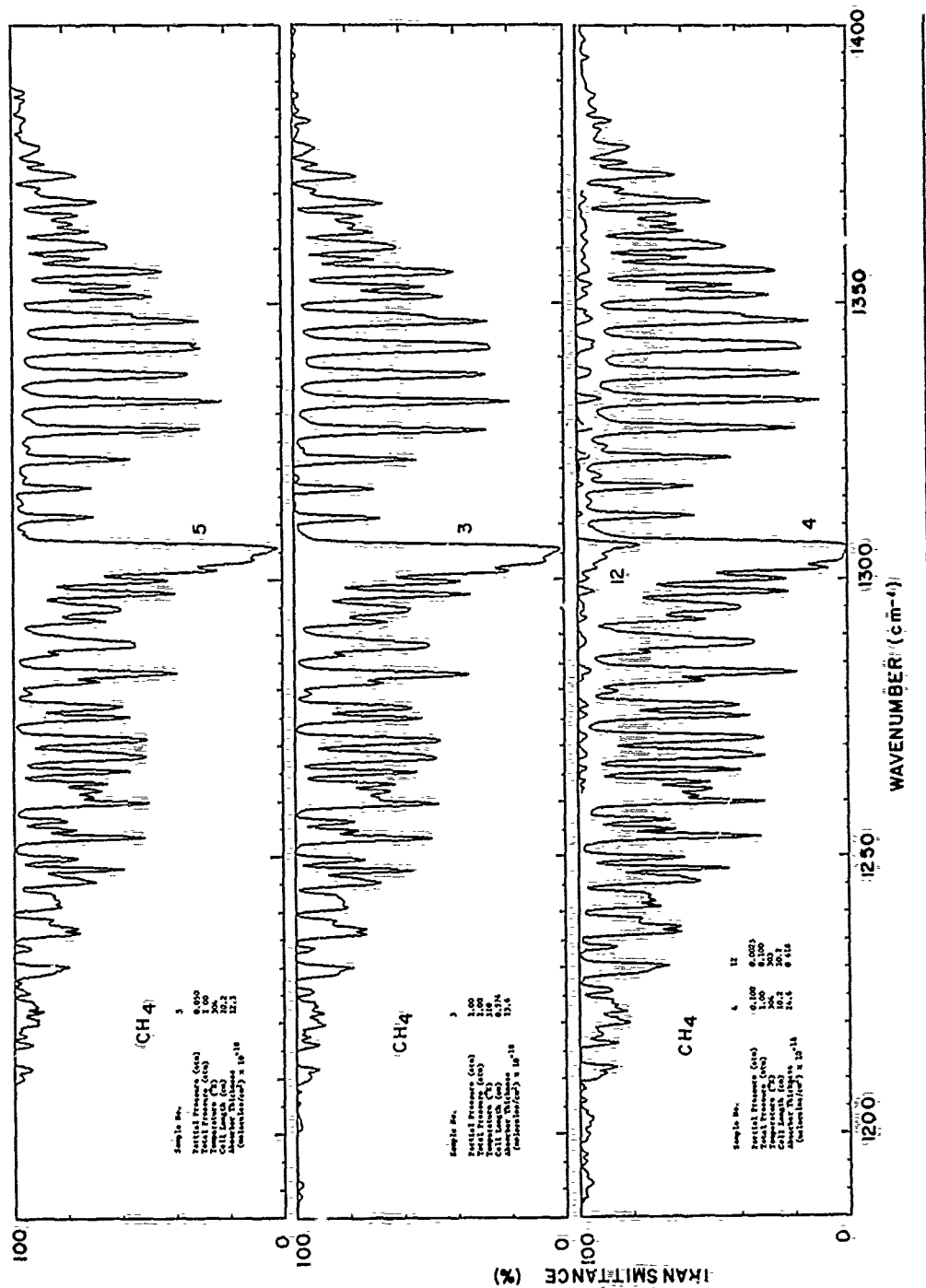


Figure 2. Spectral curves of transmittance of four CH_4 samples.

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Table I

$$\int_{\lambda}^{\nu} (1-T) d\lambda$$

Sample No.	3	4	5	6	7	8	9	10
p (atm)	1.00	0.100	0.050	0.025	0.030	0.015	0.0075	0.010
P (atm)	1.00	1.00	1.00	1.00	0.300	0.300	0.300	0.100
Temperature (°K)	310	304	304	302	304	304	303	302
Cell Length (cm)	0.574	10.2	10.2	10.2	10.2	10.2	10.1	10.2
U (molecules/cm²) x 10 ⁻¹⁸	13.6	24.6	12.3	6.20	7.39	3.70	1.86	2.48
ν (cm ⁻¹)								
1185.00	0.	0.						
1186.00	0.	0.						
1187.00	0.	0.						
1188.00	0.000	0.000						
1189.00	0.000	0.022						
1190.00	0.018	0.042						
1191.00	0.030	0.074						
1192.00	0.046	0.115						
1193.00	0.069	0.141						
1194.00	0.054	0.156						
1195.00	0.055	0.168						
1196.00	0.056	0.183						
1197.00	0.057	0.202						
1198.00	0.058	0.204						
1199.00	0.059	0.220						
1200.00	0.060	0.249						
1201.00	0.065	0.273						
1202.00	0.082	0.309						
1203.00	0.096	0.354						
1204.00	0.103	0.385						
1205.00	0.105	0.398						
1206.00	0.115	0.411						
1207.00	0.117	0.418						
1208.00	0.126	0.425						
1209.00	0.129	0.439						
1210.00	0.155	0.468	0.016	0.017	0.020	0.004	0.003	0.001
1211.00	0.200	0.556	0.065	0.066	0.066	0.029	0.020	0.010
1212.00	0.273	0.663	0.095	0.098	0.104	0.055	0.034	0.037
1213.00	0.295	0.720	0.119	0.130	0.130	0.071	0.044	0.049
1214.00	0.296	0.725	0.119	0.135	0.133	0.071	0.045	0.049
1215.00	0.296	0.730	0.119	0.135	0.136	0.072	0.046	0.048
1216.00	0.323	0.762	0.133	0.152	0.148	0.079	0.046	0.047
1217.00	0.381	0.866	0.180	0.175	0.193	0.099	0.051	0.046
1218.00	0.416	0.930	0.204	0.199	0.231	0.116	0.057	0.045
1219.00	0.445	1.009	0.227	0.226	0.271	0.128	0.062	0.043
1220.00	0.520	1.130	0.274	0.260	0.317	0.151	0.071	0.047
1221.00	0.601	1.284	0.359	0.319	0.366	0.181	0.080	0.062
1222.00	0.672	1.387	0.410	0.354	0.417	0.200	0.093	0.069
1223.00	0.742	1.545	0.500	0.417	0.477	0.231	0.119	0.083
1224.00	0.814	1.675	0.575	0.463	0.531	0.256	0.139	0.103
1225.00	0.833	1.746	0.604	0.497	0.563	0.268	0.146	0.111
1226.00	0.880	1.835	0.644	0.530	0.606	0.290	0.148	0.121
1227.00	0.909	1.896	0.661	0.556	0.630	0.304	0.149	0.133
1228.00	0.911	1.910	0.679	0.561	0.659	0.308	0.149	0.135
1229.00	0.904	2.014	0.740	0.597	0.687	0.335	0.155	0.146
1230.00	1.153	2.286	0.900	0.685	0.778	0.380	0.171	0.174
1231.00	1.240	2.520	1.030	0.759	0.859	0.415	0.186	0.194
1232.00	1.235	2.546	1.031	0.761	0.873	0.410	0.185	0.199
1233.00	1.209	2.559	1.035	0.769	0.901	0.416	0.186	0.200
1234.00	1.343	2.665	1.006	0.803	0.926	0.439	0.193	0.207
1235.00	1.353	2.691	1.098	0.815	0.940	0.442	0.200	0.220
1236.00	1.439	2.792	1.169	0.849	0.973	0.470	0.214	0.249
1237.00	1.681	3.139	1.300	0.957	1.090	0.540	0.243	0.306
1238.00	1.682	3.450	1.500	1.051	1.209	0.600	0.270	0.352
1239.00	1.618	3.605	1.714	1.123	1.290	0.632	0.282	0.370
1240.00	1.847	3.750	1.735	1.143	1.313	0.642	0.284	0.377
1241.00	2.158	3.891	1.815	1.187	1.365	0.667	0.295	0.380
1242.00	2.329	4.156	1.981	1.247	1.459	0.710	0.321	0.411
1243.00	2.499	4.422	2.136	1.369	1.556	0.744	0.348	0.431
1244.00	2.685	4.613	2.256	1.441	1.623	0.773	0.369	0.443
1245.00	2.676	4.705	2.310	1.476	1.656	0.783	0.377	0.454
1246.00	2.963	5.115	2.582	1.632	1.794	0.866	0.410	0.504
1247.00	3.154	5.430	2.700	1.754	1.899	0.927	0.446	0.537
1248.00	3.473	5.810	3.056	1.936	2.059	1.029	0.508	0.605
1249.00	3.500	5.999	3.191	2.045	2.146	1.082	0.535	0.650
1250.00	3.787	6.290	3.360	2.145	2.239	1.138	0.556	0.681
1251.00	3.843	6.448	3.448	2.196	2.282	1.167	0.569	0.700
1252.00	3.847	6.435	3.459	2.204	2.291	1.168	0.569	0.702
1253.00	3.927	6.540	3.525	2.243	2.324	1.182	0.571	0.705
1254.00	4.350	7.100	3.919	2.482	2.559	1.322	0.646	0.777
1255.00	4.550	7.411	4.113	2.685	2.666	1.379	0.682	0.809
1256.00	4.663	7.597	4.229	2.676	2.729	1.406	0.703	0.825
1257.00	4.638	7.664	4.369	2.782	2.816	1.446	0.725	0.852
1258.00	4.266	7.947	4.430	2.815	2.838	1.497	0.732	0.860
1259.00	4.098	8.018	4.472	2.836	2.898	1.460	0.734	0.862

Table I

 $\int_0^{\nu} (1-T) d\nu$ (cont'd)

Sample No.	3	4	5	6	7	8	9	10	11	12	13
p (atm)	1.0	0.100	0.050	0.025	0.030	0.015	0.0075	0.010	0.005	0.0025	0.001
T (atm)	1.00	1.00	1.00	1.00	0.300	0.300	0.300	0.100	0.100	0.100	0.030
Temperature (°K)	310	304	304	302	304	304	304	302	304	302	305
Cell Length (cm)	0.574	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
u (molecules/cm ²) x 10 ⁻¹⁸	13.6	24.6	12.3	6.20	7.39	3.70	1.36	2.48	1.23	0.618	0.742
(cm ⁻¹)											
1260.00	5.282	8.483	4.639	3.852	3.853	1.574	0.881	0.922	0.	0.	0.
1261.00	5.623	8.954	5.149	3.257	3.232	1.681	0.866	0.976	0.828	0.817	0.814
1262.00	5.931	9.376	5.428	3.429	3.371	1.753	0.913	1.012	0.858	0.831	0.822
1263.00	6.216	9.783	5.686	3.682	3.592	1.823	0.965	1.057	0.878	0.847	0.842
1264.00	6.495	10.177	5.949	3.782	3.641	1.984	1.020	1.090	0.103	0.067	0.052
1265.00	6.598	10.322	6.038	3.832	3.669	1.918	1.035	1.106	0.166	0.075	0.052
1266.00	6.952	10.812	6.385	4.051	3.851	2.013	1.103	1.162	0.131	0.098	0.071
1267.00	7.024	10.957	6.468	4.109	3.892	2.034	1.119	1.179	0.142	0.104	0.074
1268.00	7.373	11.362	6.773	4.387	4.028	2.167	1.172	1.219	0.157	0.119	0.083
1269.00	7.846	11.998	7.213	4.596	4.242	2.255	1.259	1.295	0.197	0.148	0.105
1270.00	8.028	12.294	7.383	4.713	4.329	2.311	1.286	1.315	0.202	0.160	0.112
1271.00	8.359	12.679	7.679	4.902	4.457	2.384	1.331	1.346	0.223	0.170	0.120
1272.00	8.822	13.310	8.181	5.281	4.784	2.541	1.426	1.436	0.273	0.198	0.143
1273.00	8.892	13.463	8.169	5.284	4.749	2.564	1.442	1.449	0.279	0.206	0.145
1274.00	8.986	13.517	8.190	5.282	4.754	2.564	1.443	1.449	0.279	0.207	0.145
1275.00	9.067	13.736	8.361	5.378	4.821	2.591	1.467	1.469	0.293	0.216	0.152
1276.00	9.418	14.257	8.686	5.603	4.999	2.782	1.533	1.538	0.332	0.248	0.177
1277.00	9.682	14.618	8.932	5.750	5.114	2.765	1.568	1.574	0.359	0.255	0.177
1278.00	10.025	15.114	9.247	5.974	5.287	2.879	1.630	1.632	0.401	0.281	0.191
1279.00	10.067	15.227	9.295	6.015	5.314	2.892	1.648	1.648	0.409	0.287	0.196
1280.00	10.120	15.349	9.353	6.049	5.352	2.903	1.645	1.655	0.411	0.298	0.203
1281.00	10.182	15.475	9.418	6.086	5.384	2.923	1.654	1.662	0.415	0.294	0.204
1282.00	10.462	15.858	9.688	6.258	5.518	2.991	1.691	1.708	0.437	0.305	0.209
1283.00	10.898	16.392	10.054	6.486	5.687	3.096	1.754	1.763	0.474	0.327	0.222
1284.00	11.383	17.075	10.537	6.834	5.968	3.271	1.876	1.888	0.535	0.367	0.268
1285.00	11.451	17.241	10.606	6.892	5.993	3.287	1.889	1.893	0.537	0.375	0.267
1286.00	11.477	17.315	10.642	6.914	6.006	3.287	1.889	1.895	0.539	0.377	0.276
1287.00	11.621	17.521	10.773	6.986	6.069	3.312	1.905	1.916	0.554	0.388	0.284
1288.00	11.925	17.890	11.051	7.144	6.199	3.385	1.948	1.957	0.581	0.391	0.301
1289.00	12.406	18.536	11.499	7.441	6.433	3.536	2.034	2.036	0.632	0.419	0.334
1290.00	12.683	18.973	11.765	7.616	6.565	3.625	2.082	2.092	0.667	0.439	0.361
1291.00	12.764	19.151	11.868	7.677	6.605	3.650	2.096	2.113	0.679	0.446	0.373
1292.00	12.820	19.257	11.926	7.711	6.621	3.662	2.100	2.131	0.682	0.448	0.394
1293.00	13.103	19.630	12.196	7.873	6.759	3.751	2.150	2.193	0.715	0.478	0.462
1294.00	13.338	19.988	12.488	7.994	6.865	3.822	2.186	2.242	0.736	0.486	0.506
1295.00	13.738	20.545	12.784	8.217	7.059	3.941	2.258	2.313	0.775	0.508	0.550
1296.00	14.073	21.056	13.094	8.410	7.230	4.047	2.318	2.380	0.808	0.527	0.580
1297.00	14.266	21.342	13.265	8.587	7.307	4.084	2.335	2.412	0.828	0.534	0.629
1298.00	14.821	22.087	13.786	8.863	7.638	4.274	2.457	2.538	0.887	0.578	0.713
1299.00	15.109	22.463	14.045	9.032	7.766	4.369	2.583	2.597	0.915	0.595	0.763
1300.00	15.582	23.005	14.465	9.296	7.984	4.582	2.588	2.674	0.984	0.613	0.785
1301.00	16.041	23.648	14.885	9.571	8.204	4.658	2.663	2.763	1.086	0.634	0.818
1302.00	16.726	24.394	15.531	10.016	8.595	4.888	2.810	2.917	1.094	0.686	0.863
1303.00	17.599	25.288	16.258	10.538	9.019	5.182	2.989	3.088	1.185	0.751	0.928
1304.00	18.429	26.253	17.141	11.241	9.636	5.619	3.267	3.327	1.329	0.848	1.008
1305.00	19.369	27.244	18.051	11.979	10.298	6.082	3.565	3.606	1.493	0.950	1.082
1306.00	20.346	28.241	19.018	12.844	11.115	6.722	4.008	4.019	1.769	1.115	1.225
1307.00	21.044	29.198	19.694	13.488	11.642	7.219	4.343	4.333	1.988	1.264	1.335
1308.00	21.159	29.335	19.883	13.557	11.667	7.253	4.358	4.352	1.994	1.269	1.344
1309.00	21.197	29.425	19.858	13.582	11.669	7.263	4.361	4.356	1.994	1.269	1.347
1310.00	21.216	29.478	19.878	13.598	11.669	7.265	4.363	4.359	1.994	1.270	1.350
1311.00	21.229	29.578	19.948	13.626	11.691	7.281	4.378	4.371	2.003	1.272	1.352
1312.00	21.563	29.932	20.191	13.786	11.880	7.366	4.416	4.416	2.031	1.285	1.363
1313.00	21.567	30.002	20.238	13.815	11.814	7.377	4.425	4.425	2.041	1.287	1.367
1314.00	21.575	30.052	20.263	13.828	11.830	7.388	4.431	4.429	2.043	1.288	1.375
1315.00	21.577	30.100	20.293	13.845	11.837	7.384	4.433	4.431	2.047	1.289	1.380
1316.00	21.589	30.158	20.325	13.866	11.845	7.385	4.437	4.435	2.048	1.290	1.381
1317.00	21.615	30.481	20.551	14.084	11.958	7.458	4.488	4.477	2.066	1.299	1.388
1318.00	21.877	30.619	20.631	14.061	11.981	7.478	4.497	4.489	2.088	1.307	1.392
1319.00	21.894	30.693	20.680	14.083	12.007	7.494	4.502	4.498	2.085	1.312	1.403
1320.00	21.897	30.747	20.713	14.102	12.016	7.500	4.504	4.499	2.088	1.319	1.410
1321.00	21.909	30.812	20.756	14.125	12.025	7.503	4.507	4.506	2.089	1.327	1.411
1322.00	22.198	31.168	21.053	14.318	12.165	7.588	4.563	4.567	2.119	1.346	1.423
1323.00	22.446	31.476	21.251	14.457	12.268	7.676	4.618	4.616	2.164	1.373	1.444
1324.00	22.449	31.582	21.315	14.487	12.287	7.690	4.620	4.627	2.166	1.376	1.447
1325.00	22.472	31.666	21.366	14.512	12.384	7.783	4.628	4.642	2.171	1.378	1.449
1326.00	22.508	31.747	21.423	14.535	12.314	7.713	4.628	4.649	2.177	1.388	1.449
1327.00	22.812	32.113	21.734	14.784	12.469	7.884	4.679	4.715	2.206	1.397	1.478
1328.00	23.362	32.768	22.254	15.182	12.801	8.072	4.856	4.858	2.387	1.458	1.517
1329.00	23.456	32.931	22.350	15.227	12.827	8.108	4.867	4.868	2.321	1.478	1.522

Table I

$$\int_0^{\nu} (1-T) d\nu \quad (\text{cont'd})$$

Sample No.	3	4	5	6	7	8	9	10	11	12	13
p (atm)	1.00	0.100	0.050	0.025	0.030	0.015	0.0075	0.010	0.005	0.0025	0.003
P (atm)	1.00	1.00	1.00	1.00	0.300	0.300	0.300	0.100	0.100	0.100	0.030
Temperature (°K)	310	304	304	302	304	304	303	302	304	303	303
Cell Length (cm)	0.574	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2	10.2
α (molecules/cm ²) $\times 10^{-18}$	13.6	24.6	12.3	6.20	7.39	3.70	1.86	2.46	1.23	0.618	0.742
ν (cm ⁻¹)											
1330.00	23.496	33.026	22.405	15.242	12.841	8.121	4.869	4.883	2.324	1.474	1.527
1331.00	23.531	33.114	22.459	15.268	12.852	8.128	4.870	4.893	2.328	1.475	1.527
1332.00	23.515	33.494	22.753	15.425	12.982	8.197	4.922	4.943	2.358	1.487	1.542
1333.00	23.513	34.284	23.408	16.008	13.003	8.515	5.126	5.113	2.465	1.560	1.590
1334.00	24.686	34.521	23.551	16.100	13.461	8.578	5.148	5.143	2.493	1.578	1.682
1335.00	24.728	34.625	23.601	16.126	13.479	8.587	5.149	5.145	2.495	1.571	1.603
1336.00	24.784	34.743	23.674	16.157	13.496	8.601	5.151	5.149	2.502	1.571	1.603
1337.00	25.203	35.323	24.114	16.443	13.752	8.735	5.248	5.238	2.552	1.608	1.631
1338.00	25.806	36.002	24.655	16.851	14.048	8.961	5.381	5.363	2.625	1.650	1.671
1339.00	25.941	36.185	24.774	16.919	14.086	9.010	5.394	5.384	2.636	1.650	1.678
1340.00	25.995	36.304	24.828	16.944	14.113	9.033	5.394	5.391	2.641	1.659	1.683
1341.00	26.109	36.524	24.950	17.012	14.152	9.065	5.407	5.406	2.654	1.668	1.691
1342.00	26.694	37.249	25.538	17.450	14.504	9.310	5.567	5.539	2.735	1.713	1.738
1343.00	27.395	38.025	26.190	17.943	14.830	9.587	5.738	5.698	2.833	1.774	1.786
1344.00	27.666	38.306	26.415	18.086	14.987	9.688	5.781	5.762	2.878	1.795	1.803
1345.00	27.720	38.420	26.484	18.116	15.004	9.701	5.784	5.773	2.880	1.796	1.803
1346.00	27.838	38.651	26.619	18.191	15.049	9.735	5.800	5.799	2.887	1.801	1.805
1347.00	28.436	39.409	27.183	18.597	15.372	9.962	5.930	5.929	2.964	1.844	1.843
1348.00	28.970	40.047	27.679	19.039	15.631	10.161	6.044	6.043	3.036	1.887	1.877
1349.00	29.213	40.328	27.914	19.096	15.751	10.265	6.090	6.101	3.078	1.912	1.895
1350.00	29.259	40.434	27.968	19.130	15.768	10.287	6.095	6.113	3.084	1.913	1.897
1351.00	29.504	40.820	28.205	19.282	15.889	10.350	6.137	6.172	3.102	1.929	1.908
1352.00	29.993	41.458	28.654	19.577	16.134	10.517	6.232	6.256	3.152	1.966	1.940
1353.00	31.324	41.878	28.946	19.776	16.279	10.629	6.287	6.303	3.186	1.999	1.965
1354.00	30.611	42.248	29.236	19.971	16.430	10.753	6.354	6.372	3.230	2.038	2.003
1355.00	30.749	42.448	29.361	20.052	16.480	10.794	6.369	6.414	3.244	2.049	2.025
1356.00	31.288	43.108	29.846	20.370	16.765	11.992	6.538	6.538	3.318	2.091	2.067
1357.00	31.646	43.627	30.198	20.621	16.936	11.131	6.524	6.622	3.361	2.130	2.093
1358.00	31.839	43.880	30.374	20.710	17.020	11.198	6.552	6.677	3.377	2.158	2.116
1359.00	32.005	44.133	30.558	20.823	17.101	11.266	6.586	6.716	3.395	2.191	2.137
1360.00	32.270	44.521	30.771	20.964	17.208	11.353	6.629	6.749	3.410	2.219	2.158
1361.00	32.629	45.035	31.113	21.179	17.367	11.467	6.693	6.803	3.438	2.259	2.177
1362.00	32.779	45.275	31.271	21.294	17.464	11.524	6.726	6.838	3.449	2.269	2.190
1363.00	32.987	45.550	31.452	21.413	17.535	11.597	6.771	6.878	3.465	2.321	2.199
1364.00	33.218	45.878	31.668	21.553	17.651	11.680	6.816	6.947	3.488	2.361	2.212
1365.00	33.425	46.191	31.864	21.673	17.749	11.746	6.851	6.985	3.515	2.396	2.228
1366.00	33.637	46.511	32.068	21.791	17.849	11.819	6.893	7.030	3.538	2.419	2.234
1367.00	33.727	46.673	32.176	21.865	17.901	11.854	6.912	7.053	3.555	2.439	2.234
1368.00	33.883	46.896	32.329	21.947	17.957	11.905	6.937	7.091	3.567	2.458	2.243
1369.00	34.156	47.324	32.599	22.098	18.186	11.998	6.977	7.153	3.591	2.495	2.253
1370.00	34.260	47.521	32.720	22.159	18.168	12.035	7.000	7.170	3.598	2.521	2.255
1371.00	34.338	47.685	32.821	22.214	18.203	12.058	7.018	7.195			
1372.00	34.356	47.749	32.866	22.233	18.218	12.061	7.021	7.209			
1373.00	34.510	47.995	33.046	22.319	18.274	12.101	7.053	7.236			
1374.00	34.673	48.271	33.224	22.426	18.367	12.162	7.099	7.283			
1375.00	34.727	48.394	33.306	22.483	18.398	12.186	7.119	7.303			
1376.00	34.788	48.538	33.391	22.542	18.435	12.224	7.143	7.320			
1377.00	34.812	48.634	33.445	22.582	18.456	12.257	7.152	7.338			
1378.00	34.877	48.807	33.544	22.634	18.508	12.289	7.170	7.362			
1379.00	34.941	48.952	33.629	22.681	18.543	12.313	7.193	7.394			
1380.00	34.952	49.027	33.667	22.741	18.561	12.325	7.196	7.411			
1381.00	34.972	49.116	33.694	22.722	18.561	12.325	7.196	7.411			
1382.00	34.992	49.198	33.733	22.736	18.561	12.325	7.196	7.411			
1383.00	35.035	49.310	33.782	22.758	18.561	12.325	7.196	7.412			
1384.00	35.068	49.382	33.819	22.771	18.561	12.325	7.196	7.412			
1385.00	35.087	49.455	33.846	22.772	18.561	12.325	7.196	7.412			
1386.00	35.099	49.515	33.882	22.772	18.561	12.325	7.196	7.412			
1387.00	35.106	49.576	33.928	22.772	18.561	12.325	7.196	7.412			
1388.00	35.128	49.650	33.967	22.772	18.561	12.325	7.196	7.412			
1389.00	35.133	49.698	33.991	22.772	18.561	12.325	7.196	7.412			
1390.00	35.140	49.740	33.991	22.772	18.561	12.325	7.196	7.412			
1391.00	35.141	49.774	33.991	22.772	18.561	12.325	7.196	7.412			
1392.00	35.142	49.805	33.991	22.772	18.561	12.325	7.196	7.412			
1393.00	35.145	49.835	33.991	22.772	18.561	12.325	7.196	7.412			
1394.00	35.149	49.868	33.991	22.772	18.561	12.325	7.196	7.412			
1395.00	35.161	49.912	33.991	22.772	18.561	12.325	7.196	7.412			
1396.00	35.163	49.938	33.991	22.772	18.561	12.325	7.196	7.412			
1397.00	35.167	49.968	33.991	22.772	18.561	12.325	7.196	7.412			
1398.00	35.169	50.007	33.991	22.772	18.561	12.325	7.196	7.412			
1399.00	35.179	50.032	33.991	22.772	18.561	12.325	7.196	7.412			
1400.00	35.188	50.056	33.991	22.772	18.561	12.325	7.196	7.412			

TABLE 2 $\frac{1}{u} \int_{v'}^v -\ln T \, dv$ FOR CH_4

(Multiply all integral values by 10^{-20} molecules $^{-1}$ cm ^{2} cm $^{-1}$)

v (cm $^{-1}$)	$-\frac{1}{u} \int_{v'}^v -\ln T \, dv$	v (cm $^{-1}$)	$-\frac{1}{u} \int_{v'}^v -\ln T \, dv$
1210	0.72	1285	151.6
1215	3.04	1290	167.9
1220	6.17	1295	181.3
1225	10.54	1300	207.3
1230	14.26	1305	288.1
1235	18.23	1310	350.4
1240	25.73	1315	358.9
1245	33.19	1320	366.0
1250	47.26	1325	376.8
1255	57.63	1330	399.1
1260	68.58	1335	426.3
1265	86.30	1340	447.5
1270	104.9	1345	478.3
1275	120.8	1350	502.8
1280	134.6	1355	524.0

$$v' = 1205 \text{ cm}^{-1}$$

When the wings of the band are included in the integral, the value becomes $574 \pm 25 \times 10^{-20}$ molecules $^{-1}$ cm ^{2} cm $^{-1}$, which is equal to the value of the intensity of the entire band system.

TABLE 3. COMPARISON OF EXPERIMENTAL VALUES OF BAND INTENSITY

Reference	$(-1/u) \int T dv$ $(\text{molecules}^{-1} \text{cm}^2 \text{cm}^{-1})$
Rollefson and Havens ⁸	551×10^{20}
Thorndike ⁹	558×10^{20}
Welsh and Sandiford ¹⁰	585×10^{20}
Armstrong and Welsh ¹¹	588×10^{20}
Present Investigation	574×10^{20}

-
8. R. Rollefson and R. Havens, Phys. Rev. 57, 710 (1940).
 9. A. M. Thorndike, J. Chem. Phys. 15, 868 (1947).
 10. H. L. Welsh and P. J. Sandiford, J. Chem. Phys. 20, 1646 (1952).
 11. R. K. Armstrong and H. L. Welsh, Spectrochimica Acta 16, 840 (1960).

SECTION 3

CONTINUUM ABSORPTION BY H_2O BETWEEN 600 cm^{-1} AND 1300 cm^{-1}

The absorption by H_2O in the atmospheric window between approximately 800 cm^{-1} and 1200 cm^{-1} is different from that in most regions because a significant portion of it is due to continuum absorption. Although many very weak H_2O lines are centered in this region, the contribution by these lines in a typical lower atmospheric path is much less than that by the continuum. Some of the continuum absorption is undoubtedly due to the extreme wings of strong H_2O lines centered outside of the $800 - 1200\text{ cm}^{-1}$ interval. Dimers formed by the association of two H_2O molecules ($\text{H}_2\text{O}:\text{H}_2\text{O}$) may also contribute to the continuum absorption. For purposes of calculating the attenuation by atmospheric paths it is not important that the absorbing mechanism be understood completely as long as the absorption coefficients at different wave-numbers are determined for temperatures and pressures of interest. As explained in Section 1, the attenuation over a given path length varies as the square of the H_2O partial pressure whether the absorption is due to dimers or to the extreme wings of self-broadened H_2O lines.

Within the $600 - 1300\text{ cm}^{-1}$ region there are several narrow intervals as wide as approximately 1 cm^{-1} at which the influence of lines closer than a few cm^{-1} is much less than that by the continuum absorption. Throughout much of the more transparent part of the window between 800 cm^{-1} and 1200 cm^{-1} , there is probably little contribution by all of the lines centered closer than $30 - 50\text{ cm}^{-1}$ to many of these narrow intervals between very weak nearby lines. Lines centered in the edges of the window from 600 cm^{-1} to 800 cm^{-1} and from 1200 cm^{-1} to 1300 cm^{-1} are stronger than those in the center of the window. Consequently, nearby lines can make a significant contribution to the absorption in the narrow, clean intervals in these edges of the window. Nevertheless, the continuum still plays a very important role in these intervals.

In 1970 we published a report² that included data on the H_2O continuum absorption throughout the $700 - 1250\text{ cm}^{-1}$ region. The continuum absorption was determined by measuring the absorption in several of the narrow, clean intervals discussed in the previous paragraph. The absorption was measured from spectral curves of transmittance scanned with a spectral slitwidth of less than 0.5 cm^{-1} . By making a small allowance for a few nearby lines, the continuum was determined for samples at different pressures and temperatures. Values of the continuum absorption coefficient C_s^0 (see Eq. (10)) for self-broadening were determined and published for three temperatures: 296 K, 358 K and 388 K. Attempts to measure the nitrogen broadening coefficient $C_{\text{N}_2}^0$ as part of the same experiment were unsuccessful because of the very weak dependence of the continuum absorption on the pressure of N_2 . However, the results did indicate that near room temperature the ratio $C_{\text{N}_2}^0/C_s^0$ is less than 0.005.

Since publishing these original data on the $700 - 1200\text{ cm}^{-1}$ region, we have investigated the continuum absorption in other spectral regions and have

improved some of our experimental techniques. Because of the importance of the 700 - 1250 cm^{-1} region, we have re-investigated the continuum absorption while employing some of our improved techniques, particularly those related to interference by contaminants in the sample. As a result of the more recent measurements, we have concluded that the previously published values of C_s^0 were probably too high by 5% to 20%. The highest percentage error is between 1000 cm^{-1} and 1200 cm^{-1} where absorption by contaminants was the most serious. This amount of discrepancy between two separate measurements is believed to be quite good in view of the difficulty of the experiment.

Figure 3 summarizes the results of the later measurements. The uncertainty in the results is difficult to estimate because of the possibility of some systematic experimental error that is not identified. However, we believe that any of the values represented by the 296 K curve are in error by less than $\pm 15\%$, and those for the two elevated temperatures, 392 K and 430 K, by less than $\pm 10\%$. The large decrease in C_s^0 with increasing temperature is consistent with the previous data.

At 392 K, C_s^0 increases rapidly with increasing wavenumber above approximately 1150 cm^{-1} . The intensities of the H_2O lines centered in or near the 1150 cm^{-1} - 1300 cm^{-1} region increase rapidly with increasing temperature because the lower energy levels involved in the transitions are excited. The populations of these energy levels therefore increase rapidly with temperature. The increase in C_s^0 is a result of the increasing contribution by the lines centered above 1150 cm^{-1} . The contribution by these same lines is apparently small for wavenumbers less than 1100 cm^{-1} . A large portion of the continuum below 1100 cm^{-1} is probably due to the extreme wings of the very strong lines centered below 600 cm^{-1} . This could account for the increasing C_s^0 with decreasing wavenumber below 1100 cm^{-1} as the point of observation approaches these strong lines.

Since being published, the 1970 data² have been used widely to predict atmospheric absorption and have been compared with results of a variety of experiments. The more recent data illustrated in Figure 3 have also been made available to a few workers interested in developing accurate transmission models. Among these workers are Roberts, Selby and Biberman,¹² who have summarized the results of several field measurements and laboratory measurements designed to provide new and better information on the H_2O continuum absorption. Roberts, et al., have arrived at what they believe is the best model for continuum absorption based on the variety of data they have accumulated. Their model is in essential agreement with Fig. 3 for 296 K.

¹²R. E. Roberts J. E. A. Selby and L. M. Biberman, Appl. Opt. 15, 2085 (1976).

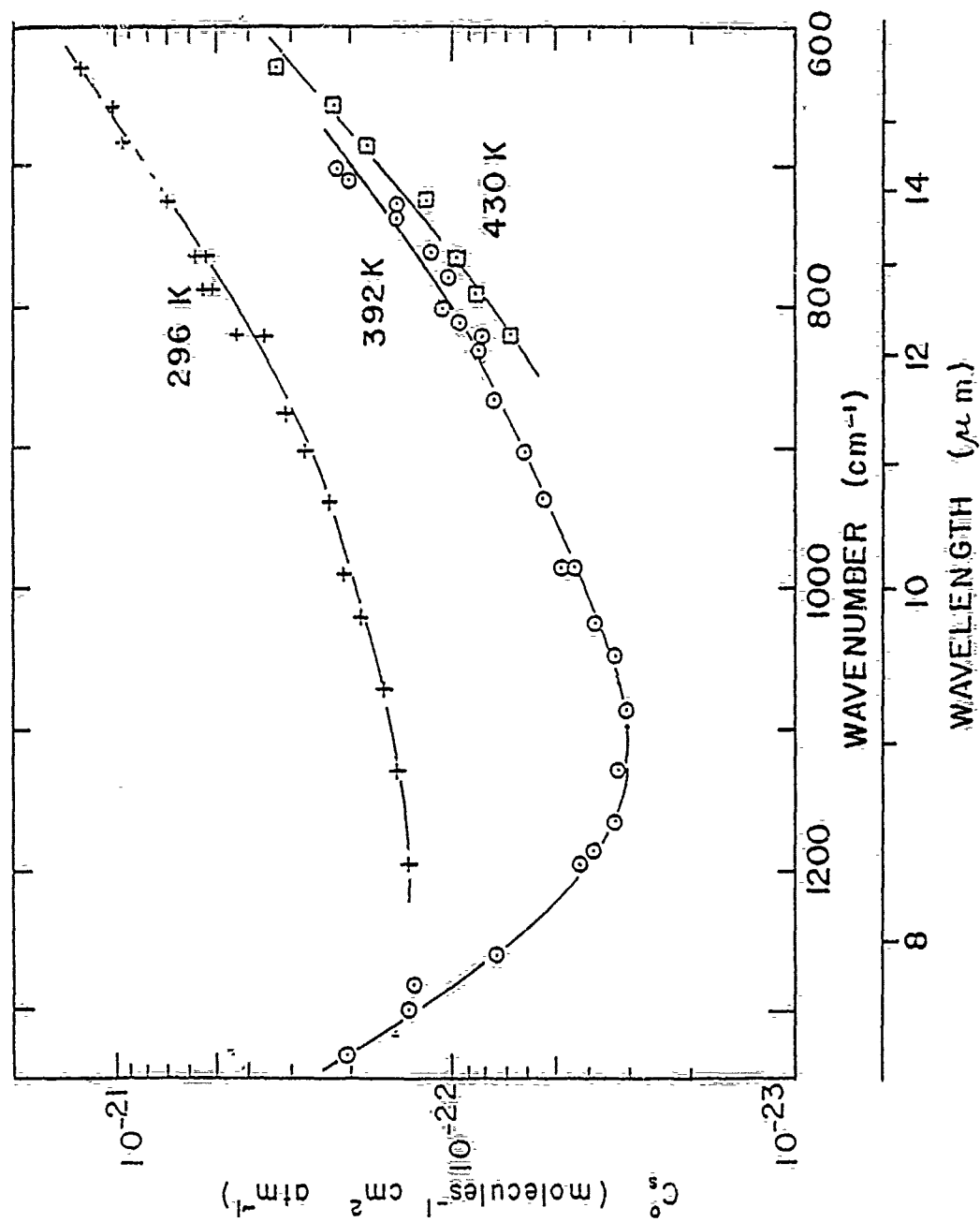


Figure 3. Spectral plot of CO between 600 cm^{-1} and 1300 cm^{-1}

SECTION 4

ABSORPTION BY H_2O BETWEEN 333 cm^{-1} AND 444 cm^{-1}

EXPERIMENTAL

The H_2O absorption data presented in this section were obtained in the same manner as the H_2O data reported previously by us in several reports. The longer of two multiple-pass cells in our laboratory was used for path lengths of 123 meters or greater; a shorter multiple-pass cell served for paths up to 28.84 meters. A custom-made grating monochromator employing a liquid-helium-cooled Ge:Cu detector was used to scan spectral curves of transmittance and to isolate very narrow spectral intervals for detailed study. Essentially all of the optical path outside of the sample cell was confined to two vacuum tanks to eliminate absorption by atmospheric gases. The only exception was a path of a few cm between the globar energy source and a window to one of the vacuum tanks. This short path was flushed with dry N_2 . Polyethylene windows were used on the sample cells and on the vacuum tank where the energy beam entered from the globar source. The detector contained a KRS-5 window.

The grating used for the data in this section contains 45 lines/mm and is blazed at $22\text{ }\mu\text{m}$. A long-pass interference filter eliminated overlapping orders of higher-wavenumber energy passed by the grating monochromator. Detector signals were processed with a synchronous demodulator and amplifier, and the dc output of the amplifier was displayed on a strip-chart recorder. Transmittances were determined by dividing the signal output observed with the sample in place to that observed with the sample cell evacuated.

All sample pressures below approximately 0.08 atm were measured with an oil manometer; higher pressures were measured with an Hg manometer. Mixtures of $\text{H}_2\text{O} + \text{N}_2$ were formed by first adding the H_2O to the evacuated sample cell and allowing the gas to stabilize before measuring its pressure. The N_2 was then added slowly, allowing it to mix with the H_2O . Table 4 summarizes the important parameters of the samples for which detailed spectral data are presented. Absorption by several other samples not listed was investigated at certain wavenumbers of interest without scanning the spectra. The H_2O partial pressure p and the total pressure P are given in the second and third columns; all samples were either pure H_2O or $\text{H}_2\text{O} + \text{N}_2$. The absorber thickness u shown in the fifth column is expressed in molecules/ cm^2 and is related to the other sample parameters by Eq. (1). The number associated with u has been abbreviated: for example, $169. +20$ denotes 169×10^{20} molecules/ cm^2 .

The final three columns of Table 4 give the resolution schedule, the region over which spectra have been scanned, and the number of the figure in which the spectrum appears. Table 5 lists the spectral slitwidth corresponding to the resolution schedules given in Table 4. Spectral slitwidths given in Table 5 correspond to the full width at half-maximum of a triangular slit function.

RESULTS

Figures 4 through 9 shows the computer-plotted spectra for the samples represented in Table 4. The important sample parameters are repeated in each figure. The original recorder tracings have been smoothed somewhat during the digitizing process; thus the original noise level was higher than that indicated by the computer-plotted curves in Figures 4 through 9. The estimated errors in the plotted values of transmittance vary from less than 0.02 near 440 cm^{-1} to 0.03 near 330 cm^{-1} . At points where T is near zero or near unity, the errors are probably lower.

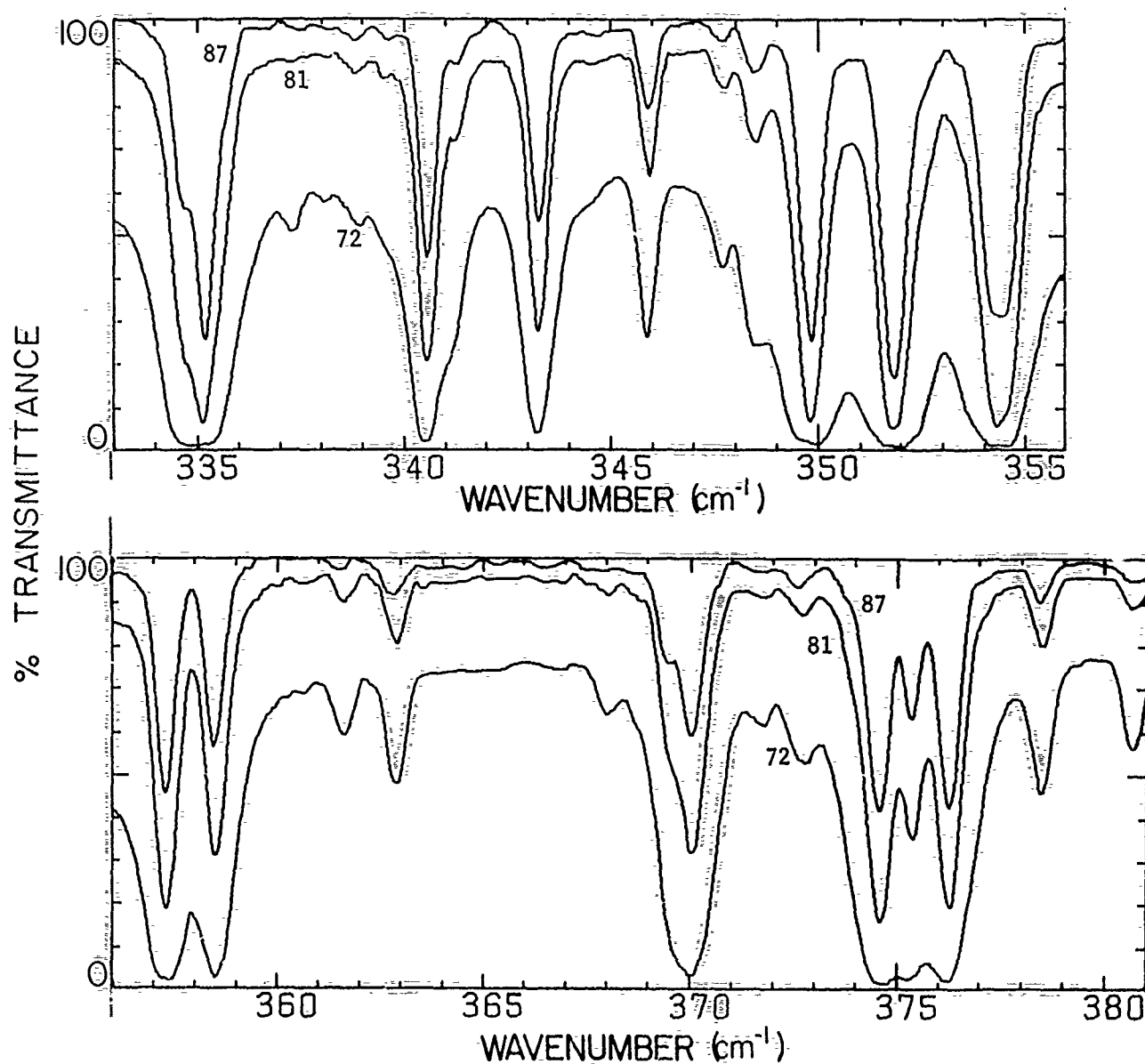
Tables 6 and 7 list values of the cumulative integrated absorptance based on the same samples as those represented by Figures 4 through 9. Each column corresponds to the sample indicated at the top.

TABLE 4. H₂O SAMPLE PARAMETERS

Sample No.	p (atm)	P (atm)	L (cm)	u (#/cm ²)	θ (°K)	Resl. Schedule	Spectral Region (cm ⁻¹)	Figure No.
173	0.0115	0.0115	59500	169.+20	296	B	380-444	9
171	0.00882	0.00882	59500	130.+20	296	B	380-444	9
170	0.00553	0.00553	59500	81.6+20	296	B	380-444	9
61	0.0213	0.0213	2884	15.2+20	296	A	380-444	7
56	0.0158	0.0158	420	1.65+20	296	A	380-444	7
136	0.0207	1.004	2884	12.9+20	338	A	380-444	8
133	0.0207	0.500	2884	12.9+20	338	A	380-444	8
115	0.0208	0.0208	2884	12.9+20	338	A	380-444	8
182	0.0141	0.0141	12300	43.0+20	296	C	333-381	6
180	0.00868	0.00868	12300	26.5+20	296	C	333-381	6
72	0.0207	0.0207	2884	14.8+20	296	C	333-381	4
81	0.0211	0.0211	420	2.19+20	296	C	333-381	4
87	0.0105	0.0105	420	1.09+20	296	C	333-381	4
111	0.0326	0.0326	2884	20.7+20	333	C	333-381	5
147	0.0212	1.000	420	1.93+20	338	C	333-381	5
141	0.0213	0.500	420	1.95+20	338	C	333-381	5
104	0.0213	0.0213	420	1.95+20	338	C	333-381	5

TABLE 5. SPECTRAL RESOLUTION SCHEDULE

ν (cm ⁻¹)	A (cm ⁻¹)	B (cm ⁻¹)	C (cm ⁻¹)
380	0.23	0.32	0.42
390	0.25	0.34	0.46
400	0.28	0.36	0.48
410	0.30	0.39	0.52
420	0.32	0.42	0.56
430	0.35	0.45	0.60
440	0.37	0.48	0.64
450	0.39	0.51	0.68



Sample No.	p = P (atm)	u (molecules/cm ²)
87	0.0105	1.09×10^{20}
81	0.0211	2.19×10^{20}
72	0.0207	14.8×10^{20}

Figure 4. Spectral curves of transmittance of H₂O from 333 to 381 cm⁻¹. $\theta = 296$ K for all samples.

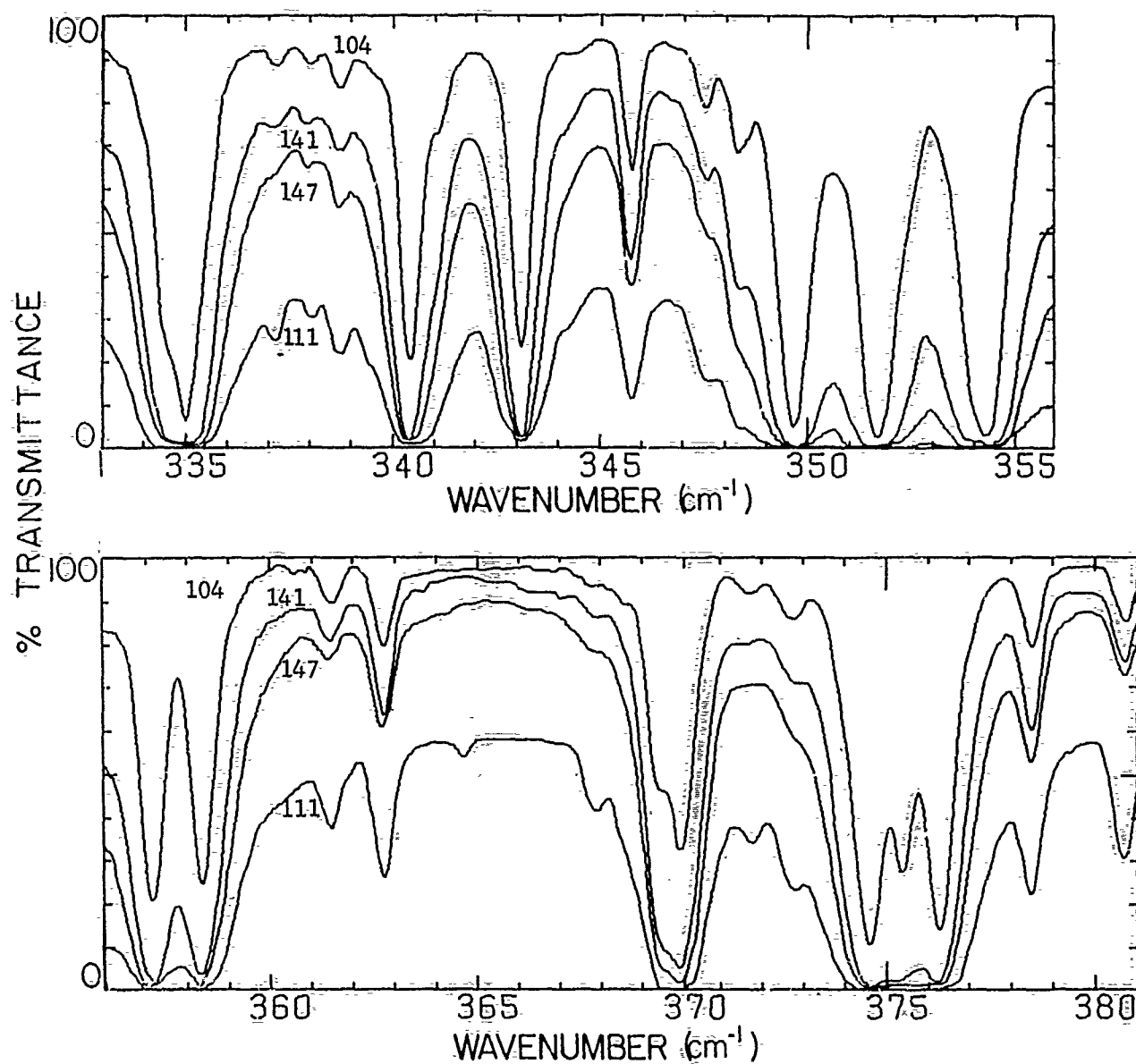


Figure 5. Spectral curves of transmittance of H_2O from 333 to 381 cm^{-1} .

Sample No.	p (atm)	P (atm)	u (molecules/ cm^2)	θ ($^\circ\text{K}$)
104	0.0213	0.0213	1.95×10^{20}	338
141	0.0213	0.500	1.95×10^{20}	338
147	0.0212	1.00	1.93×10^{20}	338
111	0.0326	0.0326	20.7×10^{20}	333

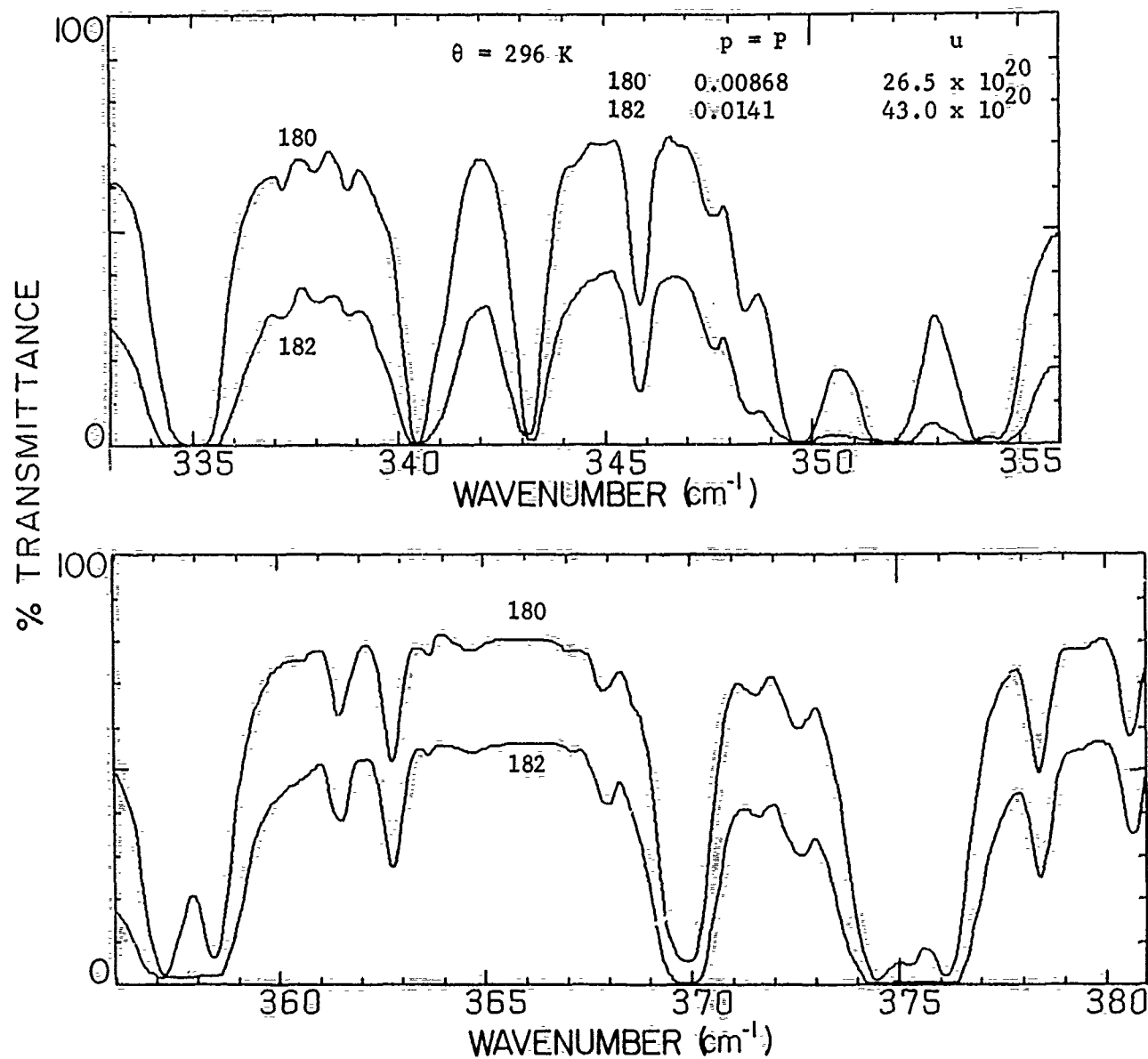


Figure 6. Spectral curves of transmittance of H_2O from 333 to 381 cm^{-1} . Pressures are atm; absorber thicknesses u are in molecules/ cm^2 .

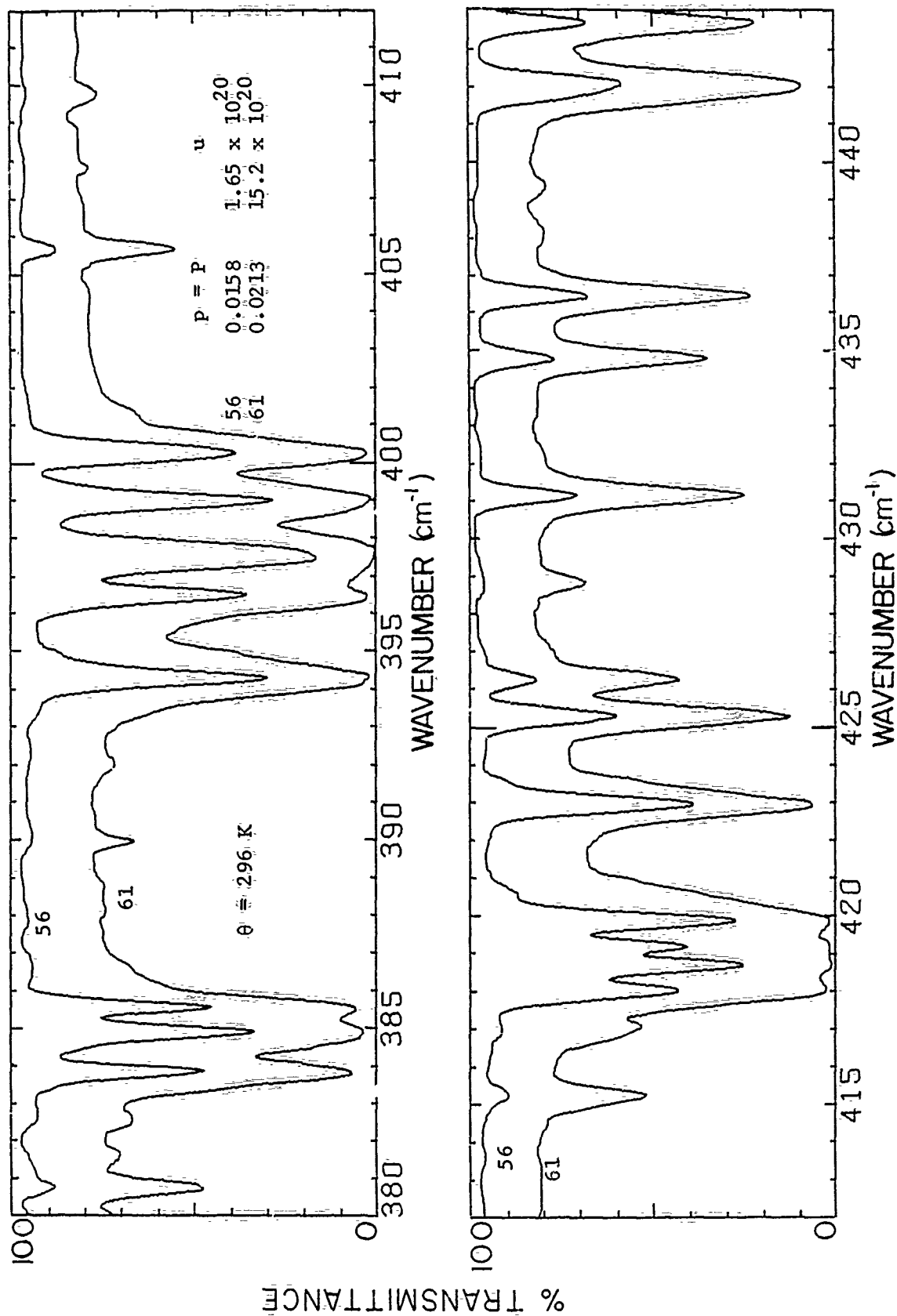


Figure 7. Spectral curves of transmittance of H_2O from 380 to 444 cm^{-1} . Pressures are in atm; absorber thicknesses u are in molecules/ cm^2 .

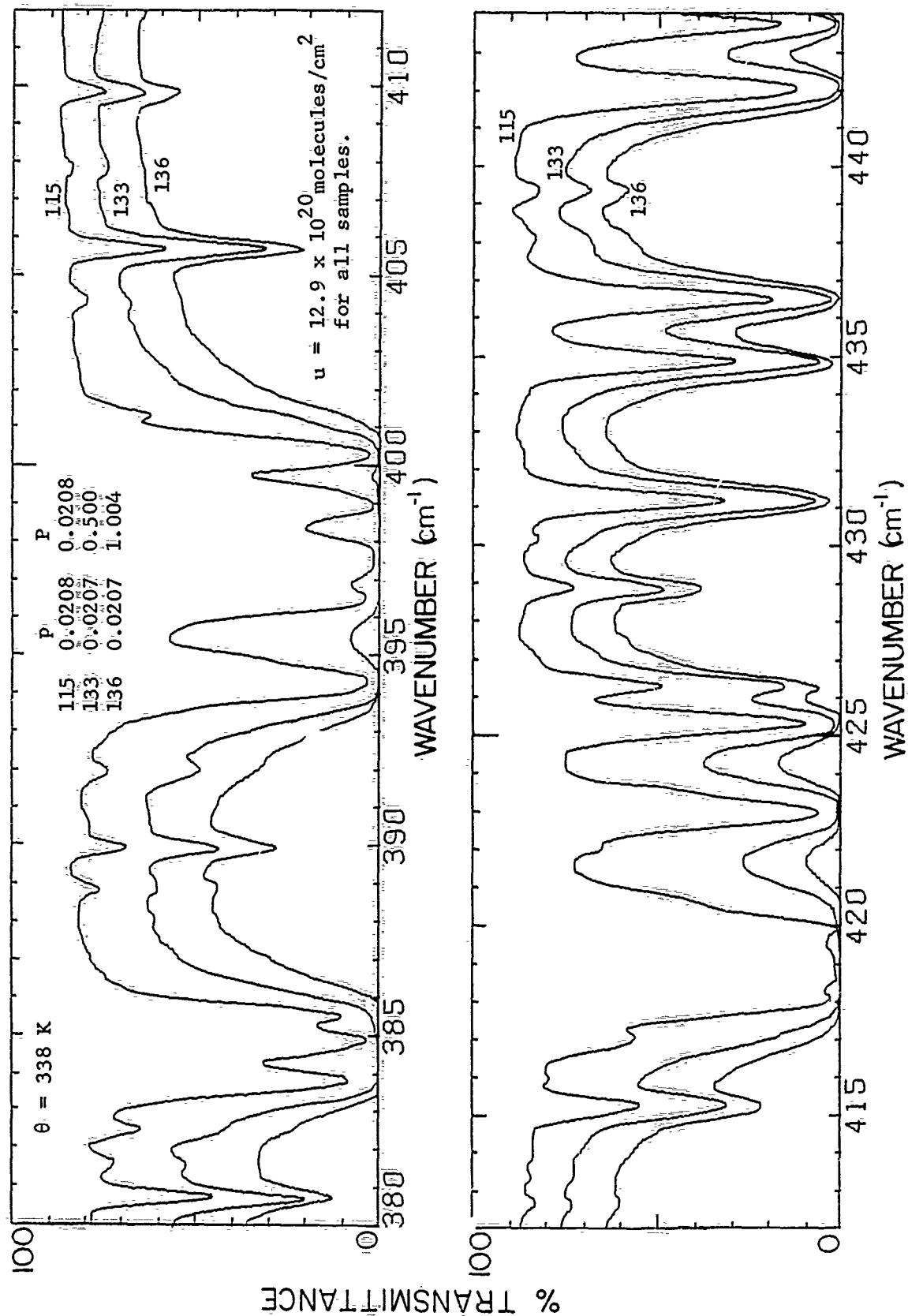


Figure 8. Spectral curves of transmittance of H_2O from 380 to 444 cm^{-1} . Pressures are in atm.

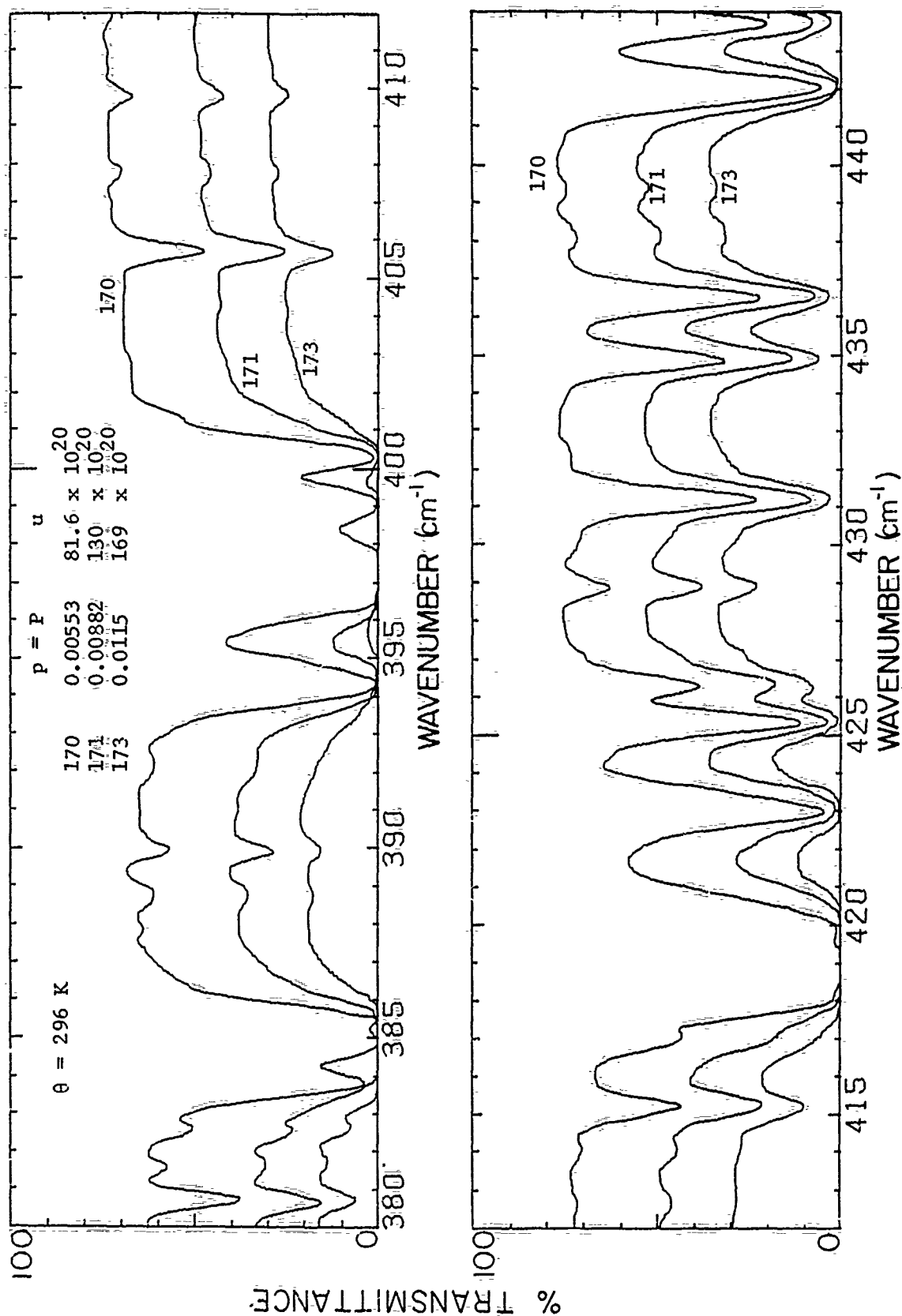


Figure 9. Spectral curves of transmittance from 380 to 444 cm⁻¹. Pressures are in atm; absorber thicknesses are in molecules/cm².

TABLE 6
 $\int_{\mathbb{R}^2} \text{Ad}^2$ [illegible]

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* The units of u are molecules/cm², abbreviated here by (θ/cm^2) .

TABLE 7 $\int \Delta \nu$

Sam. No.	173.	171.	170.	61.	56.	136.	133.	115.
Temp. (K)	296.	296.	296.	296.	296.	338.	338.	338.
Path. (cm)	59500.	59500.	59500.	2884.	2884.	2884.	2884.	2884.
ρ (atm)	0.01145	0.00882	0.00553	0.02132	0.01579	0.02044	0.02044	0.02079
ρ (atm)	0.01145	0.00882	0.00553	0.02132	0.01579	1.00395	0.50000	0.02079
u (#/cm ²)	1.490E 22	1.301E 22	8.158E 21	1.525E 21	1.445E 20	1.294E 21	1.294E 21	1.303E 21
ν (cm ⁻¹)								
380.00	0.	0.	0.	0.	0.	0.	0.	0.
380.20	0.160	0.134	0.075	0.052	0.007	0.138	0.090	0.043
380.40	0.336	0.271	0.156	0.103	0.013	0.269	0.192	0.088
380.60	0.519	0.435	0.261	0.177	0.026	0.424	0.326	0.159
380.80	0.706	0.602	0.384	0.279	0.048	0.597	0.481	0.265
381.00	0.880	0.756	0.494	0.369	0.066	0.760	0.605	0.352
381.20	1.059	0.891	0.575	0.428	0.080	0.904	0.706	0.483
381.40	1.220	1.025	0.652	0.461	0.091	1.040	0.759	0.555
381.60	1.390	1.163	0.736	0.539	0.101	1.175	0.934	0.599
381.80	1.571	1.302	0.818	0.597	0.108	1.309	0.987	0.563
382.00	1.741	1.437	0.894	0.649	0.114	1.445	1.075	0.609
382.20	1.910	1.572	0.971	0.700	0.119	1.582	1.166	0.653
382.40	2.084	1.717	1.057	0.760	0.128	1.727	1.272	0.710
382.60	2.266	1.869	1.154	0.825	0.141	1.870	1.387	0.770
382.80	2.450	2.020	1.251	0.890	0.156	2.030	1.500	0.830
383.00	2.633	2.174	1.345	0.952	0.170	2.207	1.641	0.895
383.20	2.822	2.336	1.449	1.024	0.183	2.390	1.791	0.963
383.40	3.010	2.500	1.577	1.130	0.202	2.584	1.966	1.059
383.60	3.217	2.691	1.739	1.272	0.236	2.784	2.150	1.203
383.80	3.417	2.884	1.927	1.451	0.310	2.984	2.356	1.380
384.00	3.617	3.082	2.117	1.630	0.411	3.184	2.556	1.559
384.20	3.817	3.282	2.293	1.782	0.451	3.384	2.756	1.712
384.40	4.017	3.482	2.465	1.922	0.481	3.584	2.956	1.851
384.60	4.217	3.682	2.649	2.089	0.527	3.784	3.156	2.015
384.80	4.417	3.882	2.846	2.277	0.610	3.984	3.356	2.200
385.00	4.617	4.082	3.045	2.469	0.744	4.184	3.556	2.392
385.20	4.817	4.282	3.243	2.654	0.820	4.384	3.754	2.567
385.40	5.017	4.482	3.439	2.837	0.870	4.584	3.951	2.736
385.60	5.217	4.682	3.637	3.024	0.901	4.784	4.147	2.913
385.80	5.417	4.879	3.816	3.192	1.054	4.984	4.339	3.071
386.00	5.615	5.067	3.966	3.308	1.077	5.183	4.517	3.170
386.20	5.808	5.239	4.082	3.394	1.087	5.374	4.674	3.249
386.40	5.994	5.398	4.181	3.469	1.093	5.553	4.811	3.307
386.60	6.174	5.549	4.272	3.537	1.110	5.710	4.930	3.350
386.80	6.348	5.692	4.357	3.599	1.122	5.872	5.034	3.405
387.00	6.519	5.830	4.434	3.655	1.132	6.017	5.129	3.449
387.20	6.686	5.964	4.514	3.707	1.140	6.154	5.219	3.491
387.40	6.852	6.095	4.588	3.750	1.146	6.283	5.305	3.531
387.60	7.015	6.222	4.657	3.800	1.152	6.405	5.387	3.569
387.80	7.177	6.346	4.720	3.850	1.161	6.522	5.465	3.606
388.00	7.339	6.471	4.800	3.907	1.171	6.635	5.543	3.642
388.20	7.501	6.595	4.870	3.959	1.180	6.746	5.620	3.678
388.40	7.663	6.720	4.941	4.010	1.189	6.856	5.695	3.715
388.60	7.827	6.847	5.017	4.061	1.196	6.966	5.769	3.754
388.80	7.992	6.976	5.096	4.112	1.203	7.077	5.847	3.790
389.00	8.156	7.104	5.172	4.161	1.210	7.189	5.926	3.843
389.20	8.319	7.228	5.241	4.208	1.216	7.296	6.005	3.879
389.40	8.480	7.348	5.305	4.253	1.222	7.402	6.081	3.911
389.60	8.643	7.468	5.370	4.299	1.228	7.511	6.158	3.945
389.80	8.809	7.600	5.446	4.340	1.236	7.616	6.250	3.989
390.00	8.977	7.742	5.531	4.412	1.240	7.770	6.361	4.050
390.20	9.143	7.875	5.612	4.467	1.250	7.900	6.455	4.100
390.40	9.305	7.999	5.686	4.514	1.271	8.024	6.533	4.142
390.60	9.463	8.121	5.756	4.560	1.282	8.134	6.609	4.184
390.80	9.620	8.243	5.827	4.605	1.291	8.243	6.685	4.225
391.00	9.778	8.366	5.897	4.650	1.300	8.354	6.759	4.264
391.20	9.930	8.490	5.967	4.695	1.308	8.466	6.833	4.302
391.40	10.090	8.614	6.037	4.741	1.317	8.581	6.907	4.339
391.60	10.259	8.739	6.107	4.789	1.326	8.701	6.987	4.379
391.80	10.422	8.867	6.180	4.840	1.335	8.827	7.079	4.425
392.00	10.580	8.999	6.257	4.896	1.344	8.950	7.180	4.477
392.20	10.754	9.133	6.336	4.952	1.354	9.095	7.281	4.526
392.40	10.923	9.267	6.413	5.005	1.366	9.235	7.377	4.570
392.60	11.093	9.402	6.485	5.056	1.377	9.381	7.479	4.616
392.80	11.266	9.538	6.566	5.109	1.387	9.536	7.580	4.665
393.00	11.443	9.678	6.646	5.165	1.396	9.700	7.710	4.710
393.20	11.623	9.825	6.737	5.220	1.400	9.873	7.847	4.770
393.40	11.809	9.983	6.836	5.303	1.422	10.057	8.003	4.851
393.60	11.990	10.153	6.951	5.391	1.430	10.250	8.175	4.942
393.80	12.190	10.335	7.095	5.506	1.450	10.447	8.364	5.059
394.00	12.385	10.529	7.266	5.664	1.500	10.645	8.561	5.223
394.20	12.582	10.727	7.458	5.853	1.600	10.844	8.760	5.410
394.40	12.782	10.926	7.656	6.047	1.734	11.044	8.959	5.603
394.60	12.982	11.125	7.869	6.230	1.871	11.244	9.159	5.799
394.80	13.182	11.324	8.027	6.382	1.865	11.444	9.356	5.947
395.00	13.382	11.517	8.186	6.509	1.893	11.644	9.550	6.092
395.20	13.580	11.701	8.323	6.615	1.914	11.844	9.739	6.193
395.40	13.776	11.877	8.444	6.708	1.930	12.044	9.924	6.282
395.60	13.970	12.053	8.563	6.793	1.945	12.244	10.100	6.369
395.80	14.164	12.234	8.692	6.892	1.960	12.444	10.295	6.462

* The units of u are molecules/cm², abbreviated here by (#/cm²).

TABLE 7 (cont'd)

Sam. No.	173.	171.	170.	61.	56.	136.	133.	115.
Temp. (K)	296.	296.	296.	296.	296.	336.	336.	336.
Path (cm)	59500.	59500.	59500.	2884.	2884.	2884.	2884.	2884.
ρ (atm)	0.01145	0.00882	0.00553	0.02132	0.01579	0.02066	0.02066	0.02079
ρ (atm)	0.01145	0.00882	0.00553	0.02132	0.01579	0.02066	0.02066	0.02079
u ($^{\circ}$ /cm ^{2})	1.490E 22	1.301E 22	8.158E 21	1.525E 21	1.645E 20	1.294E 21	1.994E 21	1.303E 21
v (cm $^{-1}$)								
396.00	14.359	12.422	8.830	7.812	1.981	12.644	10.486	6.573
396.20	14.556	12.614	9.005	7.174	2.025	12.844	10.682	6.723
396.40	14.750	12.816	9.196	7.364	2.119	13.044	10.881	6.908
396.60	14.953	13.015	9.395	7.557	2.243	13.244	11.080	7.181
396.80	15.153	13.215	9.594	7.743	2.323	13.444	11.280	7.289
397.00	15.353	13.415	9.794	7.930	2.370	13.644	11.480	7.474
397.20	15.553	13.615	9.994	8.123	2.463	13.844	11.680	7.666
397.40	15.753	13.815	10.194	8.328	2.609	14.044	11.880	7.862
397.60	15.953	14.015	10.394	8.519	2.779	14.244	12.080	8.055
397.80	16.153	14.215	10.594	8.717	2.928	14.444	12.280	8.255
398.00	16.353	14.415	10.798	8.907	3.029	14.644	12.480	8.447
398.20	16.553	14.615	10.977	9.075	3.073	14.844	12.680	8.621
398.40	16.753	14.815	11.157	9.224	3.102	15.044	12.880	8.782
398.60	16.953	15.015	11.339	9.383	3.134	15.244	13.080	8.940
398.80	17.153	15.215	11.529	9.566	3.202	15.444	13.280	9.131
399.00	17.353	15.415	11.726	9.761	3.331	15.644	13.480	9.327
399.20	17.553	15.615	11.925	9.955	3.450	15.844	13.679	9.520
399.40	17.753	15.814	12.118	10.126	3.588	16.044	13.878	9.708
399.60	17.952	16.009	12.295	10.270	3.536	16.244	14.077	9.854
399.80	18.151	16.203	12.456	10.397	3.553	16.444	14.273	9.987
400.00	18.350	16.399	12.623	10.554	3.596	16.644	14.470	10.142
400.20	18.550	16.597	12.812	10.742	3.698	16.844	14.669	10.327
400.40	18.750	16.796	13.008	10.931	3.817	17.044	14.868	10.521
400.60	18.949	16.995	13.198	11.101	3.899	17.244	15.066	10.701
400.80	19.145	17.187	13.359	11.229	3.931	17.444	15.259	10.844
401.00	19.335	17.361	13.483	11.322	3.946	17.644	15.438	10.981
401.20	19.519	17.524	13.584	11.394	3.958	17.844	15.602	11.015
401.40	19.697	17.676	13.676	11.463	3.970	18.044	15.752	11.048
401.60	19.869	17.828	13.762	11.526	3.981	18.244	15.882	11.148
401.80	20.036	17.956	13.837	11.580	3.991	18.444	15.997	11.194
402.00	20.198	18.083	13.904	11.638	4.000	18.644	16.098	11.233
402.20	20.357	18.206	13.970	11.679	4.008	18.844	16.191	11.271
402.40	20.515	18.327	14.036	11.726	4.016	19.044	16.270	11.327
402.60	20.671	18.446	14.101	11.772	4.022	19.244	16.363	11.343
402.80	20.826	18.564	14.167	11.817	4.029	19.444	16.442	11.378
403.00	20.980	18.681	14.231	11.861	4.036	19.644	16.517	11.412
403.20	21.132	18.796	14.293	11.904	4.043	19.844	16.589	11.445
403.40	21.284	18.909	14.355	11.947	4.050	20.044	16.658	11.478
403.60	21.434	19.022	14.416	11.990	4.057	20.244	16.726	11.511
403.80	21.584	19.134	14.478	12.032	4.065	20.444	16.791	11.545
404.00	21.734	19.246	14.539	12.075	4.072	20.644	16.855	11.578
404.20	21.885	19.359	14.600	12.118	4.079	20.844	16.919	11.615
404.40	22.035	19.474	14.662	12.162	4.086	21.044	16.983	11.655
404.60	22.184	19.588	14.724	12.205	4.091	21.244	17.044	11.693
404.80	22.333	19.701	14.786	12.247	4.098	21.444	17.102	11.726
405.00	22.483	19.814	14.848	12.287	4.105	21.644	17.160	11.757
405.20	22.635	19.927	14.910	12.328	4.112	21.844	17.220	11.788
405.40	22.791	20.047	14.970	12.376	4.120	22.044	17.285	11.825
405.60	22.961	20.166	15.030	12.420	4.128	22.244	17.346	11.867
405.80	23.134	20.334	15.172	12.536	4.164	22.444	17.539	11.966
406.00	23.295	20.471	15.258	12.594	4.177	22.644	17.637	12.016
406.20	23.465	20.544	15.324	12.637	4.184	22.844	17.708	12.049
406.40	23.592	20.698	15.382	12.678	4.190	23.044	17.752	12.079
406.60	23.736	20.885	15.438	12.718	4.196	23.244	17.802	12.110
406.80	23.879	20.912	15.493	12.759	4.203	23.444	17.851	12.140
407.00	24.027	21.017	15.547	12.799	4.210	23.644	17.898	12.168
407.20	24.165	21.171	15.601	12.838	4.217	23.844	17.946	12.196
407.40	24.307	21.225	15.654	12.875	4.225	24.044	17.992	12.225
407.60	24.450	21.331	15.711	12.912	4.234	24.244	18.040	12.254
407.80	24.596	21.440	15.771	12.953	4.243	24.444	18.091	12.286
408.00	24.740	21.549	15.830	12.995	4.252	24.644	18.143	12.319
408.20	24.882	21.655	15.884	13.033	4.260	24.844	18.195	12.347
408.40	25.023	21.758	15.937	13.071	4.267	25.044	18.242	12.374
408.60	25.164	21.862	15.990	13.108	4.273	25.244	18.289	12.401
408.80	25.306	21.965	16.044	13.145	4.279	25.444	18.337	12.428
409.00	25.447	22.069	16.097	13.182	4.284	25.644	18.384	12.454
409.20	25.597	22.172	16.150	13.214	4.291	25.844	18.430	12.479
409.40	25.728	22.274	16.204	13.247	4.298	26.044	18.476	12.505
409.60	25.872	22.380	16.261	13.288	4.306	26.244	18.527	12.533
409.80	26.021	22.494	16.325	13.335	4.315	26.444	18.594	12.576
410.00	26.171	22.608	16.388	13.380	4.324	26.644	18.663	12.623
410.20	26.316	22.716	16.443	13.418	4.332	26.844	18.715	12.656
410.40	26.459	22.820	16.494	13.454	4.339	27.044	18.760	12.684
410.60	26.601	22.922	16.549	13.491	4.346	27.244	18.803	12.712
410.80	26.743	23.024	16.601	13.529	4.354	27.444	18.847	12.739
411.00	26.883	23.125	16.654	13.567	4.362	27.644	18.891	12.766
411.20	27.023	23.226	16.706	13.605	4.370	27.844	18.936	12.793
411.40	27.162	23.325	16.756	13.642	4.378	28.044	18.982	12.820
411.60	27.302	23.425	16.808	13.679	4.386	28.244	19.028	12.846
411.80	27.441	23.525	16.861	13.717	4.392	28.444	19.076	12.872

* The units of u are molecules/cm ^{2} , abbreviated here by ($^{\circ}$ /cm ^{2})

TABLE 7 (cont'd)

Sam. No.	173.	171.	170.	61.	56.	136.	133.	115.
Temp (K)	296.	296.	296.	296.	296.	296.	296.	296.
Path (cm)	59500.	59500.	59500.	2884.	2884.	2884.	2884.	2884.
P (atm)	0.01145	0.00882	0.00553	0.02132	0.01579	0.02066	0.02066	0.02079
P (atm)	0.01145	0.00882	0.00553	0.02132	0.01579	1.00395	0.50000	0.02079
u ($^{\circ}$ /cm) ^a	1.690E 22	1.301E 22	8.158E 21	1.583E 21	1.645E 20	1.294E 21	1.294E 21	1.303E 21
ν (cm) ⁻¹								
412.00	27.562	28.626	16.917	13.752	4.400	22.885	19.124	12.698
412.20	27.723	28.720	16.972	13.790	4.407	22.879	19.173	12.925
412.40	27.866	28.833	17.020	13.830	4.415	22.955	19.223	12.954
412.60	28.009	28.940	17.065	13.869	4.423	23.034	19.277	12.986
412.80	28.153	29.049	17.142	13.909	4.429	23.115	19.331	13.020
413.00	28.296	29.156	17.197	13.940	4.436	23.194	19.382	13.050
413.20	28.439	29.259	17.251	13.987	4.442	23.272	19.433	13.080
413.40	28.582	29.362	17.305	14.026	4.449	23.350	19.486	13.111
413.60	28.725	29.464	17.359	14.064	4.457	23.430	19.544	13.142
413.80	28.869	29.570	17.416	14.101	4.466	23.513	19.599	13.174
414.00	29.014	29.680	17.475	14.139	4.473	23.599	19.656	13.207
414.20	29.160	29.791	17.535	14.176	4.480	23.684	19.717	13.241
414.40	29.307	29.901	17.592	14.219	4.487	23.768	19.780	13.274
414.60	29.455	30.013	17.653	14.262	4.495	23.860	19.847	13.308
414.80	29.611	30.131	17.723	14.309	4.505	23.951	19.924	13.340
415.00	29.778	30.267	17.813	14.375	4.517	24.125	20.029	13.410
415.20	29.956	30.419	17.919	14.462	4.535	24.279	20.159	13.492
415.40	30.133	30.575	18.026	14.553	4.556	24.436	20.295	13.570
415.60	30.329	30.715	18.109	14.616	4.571	24.577	20.412	13.630
415.80	30.458	30.839	18.180	14.665	4.581	24.709	20.506	13.670
416.00	30.615	30.950	18.247	14.712	4.591	24.843	20.550	13.720
416.20	30.774	31.070	18.314	14.760	4.602	24.983	20.655	13.760
416.40	30.936	31.203	18.384	14.810	4.613	25.131	20.800	13.802
416.60	31.105	31.335	18.463	14.869	4.626	25.280	20.917	13.852
416.80	31.283	31.482	18.559	14.945	4.640	25.457	21.053	13.923
417.00	31.469	31.643	18.669	15.034	4.650	25.639	21.206	14.009
417.20	31.653	31.809	18.783	15.127	4.675	25.829	21.372	14.096
417.40	31.852	31.980	18.908	15.216	4.692	26.024	21.551	14.183
417.60	32.049	32.162	19.039	15.327	4.714	26.222	21.739	14.297
417.80	32.243	32.351	19.206	15.470	4.767	26.421	21.935	14.450
418.00	32.448	32.548	19.397	15.666	4.867	26.621	22.133	14.636
418.20	32.648	32.740	19.593	15.861	4.974	26.821	22.332	14.829
418.40	32.848	32.940	19.791	16.055	5.055	27.021	22.532	15.022
418.60	33.048	33.140	19.991	16.240	5.170	27.221	22.732	15.210
418.80	33.240	33.340	20.191	16.446	5.316	27.421	22.932	15.415
419.00	33.440	33.540	20.391	16.642	5.424	27.621	23.132	15.611
419.20	33.640	33.740	20.591	16.839	5.532	27.821	23.332	15.808
419.40	33.840	33.940	20.790	17.034	5.636	28.021	23.532	16.003
419.60	34.040	34.140	20.987	17.226	5.707	28.221	23.732	16.196
419.80	34.240	34.340	21.185	17.422	5.820	28.421	23.931	16.389
420.00	34.440	34.540	21.382	17.617	5.961	28.621	24.130	16.586
420.20	34.640	34.740	21.575	17.799	6.056	28.821	24.327	16.760
420.40	34.847	34.946	21.755	17.955	6.080	29.021	24.526	16.910
420.60	35.046	35.141	21.919	18.091	6.115	29.221	24.719	17.046
420.80	35.243	35.330	22.066	18.208	6.138	29.420	24.909	17.161
421.00	35.435	35.507	22.191	18.303	6.154	29.616	25.089	17.256
421.20	35.621	35.673	22.290	18.380	6.166	29.807	25.256	17.324
421.40	35.801	35.826	22.390	18.446	6.176	29.994	25.412	17.389
421.60	35.977	35.972	22.476	18.511	6.188	30.177	25.560	17.445
421.80	36.154	36.115	22.561	18.575	6.199	30.358	25.700	17.501
422.00	36.332	36.261	22.650	18.643	6.205	30.541	25.859	17.567
422.20	36.513	36.413	22.745	18.715	6.217	30.730	26.019	17.630
422.40	36.699	36.572	22.851	18.797	6.230	30.926	26.191	17.719
422.60	36.893	36.744	22.981	18.909	6.241	31.121	26.379	17.833
422.80	37.091	36.932	23.144	19.066	6.252	31.321	26.575	17.992
423.00	37.290	37.128	23.331	19.252	6.261	31.519	26.773	18.174
423.20	37.489	37.325	23.515	19.422	6.268	31.716	26.971	18.350
423.40	37.687	37.517	23.679	19.557	6.284	31.917	27.160	18.507
423.60	37.881	37.708	23.816	19.668	6.300	32.114	27.353	18.626
423.80	38.086	37.865	23.927	19.739	6.322	32.302	27.514	18.714
424.00	38.237	38.011	24.015	19.790	6.331	32.480	27.663	18.774
424.20	38.440	38.143	24.080	19.853	6.339	32.669	27.793	18.826
424.40	38.560	38.271	24.161	19.900	6.348	32.815	27.919	18.876
424.60	38.732	38.401	24.230	19.964	6.350	32.986	28.050	18.920
424.80	38.902	38.530	24.325	20.030	6.360	33.165	28.196	18.992
425.00	39.094	38.695	24.439	20.129	6.391	33.355	28.351	19.091
425.20	39.276	38.873	24.592	20.276	6.399	33.552	28.501	19.237
425.40	39.474	39.063	24.760	20.447	6.427	33.750	28.757	19.414
425.60	39.670	39.251	24.929	20.580	6.480	33.949	28.990	19.578
425.80	39.859	39.422	25.049	20.675	6.480	34.142	29.125	19.676
426.00	40.039	39.577	25.149	20.747	6.494	34.325	29.280	19.746
426.20	40.222	39.734	25.260	20.844	6.494	34.508	29.437	19.827
426.40	40.406	39.897	25.381	20.955	6.494	34.692	29.606	19.927
426.60	40.583	39.954	25.486	21.040	6.496	34.868	29.740	20.003
426.80	40.745	39.107	25.564	21.093	7.006	34.980	29.849	20.049
427.00	40.898	39.305	25.630	21.141	7.016	35.100	29.929	20.080
427.20	41.046	39.410	25.690	21.186	7.025	35.200	29.999	20.123
427.40	41.189	39.525	25.745	21.220	7.032	35.290	30.063	20.154
427.60	41.326	39.624	25.797	21.266	7.037	35.374	30.121	20.181
427.80	41.460	39.720	25.847	21.303	7.042	35.454	30.176	20.207

^a The units of u are molecules/cm², abbreviated here by ($^{\circ}$ /cm)².

TABLE 7 (cont'd)

Sam. No.	173.	171.	170.	61.	56.	136.	133.	115.
Temp (K)	296.	296.	296.	296.	296.	338.	338.	338.
Path (cm)	59500.	59500.	59500.	2884.	2884.	2884.	2884.	2884.
ρ (atm)	0.01145	0.00882	0.00553	0.02132	0.01579	0.02066	0.02066	0.02079
ρ (atm)	0.01145	0.00882	0.00553	0.02132	0.01579	0.02066	0.02066	0.02079
u ($^{\circ}$ /cm)	1.690E 22	1.301E 22	8.158E 21	1.525E 21	1.445E 20	1.294E 21	1.294E 21	1.303E 21
ν (cm) ⁻¹								
428.00	41.594	35.815	25.897	21.339	7.844	35.531	30.230	20.233
428.20	41.727	35.918	25.946	21.375	7.852	35.609	30.284	20.261
428.40	41.861	36.024	25.996	21.415	7.857	35.649	30.340	20.291
428.60	41.997	36.132	26.052	21.457	7.864	35.770	30.404	20.323
428.80	42.145	36.246	26.119	21.514	7.873	35.894	30.493	20.367
429.00	42.298	36.369	26.190	21.576	7.882	36.017	30.594	20.421
429.20	42.444	36.494	26.255	21.625	7.890	36.120	30.673	20.464
429.40	42.592	36.555	26.309	21.665	7.897	36.202	30.730	20.495
429.60	42.717	36.653	26.360	21.705	7.903	36.270	30.781	20.524
429.80	42.853	36.752	26.416	21.743	7.907	36.354	30.833	20.552
430.00	42.992	36.855	26.478	21.782	7.911	36.436	30.880	20.583
430.20	43.135	36.960	26.529	21.823	7.915	36.524	30.949	20.618
430.40	43.280	37.069	26.580	21.866	7.918	36.619	31.017	20.652
430.60	43.432	37.181	26.653	21.913	7.922	36.731	31.097	20.687
430.80	43.596	37.307	26.733	21.977	7.931	36.873	31.206	20.732
431.00	43.779	37.463	26.851	22.064	7.940	37.047	31.355	20.816
431.20	43.971	37.642	27.000	22.229	7.950	37.239	31.536	20.945
431.40	44.163	37.821	27.144	22.356	7.959	37.428	31.714	21.066
431.60	44.363	37.979	27.250	22.436	7.973	37.599	31.888	21.139
431.80	44.587	38.114	27.327	22.492	7.981	37.736	31.967	21.183
432.00	44.653	38.227	27.386	22.536	7.989	37.843	32.044	21.215
432.20	44.794	38.330	27.448	22.578	7.996	37.933	32.100	21.244
432.40	44.931	38.429	27.493	22.619	7.999	38.015	32.160	21.272
432.60	45.066	38.526	27.545	22.658	7.999	38.095	32.227	21.300
432.80	45.196	38.621	27.595	22.695	7.999	38.170	32.276	21.326
433.00	45.328	38.715	27.643	22.730	7.999	38.243	32.326	21.350
433.20	45.457	38.809	27.688	22.766	7.999	38.316	32.375	21.375
433.40	45.586	38.902	27.730	22.804	7.999	38.390	32.424	21.400
433.60	45.716	39.005	27.786	22.842	7.999	38.468	32.476	21.427
433.80	45.847	39.090	27.836	22.880	7.999	38.544	32.532	21.455
434.00	45.988	39.187	27.887	22.918	7.999	38.650	32.597	21.485
434.20	46.118	39.287	27.942	22.958	7.999	38.762	32.674	21.518
434.40	46.266	39.396	28.007	23.000	7.999	38.884	32.775	21.561
434.60	46.427	39.529	28.101	23.069	7.999	39.010	32.914	21.639
434.80	46.609	39.680	28.226	23.211	7.999	39.270	33.089	21.763
435.00	46.795	39.860	28.359	23.332	7.999	39.463	33.274	21.888
435.20	46.974	40.021	28.471	23.409	7.999	39.648	33.439	21.997
435.40	47.137	40.159	28.553	23.462	7.999	39.796	33.572	22.057
435.60	47.291	40.279	28.617	23.509	7.999	39.948	33.685	22.103
435.80	47.443	40.395	28.681	23.557	7.999	40.084	33.790	22.146
436.00	47.602	40.519	28.757	23.615	7.999	40.246	33.915	22.205
436.20	47.776	40.681	28.868	23.704	7.999	40.425	34.067	22.294
436.40	47.963	40.828	28.999	23.819	7.999	40.622	34.249	22.430
436.60	48.155	41.012	29.153	23.989	7.999	40.820	34.443	22.590
436.80	48.345	41.191	29.287	24.108	7.999	41.013	34.625	22.716
437.00	48.528	41.363	29.381	24.166	7.999	41.186	34.775	22.787
437.20	48.677	41.472	29.446	24.213	7.999	41.331	34.892	22.835
437.40	48.824	41.583	29.506	24.252	7.999	41.450	34.979	22.871
437.60	48.964	41.684	29.557	24.290	7.999	41.552	35.051	22.902
437.80	49.099	41.783	29.610	24.329	7.999	41.645	35.110	22.933
438.00	49.235	41.884	29.666	24.370	7.999	41.735	35.164	22.967
438.20	49.372	41.986	29.723	24.412	7.999	41.821	35.247	23.021
438.40	49.508	42.087	29.777	24.452	7.999	41.902	35.305	23.032
438.60	49.643	42.184	29.828	24.489	7.999	41.976	35.356	23.068
438.80	49.772	42.276	29.875	24.523	7.999	42.047	35.403	23.083
439.00	49.901	42.366	29.922	24.557	7.999	42.119	35.452	23.107
439.20	50.031	42.458	29.972	24.596	7.999	42.198	35.507	23.139
439.40	50.164	42.553	30.023	24.638	7.999	42.282	35.570	23.195
439.60	50.296	42.648	30.073	24.679	7.999	42.361	35.630	23.208
439.80	50.426	42.739	30.121	24.716	7.999	42.435	35.683	23.232
440.00	50.554	42.829	30.167	24.751	7.999	42.508	35.734	23.256
440.20	50.683	42.918	30.214	24.786	7.999	42.585	35.786	23.279
440.40	50.812	43.009	30.261	24.822	7.999	42.666	35.842	23.304
440.60	50.943	43.102	30.310	24.866	7.999	42.753	35.901	23.329
440.80	51.074	43.199	30.361	24.908	7.999	42.850	35.966	23.356
441.00	51.220	43.308	30.416	24.939	7.999	42.963	36.042	23.384
441.20	51.372	43.413	30.472	24.987	7.999	43.096	36.134	23.418
441.40	51.535	43.542	30.578	25.053	7.999	43.255	36.254	23.460
441.60	51.714	43.699	30.692	25.157	7.999	43.437	36.409	23.551
441.80	51.906	43.880	30.847	25.302	7.999	43.631	36.591	23.682
442.00	52.102	44.074	31.029	25.479	7.999	43.838	36.786	23.851
442.20	52.308	44.271	31.215	25.650	8.046	44.029	36.903	24.022
442.40	52.496	44.462	31.381	25.809	8.102	44.220	37.176	24.161
442.60	52.656	44.636	31.580	25.980	8.120	44.410	37.350	24.244
442.80	52.867	44.789	31.685	25.975	8.128	44.597	37.498	24.383
443.00	53.039	44.929	31.887	26.085	8.135	44.769	37.636	24.368
443.20	53.209	45.067	31.773	26.099	8.143	44.946	37.779	24.426
443.40	53.387	45.216	31.881	26.105	8.150	45.133	37.911	24.514
443.60	53.574	45.389	32.021	26.816	8.205	45.329	38.125	24.652
443.80	53.768	45.573	32.179	26.871	8.268	45.527	38.320	24.815
444.00	53.968	45.793	32.321	26.995	8.304	45.722	38.511	24.953

* The units of u are molecules/cm², abbreviated here by ($^{\circ}$ /cm²).

SECTION 5

ABSORPTION BY CO_2 BETWEEN 500 AND 850 cm^{-1}

SAMPLING

The temperatures and total pressures of the samples studied were varied over wide ranges representative of the earth's atmosphere. Samples varied in pressure from 1 atm to less than 0.03 atm and were maintained near one of three different temperatures: 310 K, 274 K, and 245 K. The highest temperature corresponds approximately to the maximum atmospheric temperature in the tropics. The lowest temperature, 245 K, approximately represents stratospheric temperatures. Ideally, somewhat lower temperatures should be employed to cover the full temperature range of the atmosphere; however, the experimental difficulties associated with operating at lower temperatures would greatly increase the time involved in obtaining the data and would also reduce the accuracy. As a compromise, the lower temperature of 245 K was chosen. An intermediate temperature near 274 K was also employed in order to provide additional data on the temperature dependence of the absorption.

All of the samples studied were contained in a multiple-pass absorption cell that has been described previously⁶. The base length of the cell is 1 meter, and the optical path can be varied in increments of approximately 4 m up to a maximum of approximately 40 m. The number of passes of the monitoring beam can be adjusted externally without disturbing the sample in the cell. Electrical resistance wire coiled around the outside of the stainless steel body of the cell provides the heat when operating the cell above room temperature. The cell is well insulated so that only approximately 30 watts of power are required to maintain it at 310 K. When operating at this temperature, the gas in the cell is maintained uniform to less than ± 1 K. The temperature is controlled manually by adjusting the current through the heating wires.

The main body of the absorption cell is contained within a stainless steel tub that can be filled with liquid to submerge the cell. The intermediate temperature, 274 K, was maintained stable to ± 0.5 K by filling the tub with ice-water. The lower temperature, approximately 245 K, was attained by submerging the cell in a mixture of commercial "anti-freeze" and water that was chilled by bubbling liquid nitrogen through it. A piece of copper tubing submerged in the bottom of the tub that contained the anti-freeze mixture carried the liquid nitrogen from a large commercial dewar. Ten holes located at different places along the tubing allowed the nitrogen to evaporate and bubble from the tubing through the liquid. The movement of the bubbles mixed the liquid enough to maintain the temperature throughout the length of the absorption cell constant to approximately ± 1 K. The cell temperature was controlled by adjusting the rate of flow of the liquid nitrogen. After the cell temperature had been reasonably well stabilized, the temperature could be maintained constant to within ± 1 K for several hours. The low-temperature samples varied from approximately 243 to approximately 249 K. It was not important that all of the samples be at exactly the same temperature as long as

the temperature was measured accurately. Therefore, if the cell temperature was stabilized within this range, no effort was made to readjust the temperature. The stability of the optical system, and thus the accuracy of the data, are strongly dependent on temperature gradients and temperature changes in the cell.

A few of the data were obtained for samples of pure CO_2 ; most of the data represent samples of CO_2 mixed with dry air. The dry air consists of 79% N_2 and 21% O_2 to match the atmosphere. The mixtures of CO_2 plus dry air were obtained pre-mixed from a commercial gas supplier in cylinders at total pressures of approximately 150 atm. Table 8 lists the concentrations, in mole percent, of the different mixtures studied. The values of CO_2 concentration listed in the left-hand column are those determined spectroscopically by us in the laboratory before any spectral data were obtained; these values are the ones used in calculating the absorber thickness of the samples. The concentrations listed in the second column from the left are those provided by the gas supplier. Five of the eight measured concentrations agreed with the values provided by the gas supplier to within our measurement accuracy.

The concentration of each mixture was checked carefully by comparing its infrared absorption to that of a laboratory-mixed sample with very nearly the same concentration of CO_2 . Samples used in these concentration measurements ordinarily varied in pressure from approximately 0.3 atm to 1 atm because pressures in this range can be measured quite accurately. The sample cell was at room temperature and was adjusted to either 4 or 8 passes in order to attain good stability. The spectrometer slits were adjusted wide to smooth out most of the structure in the spectrum over the short spectral interval used for the concentration measurements. The spectral interval was chosen so that the absorbance was nearly constant over the interval and was between approximately 0.4 and 0.7. With the absorbance in this range, the smallest fractional difference in the CO_2 concentration could be detected. Each measurement was repeated several times. Two separate batches of laboratory mixtures were made for each concentration, and the absorption by a given pressure of gas from each batch was compared. If the agreement between the measurements for a given concentration was not excellent, a new batch was made and the measurements were repeated.

The laboratory mixtures were made by introducing carefully measured amounts of CO_2 and dry air into a glass-lined mix-tank. The mix-tank is supplied with a small mixing blade that is driven from outside the tank by a drill motor. The shaft on which the mixing blade is mounted extends through a rotating seal that employs lubricated "O-rings". Partial pressures of the CO_2 and the dry air introduced into the mix tank could be measured with an accuracy of approximately 0.1 to 0.2%. The total pressure of the mixture was typically 10 atm. The estimated uncertainty in the values assigned to the concentrations for each of the laboratory mixtures varies from approximately 0.2% of the concentration for the higher concentrations to 0.5% for the lower concentrations. The laboratory-mixed samples were employed only to check the concentrations of the commercial mixtures, which were employed for all of the samples for which spectral data are presented.

No evidence of systematic error due to selective adsorption of CO_2 on the walls of the sample cell could be observed. The possibility of this phenomenon occurring was checked carefully for the most dilute (0.125% CO_2) mixture. Errors due to adsorption would probably be largest in the dilute samples. During the tests for adsorption, the infrared absorption at a fixed wavelength was measured, starting immediately after a sample had been introduced into the sample cell. Approximately one minute was required for the apparent absorption to stabilize because of the changing temperature of the gas as it expanded into a previously evacuated cell. After this short period of stabilization, the absorption by a sample remained constant for several days and was the same as the absorption by a sample of the same concentration that was flushed continuously through the cell. We concluded that no significant errors were being introduced by the adsorption and desorption of CO_2 from the cell walls. Some evidence of adsorption and desorption could be observed under extreme conditions that did not apply to our sampling procedures. For example, if the cell were filled with 1 atm of pure CO_2 , then evacuated quickly to less than 1 torr of pressure, a slight increase in the infrared absorption could be observed for a few minutes after the valve to the pump was closed. This increase in absorption was apparently due to a small amount of CO_2 desorbing from the walls of the cell. However, we made certain that the cell was out-gassed before introducing a dilute mixture into the cell for investigation.

Three different gauges measured the sample pressures. A mercury manometer served for pressures between 0.1 and 1 atm, an oil manometer for pressures between approximately 0.003 and 0.1 atm, and a McLeod gauge for lower pressures. The parameters of the samples studied are summarized in Table 8. As explained above, the concentrations of the mixtures of CO_2 plus dry air used to determine sample absorber thicknesses are given in the left-hand column. Only a few data were obtained for samples of 100% CO_2 ; these are summarized in the upper portion of Table 8. The three right-hand columns of the table correspond to the three sample temperatures employed. For the 100% CO_2 samples, the pressures listed under a given temperature correspond to the samples for which spectral data were scanned. Not all of the samples of CO_2 plus dry air are represented in the table. A series of samples at different equivalent pressures were studied for each combination of path length and concentration. The maximum equivalent pressure for each series was 1.00 atm; each succeeding equivalent pressure was reduced by approximately a factor of two, giving pressures of 0.500, 0.250, 0.125 atm, etc. Only the lowest pressure is listed in Table 8 for the mixtures. In some cases, particularly for the lower pressures, the equivalent pressures were not adjusted to exactly an integral power of 0.5 atm; the measured pressures were used to calculate absorber thicknesses. The exact parameters for each sample are listed below in tables that include detailed results.

SPECTROSCOPIC PROCEDURES

The procedures employed in scanning the spectral data are essentially the same as those used to obtain the data presented in Sections 2 and 4. All of the optical path external to the sample cell passed either through a vacuum or through non-absorbing N_2 to eliminate absorption by CO_2 or any other atmospheric gas. The grating employed for the CO_2 data contains 40 grooves/mm and is blazed for maximum efficiency at 22 μm . All orders of wavelengths except for the first order were eliminated by a KBr prism.

TABLE 8. SUMMARY OF SAMPLES

% CO ₂ (Measured)	% CO ₂ (Gas Supplier)	Path Length (cm ⁻¹)	Minimum Equivalent Pressure (atm)		
			310K	Temperature 274K	245K
	100*	3291	1.00*	1.00*	1.00*
	100	3291	0.500*	0.500*	
	100	3291	0.250*	0.250*	
	100	3291	0.125*		
	100	3291	0.00198*		
	100	3291	0.00393*		
15.3	15.3	3291	0.00198	0.00195	0.00193
8.09	8.09	3291	0.00197		
3.85	3.85	3291	0.00194	0.00192	0.00386
3.85	3.85	1648	0.00386		
1.91	1.91	1648	0.00781	0.00781	0.00781
0.977	0.977	1648	0.00779		
0.503	0.511	1648	0.0157	0.0157	0.0157
0.250	0.260	1648	0.0155		
0.125	0.128	1648	0.0313	0.0313	0.0313
0.125	0.128	826	0.0619	0.0625	0.0625

* The pure (100%) CO₂ samples are from a cylinder of commercial grade CO₂ with purity reportedly greater than 99.5%. The equivalent pressures listed for pure CO₂ represent all of the pure CO₂ samples studied. A series of samples at different equivalent pressures were studied for each combination of path length and concentration of the CO₂+ dry air mixtures. The equivalent pressures for each series were 1.00 atm, 0.500 atm, 0.250 atm, etc. down to the equivalent pressure tabulated.

A background curve that corresponded to 100% transmittance was scanned with the sample cell evacuated, either immediately before or after each sample spectrum was scanned. In order to check for possible sampling errors or changes in the signal level corresponding to 100% transmittance during a scan, portions of each spectrum were re-run and the results were compared with the spectrum that was to be reduced further. Separate samples having the same parameters were employed in the comparisons as further checks for possible sampling errors. Each sample spectrum and its corresponding background spectrum were digitized with the data related directly to detector signal punched on computer cards. A computer then calculated values of transmittance, integrated absorbance, etc.

The spectral slitwidth was adjusted wide enough to smooth out most of the structure due to individual vibration-rotation lines in the P- and R-branches of the bands. The Q-branches appear as single absorption features in the spectra. Smoothing the spectra in this manner simplifies the reduction and analysis of the data while maintaining adequate resolution for quantitative comparison with calculated spectra. The physical widths of both the entrance and exit slits of the grating monochromator were fixed at 1.7 mm. This resulted in the spectral slitwidth changing with wavenumber as given in Table 9. The values tabulated represent the full width at half-maximum of a triangular slit function. As can be seen in the transmittance curves shown below in this section, a small amount of structure remains in some of the P- and R-branches because of the individual lines. Slightly wider slits would have smoothed out this remaining structure as was originally intended. However, further widening the slits beyond the 1.7 mm used would have produced an irregular and unknown slit function for two reasons: The image of the Nernst glower source formed at the entrance slit was not sufficiently wide to illuminate a wider slit uniformly. In addition, the image of a wider exit slit formed on the detector would have overfilled the sensitive element of the detector. It is apparent that the outer portions of wider slits would not contribute properly to the detector signal, thus producing an irregular slit function. Interchanging or readjusting the optical components to overcome this problem so that wider slits could be used was not believed to be justified because of the small amount of undesired residual structure in the spectra.

A few checks were made on the uniformity of the sensitivity of the instrument to different narrow portions of the 1.7 mm wide slits that were used. The non-uniformities that were observed could lead to effective spectral slitwidths that differ by no more than 5 to 10% from the values listed in Table 9. Non-symmetry of the sensitivity about the center of the slit can also lead to slight shifts in the effective center of the spectral band passed by the slits. This phenomenon can lead to apparent shifts in the calibration that relates wavenumber to grating position as the slitwidth is changed. Errors in wavenumber calibration due to such non-uniformity in sensitivity could not be larger than 10% of the spectral slit width.

Table 10 lists the absorption lines used to provide wavenumber calibration. Transmission spectra of the calibration gases were scanned with the spectral slitwidths adjusted to about one-fourth of the values listed in Table 9. The calibration lines were well resolved with this improved resolution. The line positions were determined in terms of fiducial marks that were related directly

TABLE 9. RESOLUTION SCHEDULE

ν (cm^{-1})	Spectral Slitwidth (cm^{-1})
500	1.2
550	1.5
600	1.9
650	2.3
700	2.7
750	3.2
800	3.6
850	4.2

TABLE 10. CALIBRATION DATA

ν_0 (cm^{-1})	Gas	ν_0 (cm^{-1})	Gas
481.5	extrapolation	633.87	CO ₂
494.19	H ₂ O	645.86	CO ₂
506.93	H ₂ O	661.16	CO ₂
519.60	H ₂ O	674.44	CO ₂
525.98	H ₂ O	687.16	CO ₂
536.26	H ₂ O	700.06	CO ₂
547.83	H ₂ O	725.47	CO ₂
554.64	H ₂ O	743.83	CO ₂
567.23	H ₂ O	760.27	CO ₂
576.14	H ₂ O	775.81	CO ₂
584.74	H ₂ O	788.32	CO ₂
594.96	H ₂ O	806.26	CO ₂
604.46	H ₂ O	826.51	CO ₂
620.59	H ₂ O	860.0	extrapolation

to grating position. It was assumed that the relationship between wavenumber and grating position remained fixed when the slits were widened to scan the spectral data. The errors introduced by making this assumption are essentially those caused by the non-uniformities in slit illumination discussed in the previous paragraph. The CO_2 line positions are well-known throughout most of the spectral region and were used from approximately 630 cm^{-1} to the high-wavenumber side of the band. All of the wavenumbers listed in Table 10 from 633.87 to 826.51 cm^{-1} correspond to the centers of CO_2 lines that are not "blended" with weaker adjacent lines enough to shift the apparent line centers significantly. The CO_2 line positions listed are from a report by Drayson.¹³ No easily identifiable absorption line was available as a calibration standard near 850 cm^{-1} , the high wavenumber limit of the region of interest. Therefore, the position of a "false" line at 860.0 cm^{-1} on each spectrum was determined by extrapolation and used as a standard. Accurate calibration is not critical between 826 and 850 cm^{-1} because of the small amount of absorption and the lack of spectral structure in this region.

Absorption lines of H_2O were employed for the low-wavenumber side of the region. The H_2O lines used are reasonably well isolated from other lines so that the center positions can be located accurately and the points of maximum absorption are nearly independent of the slitwidth. Many of the CO_2 lines in the 490 - 625 cm^{-1} region are blended, making it difficult to determine their center positions accurately. All of the H_2O line positions from 494.19 to 620.59 cm^{-1} are from unpublished data provided by W. S. Benedict and R. F. Calfee.¹⁴ The values listed for these lines agree within a few hundredths of a cm^{-1} with the corresponding values in the AFGL listing of line parameters (Ref. 1). The "false" line at 481.5 cm^{-1} was located by extrapolation in the same manner as that used for the 860.0 cm^{-1} line. A spectrum of N_2O was scanned, and the known positions of the lines were used to confirm the positions of the H_2O lines between 590 and 634 cm^{-1} . The $6.3 \mu\text{m}$ H_2O band was scanned in 2nd order and its line positions used to confirm the calibration from 670 to 730 cm^{-1} .

Before each recorded spectrum was digitized, the positions of the calibration lines were marked on the recording. During the digitizing process, the positions of these calibration lines were also digitized in terms of their physical position on the recording. Wavenumber positions between the calibration lines were computed by interpolating on a linear wavenumber scale. The maximum error introduced by the assumption of a linear wavenumber scale was

¹³ S. R. Drayson, "A Listing of Wavenumbers and Intensities of Carbon Dioxide Absorption Lines Between 12 and $20 \mu\text{m}$." Technical Report 036350-4-T, National Aeronautics and Space Administration, Contract No. NSR 23-005-376, May 1973.

¹⁴ W. S. Benedict, Inst. for Molecular Physics, College Park Maryland, 90742; R. Calfee, Wave Propagation Labs., Environmental Research Labs. National Oceanic Atmospheric Administration, Boulder Colorado 80302, (Private Communication).

approximately 0.1 cm^{-1} . The estimated total error in wavenumber calibration is less than 0.2 cm^{-1} for most of the spectrum, but it may be as large as 0.4 cm^{-1} in a few places.

RESULTS

The results of the CO_2 transmission measurements are presented in detail in the form of tables of integrated absorptance, $\int \text{Adv}$, and in spectral plots of transmittance. Tables 12 through 27 contain extensive lists of the cumulative value of the integral $\int \text{Adv}$. Table 11 summarizes the samples represented and the wavenumber interval covered by Tables 12 - 27. The table is divided into three sections, one section for each temperature. The first letter of each sample number identifies the temperature as follows: H, 310K; Z, 274K; L, 245K. The second letter identifies a group of samples for which the corresponding spectra were processed together. Several groups may cover the same spectral region, and the data appear in a single table. As examples, HB01, 2 refers to two samples: HB01 and HB02; HC01-3 refers to samples HC01-3 refers to samples HC01, HC02 and HC03. The two right-hand columns of each section of Table 11 lists the number of the table that the integral values appear and the figure number that the spectra appear for each sample.

Each column in Tables 12 - 27 corresponds to a given sample with the sample parameters listed at the top of the column. The molar concentrations of CO_2 in the mixtures with dry air are listed along with temperature, path length, total pressure, equivalent pressure P_e (see Equation (8)), and absorber thickness. The pressures were originally measured in torr, and the values were submitted to the computer with the appropriate number of significant figures. Values of the pressures were computed in atm and listed in the table without rounding them off to the corresponding number of significant figures. For the same reason, many values of absorber are also listed to more than the significant number of figures.

The lower limit of integration, ν' , is lower for large samples that absorb a measurable amount far into the wings of the band system that it is for small samples. The tabulated value for a given wavenumber ν represents the value of the integral from ν' up to ν . Successive values of ν differ by 2 cm^{-1} ; the maximum value of ν listed depends on the amount of absorption by the sample. Several samples absorb a small, but measurable amount beyond the spectral limits included in Tables 12 - 27. The data for these samples have been omitted in the wings of the band system because data for larger samples provide more accurate checks on line parameters. When the absorptance is small, very slight errors in placing the 100% transmittance curve can result in large relative errors in the apparent line intensities.

The integrated absorptance between any two wavenumbers listed in Tables 12 - 27 is equal to the difference between the tabulated values of the integral. Some deviation from the true integrated absorptance that would be observed with infinite resolving power occurs because of the finite slitwidth employed in scanning the spectra. Enough significant figures are carried in the integral values so that the difference between two successive values retains all of the significant figures justified by the accuracy of the original data.

Computer plots of transmittance for the samples are shown in Figures 10-24. The spectral resolution is the same as that of the original spectra (Table 9) that were scanned and recorded by a strip-chart recorder. Only three of the parameters for each sample are given in the figures. The listings appear in the same order, top to bottom, as the spectral curves. Values of absorber thickness ν are expressed in exponential form. For example, 1.528E 18 indicates 1.528×10^{18} molecules/cm². All of the samples represented in Figures 10 - 16 were near 310K; Figures 17 - 20, near 274K; and Figures 21 - 24, near 245K.

Values of P_e and P are related by Equation (8) with $B = 1.30$; these two values of pressure approach each other for very dilute mixtures of CO₂ in dry air. In a few spectral regions within the band system, a significant portion of the absorption may be due to the extreme wings of distant lines. In these cases the value of $B = 1.30$ on which P_e is based may not be appropriate (see Reference 3). The path lengths and CO₂ concentrations are not given in Figures 16 - 24, but they can be found in the headings of Tables 12 - 27.

TABLE 11. SUMMARY OF TABLES AND FIGURES

301 K				274 K				245 K			
Sample No.	$\nu_0 - \nu_L$ (cm ⁻¹)	Table No.	Fig. No.	Sample No.	$\nu_0 - \nu_L$ (cm ⁻¹)	Table No.	Fig. No.	Sample No.	$\nu_0 - \nu_L$ (cm ⁻¹)	Table No.	Fig. No.
HQ01-2	560-780	12	10	ZA01	560-780	19	17	LA01	560-780	24	21
HA01			10	ZB02			17	LB02			21
HH01-2			10	ZC01-3			17	LC01-3			21
HC01-3			10	ZD02-4			17	LD02-4			21
HD01-4			10	ZE01-3,5			17	LE01-3,5			21
HS01-5			11	ZF02-4,6			18	LF02-4,6			22
HF01-6			11	ZG01-3,5,7			19	LG01-3,5,7			23
HG01-7	560-780	13	11	ZH02-4,6,8	590-750		19	LH02-4,6,8	590-750		23
HO01-8			13	ZI01-3,5,7,9	590-750	20	19	LI01-3,5,7,9	590-750	25	23
HT01-9	590-750	14	12,13	ZJ01-2,4,6,8,10	610-735		18	LJ01-2,4,6,8,10	610-735		22
			12								
HJ01-10	610-735	15	14	ZK01-2,4,6,8	610-735	21	17	LK01-2,4,6,8	610-735	26	21
HK01-9			14,15	ZL01-2,4,6,8			17	LL01-2,4,6,8			21
HL01-8	610-735	16	15	ZM01-2,4	656-680		17	LM01-2,4	656-680		21
HM01-5	656-680		10	ZN01-2			18	LN01-2			22
HN01-3	656-680		10								
HP01-2,3,4,6,8	500-560	17	16	ZP01-6	500-560	22	20	LP01	500-560	27	24
HP01-5,7,9				ZQ01-6	780-850	23	20	LQ01	780-850	27	24
HQ01-2,3,4,6,8	780-850	18	16								
HQ01-5,7											

TABLE 12

Sam. No.	HA01	HA02	HA03	HA04	HA05	HA06	HA07	HA08	HA09	HA10	HA11	HA12	HA13	HA14	HA15	HA16	HA17	HA18	HA19	HA20	HA21	HA22	HA23	HA24	HA25	HA26	HA27	HA28	HA29	HA30	HA31	HA32	HA33	HA34	HA35	HA36	HA37	HA38	HA39	HA40	HA41	HA42	HA43	HA44	HA45	HA46	HA47	HA48	HA49	HA50	HA51	HA52	HA53	HA54	HA55	HA56	HA57	HA58	HA59	HA60	HA61	HA62	HA63	HA64	HA65	HA66	HA67	HA68	HA69	HA70	HA71	HA72	HA73	HA74	HA75	HA76	HA77	HA78	HA79	HA80	HA81	HA82	HA83	HA84	HA85	HA86	HA87	HA88	HA89	HA90	HA91	HA92	HA93	HA94	HA95	HA96	HA97	HA98	HA99	HA100	HA101	HA102	HA103	HA104	HA105	HA106	HA107	HA108	HA109	HA110	HA111	HA112	HA113	HA114	HA115	HA116	HA117	HA118	HA119	HA120	HA121	HA122	HA123	HA124	HA125	HA126	HA127	HA128	HA129	HA130	HA131	HA132	HA133	HA134	HA135	HA136	HA137	HA138	HA139	HA140	HA141	HA142	HA143	HA144	HA145	HA146	HA147	HA148	HA149	HA150	HA151	HA152	HA153	HA154	HA155	HA156	HA157	HA158	HA159	HA160	HA161	HA162	HA163	HA164	HA165	HA166	HA167	HA168	HA169	HA170	HA171	HA172	HA173	HA174	HA175	HA176	HA177	HA178	HA179	HA180	HA181	HA182	HA183	HA184	HA185	HA186	HA187	HA188	HA189	HA190	HA191	HA192	HA193	HA194	HA195	HA196	HA197	HA198	HA199	HA200	HA201	HA202	HA203	HA204	HA205	HA206	HA207	HA208	HA209	HA210	HA211	HA212	HA213	HA214	HA215	HA216	HA217	HA218	HA219	HA220	HA221	HA222	HA223	HA224	HA225	HA226	HA227	HA228	HA229	HA230	HA231	HA232	HA233	HA234	HA235	HA236	HA237	HA238	HA239	HA240	HA241	HA242	HA243	HA244	HA245	HA246	HA247	HA248	HA249	HA250	HA251	HA252	HA253	HA254	HA255	HA256	HA257	HA258	HA259	HA260	HA261	HA262	HA263	HA264	HA265	HA266	HA267	HA268	HA269	HA270	HA271	HA272	HA273	HA274	HA275	HA276	HA277	HA278	HA279	HA280	HA281	HA282	HA283	HA284	HA285	HA286	HA287	HA288	HA289	HA290	HA291	HA292	HA293	HA294	HA295	HA296	HA297	HA298	HA299	HA300	HA301	HA302	HA303	HA304	HA305	HA306	HA307	HA308	HA309	HA310	HA311	HA312	HA313	HA314	HA315	HA316	HA317	HA318	HA319	HA320	HA321	HA322	HA323	HA324	HA325	HA326	HA327	HA328	HA329	HA330	HA331	HA332	HA333	HA334	HA335	HA336	HA337	HA338	HA339	HA340	HA341	HA342	HA343	HA344	HA345	HA346	HA347	HA348	HA349	HA350	HA351	HA352	HA353	HA354	HA355	HA356	HA357	HA358	HA359	HA360	HA361	HA362	HA363	HA364	HA365	HA366	HA367	HA368	HA369	HA370	HA371	HA372	HA373	HA374	HA375	HA376	HA377	HA378	HA379	HA380	HA381	HA382	HA383	HA384	HA385	HA386	HA387	HA388	HA389	HA390	HA391	HA392	HA393	HA394	HA395	HA396	HA397	HA398	HA399	HA400	HA401	HA402	HA403	HA404	HA405	HA406	HA407	HA408	HA409	HA410	HA411	HA412	HA413	HA414	HA415	HA416	HA417	HA418	HA419	HA420	HA421	HA422	HA423	HA424	HA425	HA426	HA427	HA428	HA429	HA430	HA431	HA432	HA433	HA434	HA435	HA436	HA437	HA438	HA439	HA440	HA441	HA442	HA443	HA444	HA445	HA446	HA447	HA448	HA449	HA450	HA451	HA452	HA453	HA454	HA455	HA456	HA457	HA458	HA459	HA460	HA461	HA462	HA463	HA464	HA465	HA466	HA467	HA468	HA469	HA470	HA471	HA472	HA473	HA474	HA475	HA476	HA477	HA478	HA479	HA480	HA481	HA482	HA483	HA484	HA485	HA486	HA487	HA488	HA489	HA490	HA491	HA492	HA493	HA494	HA495	HA496	HA497	HA498	HA499	HA500	HA501	HA502	HA503	HA504	HA505	HA506	HA507	HA508	HA509	HA510	HA511	HA512	HA513	HA514	HA515	HA516	HA517	HA518	HA519	HA520	HA521	HA522	HA523	HA524	HA525	HA526	HA527	HA528	HA529	HA530	HA531	HA532	HA533	HA534	HA535	HA536	HA537	HA538	HA539	HA540	HA541	HA542	HA543	HA544	HA545	HA546	HA547	HA548	HA549	HA550	HA551	HA552	HA553	HA554	HA555	HA556	HA557	HA558	HA559	HA560	HA561	HA562	HA563	HA564	HA565	HA566	HA567	HA568	HA569	HA570	HA571	HA572	HA573	HA574	HA575	HA576	HA577	HA578	HA579	HA580	HA581	HA582	HA583	HA584	HA585	HA586	HA587	HA588	HA589	HA590	HA591	HA592	HA593	HA594	HA595	HA596	HA597	HA598	HA599	HA600	HA601	HA602	HA603	HA604	HA605	HA606	HA607	HA608	HA609	HA610	HA611	HA612	HA613	HA614	HA615	HA616	HA617	HA618	HA619	HA620	HA621	HA622	HA623	HA624	HA625	HA626	HA627	HA628	HA629	HA630	HA631	HA632	HA633	HA634	HA635	HA636	HA637	HA638	HA639	HA640	HA641	HA642	HA643	HA644	HA645	HA646	HA647	HA648	HA649	HA650	HA651	HA652	HA653	HA654	HA655	HA656	HA657	HA658	HA659	HA660	HA661	HA662	HA663	HA664	HA665	HA666	HA667	HA668	HA669	HA670	HA671	HA672	HA673	HA674	HA675	HA676	HA677	HA678	HA679	HA680	HA681	HA682	HA683	HA684	HA685	HA686	HA687	HA688	HA689	HA690	HA691	HA692	HA693	HA694	HA695	HA696	HA697	HA698	HA699	HA700
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TABLE 13 $\int \Delta d\lambda$

Sam. No.	HF01	HF02	HF03	HF04	HF05	HF06	MG01	MG02	MG03	MG04	MG05	MG06	MG07
Temp (K)	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.	310.
Path (cm)	1648.	1648.	1648.	1648.	1648.	1648.	1648.	1648.	1648.	1648.	1648.	1648.	1648.
Conc.	0.00977	0.01910	0.03850	0.07700	0.15400	0.30800	0.00503	0.00977	0.01910	0.03850	0.07700	0.15400	0.30800
P (atm)	0.997368	0.497368	0.247368	0.123684	0.061842	0.030921	1.000000	0.498684	0.248684	0.123684	0.061842	0.030921	0.015468
ρ (g/cm ³)	1.000292	0.500218	0.250026	0.125113	0.062534	0.031239	1.001509	0.500146	0.250109	0.125113	0.062534	0.031239	0.015551
ν (1/cm ²)	3.804E 20	3.709E 20	3.718E 20	3.712E 20	3.851E 20	3.563E 20	1.964E 20	1.902E 20	1.854E 20	1.859E 20	1.856E 20	1.925E 20	1.774E 20
ν (cm ⁻¹)													
360.00	0.028	0.023	0.033	0.03	0.	0.005	0.	0.218	0.173	0.122	0.	0.088	0.060
362.00	0.058	0.052	0.061	0.	0.	0.035	0.258	0.447	0.368	0.264	0.103	0.133	0.128
364.00	0.088	0.074	0.093	0.003	0.013	0.072	0.538	0.931	0.615	0.446	0.336	0.517	0.355
366.00	0.119	0.106	0.125	0.031	0.039	0.111	0.903	1.309	1.089	0.839	0.744	0.612	0.474
370.00	0.158	0.149	0.159	0.066	0.071	0.152	2.029	1.692	1.382	1.064	0.920	0.740	0.592
372.00	0.203	0.193	0.225	0.103	0.115	0.195	2.462	2.026	1.631	1.239	1.055	0.851	0.672
374.00	0.253	0.238	0.264	0.159	0.181	0.252	2.957	2.450	1.998	1.432	1.222	0.968	0.772
376.00	0.313	0.295	0.333	0.217	0.254	0.315	3.432	2.774	2.191	1.642	1.390	1.095	0.875
378.00	0.433	0.356	0.445	0.294	0.343	0.385	3.951	3.178	2.501	1.873	1.576	1.238	0.992
380.00	0.555	0.506	0.554	0.397	0.430	0.457	4.473	3.550	2.819	2.113	1.774	1.384	1.114
382.00	0.715	0.661	0.702	0.517	0.555	0.564	4.974	3.988	3.124	2.341	1.968	1.527	1.258
384.00	0.918	0.851	0.877	0.661	0.688	0.681	5.455	4.387	3.441	2.583	2.170	1.682	1.373
386.00	1.118	1.029	1.056	0.806	0.807	0.732	5.901	4.807	3.901	2.907	2.503	1.959	1.506
388.00	1.429	1.307	1.264	0.956	0.942	0.906	6.389	5.204	4.128	3.433	2.793	2.310	1.806
390.00	1.770	1.593	1.595	1.116	1.091	1.039	6.841	5.613	4.506	3.995	3.292	2.748	2.210
392.00	2.162	1.914	1.769	1.300	1.259	1.173	7.272	6.040	4.906	4.422	3.629	3.071	2.506
394.00	2.628	2.278	2.036	1.523	1.449	1.324	7.689	6.439	5.266	4.769	3.942	3.288	2.706
396.00	3.137	2.733	2.418	1.822	1.700	1.515	8.043	6.808	5.581	5.083	4.251	3.526	2.910
398.00	4.120	3.528	3.118	2.426	2.231	1.972	8.415	7.187	5.906	5.398	4.569	3.842	3.226
400.00	4.842	4.042	3.530	2.755	2.502	2.143	8.713	7.487	6.154	5.646	4.819	4.095	3.413
402.00	5.491	4.572	3.906	3.132	2.725	2.359	9.041	7.823	6.460	5.952	5.125	4.401	3.717
404.00	6.181	5.100	4.297	3.526	2.957	2.550	9.399	8.091	6.726	6.218	5.392	4.667	3.981
406.00	6.911	5.659	4.721	3.945	3.229	2.757	9.789	8.417	7.006	6.497	5.673	4.944	4.256
408.00	7.674	6.252	5.177	4.395	3.513	2.989	10.113	8.789	7.366	6.858	6.033	5.308	4.572
410.00	8.449	6.859	5.646	4.759	3.805	3.225	10.439	9.155	7.706	7.198	6.373	5.648	4.914
412.00	9.213	7.419	6.112	5.099	4.102	3.458	10.761	9.523	8.054	7.546	6.721	6.006	5.242
414.00	9.967	7.959	6.588	5.499	4.406	3.709	11.079	9.891	8.401	7.893	7.068	6.346	5.578
416.00	10.711	8.456	7.078	5.898	4.713	3.951	11.393	10.259	8.759	8.251	7.426	6.701	5.934
418.00	12.493	10.356	8.734	6.657	5.389	4.198	11.717	10.623	9.119	8.511	7.686	6.961	6.136
420.00	13.744	11.510	9.661	7.058	5.641	4.445	12.041	10.991	9.486	8.878	8.053	7.328	6.503
422.00	15.529	12.127	10.199	7.461	6.045	4.692	12.365	11.359	9.850	9.241	8.416	7.691	6.866
424.00	16.791	13.014	10.967	8.001	6.598	5.099	12.689	11.727	10.218	9.605	8.780	8.053	7.228
426.00	18.243	14.262	12.049	8.841	7.309	5.613	13.013	12.091	10.586	9.979	9.153	8.328	7.594
430.00	19.819	16.028	13.757	10.070	8.415	6.445	13.337	12.453	10.957	10.321	9.517	8.680	7.959
432.00	21.573	17.100	15.006	11.279	9.233	7.272	13.661	12.817	11.328	10.695	9.895	9.053	8.324
434.00	23.375	18.766	16.349	12.501	10.146	8.115	13.985	13.181	11.703	11.071	10.271	9.429	8.699
436.00	25.223	21.438	17.868	13.747	11.131	9.048	14.309	13.545	12.078	11.445	10.645	9.803	9.074
438.00	27.117	23.175	19.378	15.000	12.206	10.076	14.633	13.909	12.451	11.819	11.019	10.179	9.449
440.00	29.052	24.991	20.908	16.264	13.340	11.204	14.957	14.273	12.826	12.193	11.393	10.553	9.824
442.00	31.033	26.821	22.613	17.542	14.545	12.458	15.281	14.645	13.201	12.567	11.767	10.927	10.199
444.00	32.963	28.674	24.463	18.836	15.815	13.743	15.605	15.013	13.576	12.941	12.141	11.301	10.574
446.00	34.946	30.555	25.954	20.141	17.133	15.090	15.929	15.386	13.951	13.315	12.515	11.675	10.949
448.00	36.937	32.475	27.728	21.469	18.493	16.500	16.253	15.758	14.326	13.689	12.889	12.049	11.324
450.00	38.936	34.456	29.668	22.801	20.002	17.204	16.577	16.136	14.701	14.063	13.263	12.423	11.700
452.00	40.936	36.438	31.579	24.142	21.675	18.590	16.899	16.545	15.076	14.437	13.637	12.797	12.075
454.00	42.936	38.417	33.482	25.486	23.412	19.914	17.161	16.954	15.451	14.811	14.011	13.171	12.450
456.00	44.936	40.400	35.386	26.836	25.216	21.198	17.423	17.363	15.826	15.185	14.385	13.545	12.825
458.00	46.936	42.386	37.290	28.186	27.052	22.459	17.685	17.776	16.201	15.559	14.759	13.919	13.200

680.00	44.936	44.361	39.190	33.445	28.778	23.707	39.759	35.364	30.402	24.763	28.947	16.518	13.367
685.00	53.936	46.340	41.031	35.162	30.270	25.919	41.556	37.235	32.036	26.179	22.132	17.443	14.104
690.00	52.936	45.320	42.998	36.944	31.966	26.366	43.720	39.112	33.817	27.702	23.486	18.570	15.070
695.00	54.936	50.505	44.911	38.729	33.520	28.749	45.651	40.972	35.502	29.163	24.718	19.629	15.939
698.00	56.936	52.301	46.849	40.553	35.215	29.223	47.662	42.915	37.286	30.715	26.170	20.971	16.961
670.00	58.936	54.301	48.845	42.534	37.180	31.137	49.662	44.980	39.266	32.658	25.077	22.721	18.716
675.00	58.936	58.380	50.829	44.461	39.003	33.604	51.662	46.960	41.132	34.460	29.693	24.119	19.978
678.00	62.936	58.255	52.768	46.266	40.624	35.111	53.662	48.785	42.957	36.014	31.014	25.837	20.337
679.00	64.936	60.234	54.692	48.043	42.315	36.528	55.662	50.696	44.712	37.531	32.313	26.622	21.660
678.00	66.936	62.272	56.618	49.820	43.608	38.473	57.662	52.613	46.470	39.055	33.614	27.259	22.494
680.00	68.936	64.260	58.541	51.595	45.383	39.201	59.616	54.521	48.222	40.562	34.900	28.293	23.105
685.00	72.936	66.249	60.463	53.339	46.937	39.505	61.616	56.443	49.963	42.043	36.160	30.303	24.114
688.00	72.936	68.233	62.374	55.069	48.455	40.764	63.616	58.349	51.679	43.493	37.376	30.271	24.896
688.00	74.936	70.215	64.266	56.767	49.929	41.969	65.616	60.234	53.360	44.890	38.538	31.185	25.639
688.00	76.936	72.191	66.133	58.425	51.342	43.107	67.616	62.033	54.990	46.230	39.627	32.031	26.314
690.00	78.936	74.167	68.007	60.106	52.807	44.328	69.616	63.949	56.653	47.617	40.883	32.963	27.054
695.00	80.936	76.128	69.861	61.776	54.262	45.516	71.616	65.775	58.231	49.049	41.943	33.966	27.793
698.00	82.936	78.053	71.629	63.322	55.583	46.584	73.616	67.519	59.795	50.221	42.559	34.655	28.412
698.00	84.910	79.942	73.315	64.793	56.821	47.565	75.616	69.195	61.213	51.382	43.498	35.373	29.074
698.00	86.877	81.790	74.966	66.161	57.945	48.649	77.616	70.812	62.555	52.435	44.733	36.009	29.879
700.00	88.829	83.559	76.530	67.443	58.973	49.236	79.616	72.356	63.906	53.399	45.494	36.584	29.932
705.00	90.760	85.380	78.057	68.688	59.969	50.002	81.591	73.849	65.015	54.324	46.222	37.127	30.359
708.00	92.654	87.110	79.525	69.837	60.926	50.750	83.511	75.828	66.155	55.195	46.910	37.648	30.769
708.00	94.661	88.705	80.838	70.940	61.759	51.391	85.345	77.516	67.154	55.964	47.501	38.089	31.125
708.00	96.174	90.166	82.011	71.954	62.473	51.937	87.037	79.039	68.029	56.624	48.011	38.469	31.424
710.00	97.793	91.532	83.891	72.684	63.116	52.431	88.606	79.654	68.319	57.216	48.466	38.809	31.691
712.00	99.286	92.773	84.061	73.432	63.695	52.874	89.557	79.557	68.514	57.337	48.870	39.100	31.936
714.00	100.623	93.471	84.914	74.092	64.208	53.265	90.511	80.347	70.121	58.199	49.229	39.376	32.155
716.00	101.806	94.827	85.656	74.670	64.660	53.613	91.779	81.025	70.640	59.000	49.546	39.611	32.349
718.00	102.925	95.755	86.408	75.261	65.124	53.956	93.117	81.672	71.168	59.595	49.195	39.863	32.549
720.00	104.418	97.150	87.666	76.314	66.018	54.801	94.322	82.763	72.157	59.790	50.642	40.456	32.944
725.00	106.069	98.717	89.117	77.684	67.257	55.553	95.805	84.169	73.436	60.951	51.649	41.335	33.229
728.00	106.915	99.435	89.716	78.241	67.723	56.209	96.410	84.784	73.890	61.358	51.960	41.613	33.995
728.00	107.518	99.926	90.108	78.954	68.968	56.809	97.779	85.013	74.139	61.554	52.125	41.742	34.100
728.00	108.179	100.468	90.531	79.436	69.236	56.628	98.216	85.374	74.422	61.769	52.304	41.881	34.211
730.00	108.912	101.052	90.931	79.237	69.515	56.954	98.708	85.775	74.729	62.000	52.493	42.027	34.321
735.00	109.666	101.659	91.447	79.598	69.797	57.074	99.239	86.197	75.040	62.239	52.686	42.174	34.430
738.00	110.473	102.269	91.912	79.956	69.078	57.229	99.736	86.627	75.371	62.400	52.877	42.322	34.542
738.00	111.259	102.871	92.366	80.297	69.355	57.500	99.831	87.056	75.608	62.718	53.064	42.468	34.656
738.00	112.040	103.475	92.821	80.647	69.638	57.728	99.870	87.480	76.004	62.952	53.255	42.616	34.772
740.00	112.844	104.121	93.320	81.049	69.912	57.986	99.824	87.922	76.350	63.212	53.477	42.754	34.914
745.00	113.819	104.959	94.032	81.656	70.498	58.414	99.813	88.300	76.849	63.613	53.844	43.105	35.152
748.00	114.736	105.706	94.630	82.171	70.985	58.765	99.747	88.647	77.271	63.981	54.133	43.348	35.365
748.00	115.533	106.158	94.957	82.419	71.114	58.914	99.714	88.971	77.503	64.160	54.267	43.454	35.447
748.00	115.331	106.553	95.253	82.635	71.286	59.054	99.445	89.656	77.712	64.311	54.386	43.550	35.520
750.00	116.304	106.925	95.526	82.841	71.451	59.195	99.781	89.986	77.899	64.451	54.494	43.643	35.594
755.00	116.697	107.258	95.773	83.034	71.611	59.333							
758.00	117.027	107.550	95.999	83.214	71.760	59.471							
758.00	117.303	107.803	96.209	83.383	71.902	59.611							
758.00	117.548	108.033	96.404	83.557	72.052	59.755							
760.00	117.735	108.211	96.559	83.699	72.166	59.865							
765.00	117.971	108.443	96.672	83.805	72.254	59.956							
768.00	118.053	108.549	96.761	83.899	72.336	60.037							
768.00	118.121	108.627	96.902	84.034	72.414	60.109							
770.00	118.159	108.650	96.959	84.042	72.523	60.245							
775.00	118.337	108.743	97.003	84.125	72.563	60.309							
778.00	118.205	108.789	97.043	84.164	72.597	60.367							
778.00	118.211	108.821	97.065	84.199	72.625	60.417							
778.00	118.211	108.867	97.131	84.223	72.655	60.464							
780.00	118.211	108.901	97.898	84.253	72.682	60.512							

* The units of μ are molecules/cm², abbreviated here by (μ/cm^2)

TABLE 14 $\int \ddot{A} dv$ [illegible]

640.00	31.566	27.925	71.323	19.343	15.253	12.093	9.133	7.184	21.716	27.116	17.116	14.092	10.949	9.145	6.441	5.090	4.017
642.00	31.390	27.921	71.321	19.341	15.251	12.091	9.131	7.183	21.715	27.115	17.115	14.091	10.948	9.144	6.440	5.089	4.016
644.00	31.214	27.917	71.317	19.337	15.247	12.087	9.127	7.179	21.713	27.113	17.113	14.089	10.946	9.142	6.438	5.087	4.014
646.00	31.038	27.913	71.313	19.333	15.243	12.083	9.123	7.177	21.711	27.111	17.111	14.087	10.944	9.140	6.436	5.085	4.012
648.00	30.862	27.909	71.309	19.329	15.239	12.079	9.119	7.175	21.709	27.109	17.109	14.085	10.942	9.138	6.434	5.083	4.010
650.00	30.686	27.905	71.305	19.325	15.235	12.075	9.115	7.173	21.707	27.107	17.107	14.083	10.940	9.136	6.432	5.081	4.008
652.00	30.510	27.901	71.301	19.321	15.231	12.071	9.111	7.171	21.705	27.105	17.105	14.081	10.938	9.134	6.430	5.079	4.006
654.00	30.334	27.897	71.297	19.317	15.227	12.067	9.107	7.169	21.703	27.103	17.103	14.079	10.936	9.132	6.428	5.077	4.004
656.00	30.158	27.893	71.293	19.313	15.223	12.063	9.103	7.167	21.701	27.101	17.101	14.077	10.934	9.130	6.426	5.075	4.002
658.00	29.982	27.889	71.289	19.309	15.219	12.059	9.100	7.165	21.699	27.099	17.099	14.075	10.932	9.128	6.424	5.073	4.000
660.00	29.806	27.885	71.285	19.305	15.215	12.055	9.097	7.163	21.697	27.097	17.097	14.073	10.930	9.126	6.422	5.071	3.998
662.00	29.630	27.881	71.281	19.301	15.211	12.051	9.093	7.161	21.695	27.095	17.095	14.071	10.928	9.124	6.420	5.069	3.996
664.00	29.454	27.877	71.277	19.297	15.207	12.047	9.089	7.159	21.693	27.093	17.093	14.069	10.926	9.122	6.418	5.067	3.994
666.00	29.278	27.873	71.273	19.293	15.203	12.043	9.085	7.157	21.691	27.091	17.091	14.067	10.924	9.120	6.416	5.065	3.992
668.00	29.102	27.869	71.269	19.289	15.199	12.039	9.081	7.155	21.689	27.089	17.089	14.065	10.922	9.118	6.414	5.063	3.990
670.00	28.926	27.865	71.265	19.285	15.195	12.035	9.077	7.153	21.687	27.087	17.087	14.063	10.920	9.116	6.412	5.061	3.988
672.00	28.750	27.861	71.261	19.281	15.191	12.031	9.073	7.151	21.685	27.085	17.085	14.061	10.918	9.114	6.410	5.059	3.986
674.00	28.574	27.857	71.257	19.277	15.187	12.027	9.069	7.149	21.683	27.083	17.083	14.059	10.916	9.112	6.408	5.057	3.984
676.00	28.398	27.853	71.253	19.273	15.183	12.023	9.065	7.147	21.681	27.081	17.081	14.057	10.914	9.110	6.406	5.055	3.982
678.00	28.222	27.849	71.249	19.269	15.179	12.019	9.061	7.145	21.679	27.079	17.079	14.055	10.912	9.108	6.404	5.053	3.980
680.00	28.046	27.845	71.245	19.265	15.175	12.015	9.057	7.143	21.677	27.077	17.077	14.053	10.910	9.106	6.402	5.051	3.978
682.00	27.870	27.841	71.241	19.261	15.171	12.011	9.053	7.141	21.675	27.075	17.075	14.051	10.908	9.104	6.400	5.049	3.976
684.00	27.694	27.837	71.237	19.257	15.167	12.007	9.049	7.139	21.673	27.073	17.073	14.049	10.906	9.102	6.398	5.047	3.974
686.00	27.518	27.833	71.233	19.253	15.163	12.003	9.045	7.137	21.671	27.071	17.071	14.047	10.904	9.100	6.396	5.045	3.972
688.00	27.342	27.829	71.229	19.249	15.159	12.000	9.041	7.135	21.669	27.069	17.069	14.045	10.902	9.098	6.394	5.043	3.970
690.00	27.166	27.825	71.225	19.245	15.155	11.996	9.037	7.133	21.667	27.067	17.067	14.043	10.900	9.096	6.392	5.041	3.968
692.00	26.990	27.821	71.221	19.241	15.151	11.992	9.033	7.131	21.665	27.065	17.065	14.041	10.898	9.094	6.390	5.039	3.966
694.00	26.814	27.817	71.217	19.237	15.147	11.988	9.029	7.129	21.663	27.063	17.063	14.039	10.896	9.092	6.388	5.037	3.964
696.00	26.638	27.813	71.213	19.233	15.143	11.984	9.025	7.127	21.661	27.061	17.061	14.037	10.894	9.090	6.386	5.035	3.962
698.00	26.462	27.809	71.209	19.229	15.139	11.980	9.021	7.125	21.659	27.059	17.059	14.035	10.892	9.088	6.384	5.033	3.960
700.00	26.286	27.805	71.205	19.225	15.135	11.976	9.017	7.123	21.657	27.057	17.057	14.033	10.890	9.086	6.382	5.031	3.958
702.00	26.110	27.801	71.201	19.221	15.131	11.972	9.013	7.121	21.655	27.055	17.055	14.031	10.888	9.084	6.380	5.029	3.956
704.00	25.934	27.797	71.197	19.217	15.127	11.968	9.009	7.119	21.653	27.053	17.053	14.029	10.886	9.082	6.378	5.027	3.954
706.00	25.758	27.793	71.193	19.213	15.123	11.964	9.005	7.117	21.651	27.051	17.051	14.027	10.884	9.080	6.376	5.025	3.952
708.00	25.582	27.789	71.189	19.209	15.119	11.960	9.001	7.115	21.649	27.049	17.049	14.025	10.882	9.078	6.374	5.023	3.950
710.00	25.406	27.785	71.185	19.205	15.115	11.956	8.997	7.113	21.647	27.047	17.047	14.023	10.880	9.076	6.372	5.021	3.948
712.00	25.230	27.781	71.181	19.201	15.111	11.952	8.993	7.111	21.645	27.045	17.045	14.021	10.878	9.074	6.370	5.019	3.946
714.00	25.054	27.777	71.177	19.197	15.107	11.948	8.989	7.109	21.643	27.043	17.043	14.019	10.876	9.072	6.368	5.017	3.944
716.00	24.878	27.773	71.173	19.193	15.103	11.944	8.985	7.107	21.641	27.041	17.041	14.017	10.874	9.070	6.366	5.015	3.942
718.00	24.702	27.769	71.169	19.189	15.099	11.940	8.981	7.105	21.639	27.039	17.039	14.015	10.872	9.068	6.364	5.013	3.940
720.00	24.526	27.765	71.165	19.185	15.095	11.936	8.977	7.103	21.637	27.037	17.037	14.013	10.870	9.066	6.362	5.011	3.938
722.00	24.350	27.761	71.161	19.181	15.091	11.932	8.973	7.101	21.635	27.035	17.035	14.011	10.868	9.064	6.360	5.009	3.936
724.00	24.174	27.757	71.157	19.177	15.087	11.928	8.969	7.099	21.633	27.033	17.033	14.009	10.866	9.062	6.358	5.007	3.934
726.00	23.998	27.753	71.153	19.173	15.083	11.924	8.965	7.097	21.631	27.031	17.031	14.007	10.864	9.060	6.356	5.005	3.932
728.00	23.822	27.749	71.149	19.169	15.079	11.920	8.961	7.095	21.629	27.029	17.029	14.005	10.862	9.058	6.354	5.003	3.930
730.00	23.646	27.745	71.145	19.165	15.075	11.916	8.957	7.093	21.627	27.027	17.027	14.003	10.860	9.056	6.352	5.001	3.928
732.00	23.470	27.741	71.141	19.161	15.071	11.912	8.953	7.091	21.625	27.025	17.025	14.001	10.858	9.054	6.350	4.999	3.926
734.00	23.294	27.737	71.137	19.157	15.067	11.908	8.949	7.089	21.623	27.023	17.023	13.999	10.856	9.052	6.348	4.997	3.924
736.00	23.118	27.733	71.133	19.153	15.063	11.904	8.945	7.087	21.621	27.021	17.021	13.997	10.854	9.050	6.346	4.995	3.922
738.00	22.942	27.729	71.129	19.149	15.059	11.900	8.941	7.085	21.619	27.019	17.019	13.995	10.852	9.048	6.344	4.993	3.920
740.00	22.766	27.725	71.125	19.145	15.055	11.896	8.937	7.083	21.617	27.017	17.017	13.993	10.850	9.046	6.342	4.991	3.918
742.00	22.590	27.721	71.121	19.141	15.051	11.892	8.933	7.081	21.615	27.015	17.015	13.991	10.848	9.044	6.340	4.989	3.916
744.00	22.414	27.717	71.117	19.137	15.047	11.888	8.929	7.079	21.613	27.013	17.013	13.989	10.846	9.042	6.338	4.987	3.914
746.00	22.238	27.713	71.113	19.133	15.043	11.884	8.925	7.077	21.611	27.011	17.011	13.987	10.844	9.040	6.336	4.985	3.912
748.00	22.062	27.709	71.109	19.129	15.039	11.880	8.921	7.075	21.609	27.009	17.009	13.985	10.842	9.038	6.334	4.983	3.910
750.00	21.886	27.705	71.105	19.125	15.035	11.876	8.917	7.073	21.607	27.007	17.007	13.983	10.840	9.036	6.332	4.981	3.908

* The units of u are molecules/cm², abbreviated here by (f/cm²)

TABLE 15 $\int \tilde{A} dz$

Year	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100
1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050	2051	2052	2053	2054	2055	2056	2057	2058	2059	2060	2061	2062	2063	2064	2065	2066	2067	2068	2069	2070	2071	2072	2073	2074	2075	2076	2077	2078	2079	2080	2081	2082	2083	2084	2085	2086	2087	2088	2089	2090	2091	2092	2093	2094	2095	2096	2097	2098	2099	2100	

The units of μ are molecules/cm², abbreviated here by $10^2/\text{cm}^2$

TABLE 16 $\int_v \mathbf{A} dv$ [illegible]

The units of u are molecules/cm², abbreviated here by (θ/cm^2) .

TABLE 17 $\int_{\nu} \text{Ad}\nu$

Sam. No.	HP01	HP02	HP03	HP04	HP05	HP06	HP07	HP08	HP09
Temp (K)	310.	310.	310.	310.	310.	310.	310.	310.	310.
Path (cm)	3291.	3291.	3291.	3291.	3291.	3291.	3291.	3291.	3291.
Conc.	1.00000	0.15300	1.00000	0.08090	0.15300	1.00000	0.08090	0.15300	1.00000
P (atm)	0.769737	0.955263	0.385526	0.976316	0.477632	0.192105	0.488158	0.238158	0.096053
P _e (atm)	1.000658	0.999110	0.501184	1.000011	0.499555	0.249737	0.500005	0.249089	0.124868
U (#/cm ²)*	6.001E 22	1.139E 22	3.006E 22	6.158E 21	5.697E 21	1.498E 22	3.079E 21	2.841E 21	7.488E 21
ν (cm ⁻¹)									
500.00	0.	0.	0.	0.	0.	0.	0.	0.	0.
502.00	0.037	0.024	0.024	0.007	0.006	0.006	0.	0.	0.005
504.00	0.107	0.052	0.064	0.025	0.012	0.034	0.	0.	0.023
506.00	0.138	0.075	0.090	0.040	0.014	0.035	0.000	0.	0.031
508.00	0.222	0.110	0.122	0.058	0.025	0.063	0.007	0.008	0.055
510.00	0.465	0.190	0.248	0.072	0.046	0.136	0.021	0.025	0.095
512.00	0.582	0.219	0.300	0.093	0.054	0.177	0.025	0.025	0.120
514.00	0.694	0.254	0.347	0.111	0.066	0.212	0.028	0.025	0.144
516.00	0.833	0.302	0.408	0.124	0.077	0.254	0.032	0.027	0.166
518.00	1.025	0.363	0.500	0.140	0.095	0.317	0.044	0.036	0.196
520.00	1.251	0.427	0.611	0.163	0.118	0.388	0.057	0.051	0.229
522.00	1.503	0.498	0.735	0.196	0.143	0.463	0.073	0.067	0.260
524.00	1.773	0.576	0.868	0.231	0.168	0.542	0.084	0.081	0.284
526.00	2.094	0.666	1.027	0.272	0.209	0.637	0.099	0.102	0.318
528.00	2.490	0.774	1.221	0.317	0.257	0.753	0.122	0.126	0.365
530.00	3.852	0.885	1.405	0.369	0.305	0.855	0.143	0.144	0.401
532.00	3.229	0.997	1.585	0.427	0.349	0.956	0.166	0.162	0.439
534.00	3.603	1.110	1.764	0.482	0.391	1.060	0.188	0.183	0.481
536.00	3.977	1.216	1.942	0.534	0.435	1.164	0.208	0.205	0.524
538.00	4.352	1.319	2.128	0.582	0.479	1.274	0.230	0.232	0.569
540.00	4.653	1.404	2.291	0.620	0.512	1.361	0.247	0.255	0.599
542.00	4.913	1.475	2.406	0.654	0.539	1.434	0.264	0.266	0.625
544.00	5.305	1.628	2.611	0.731	0.614	1.569	0.308	0.301	0.700
546.00	6.885	2.629	3.959	1.380	1.254	2.561	0.686	0.661	1.287
548.00	8.135	3.068	4.726	1.637	1.486	2.983	0.819	0.797	1.489
550.00	8.741	3.233	5.037	1.722	1.570	3.156	0.869	0.832	1.572
552.00	9.327	3.393	5.342	1.798	1.654	3.312	0.912	0.878	1.657
554.00	9.999	3.582	5.690	1.890	1.745	3.499	0.965	0.926	1.754
556.00	10.771	3.806	6.105	2.004	1.851	3.721	1.028	0.998	1.863
558.00	11.623	4.073	6.535	2.140	1.979	3.971	1.101	1.064	1.989
560.00	12.577	4.375	7.120	2.306	2.129	4.259	1.182	1.142	2.134

TABLE 18 $\int_{\nu} \text{Ad}\nu$

Sam. No.	H2O1	H2O2	H2O3	H2O4	H2O5	H2O6	H2O7	H2O8
Temp (K)	310.	310.	310.	310.	310.	310.	310.	310.
Path (cm)	3291.	3291.	3291.	3291.	3291.	3291.	3291.	3291.
Conc.	1.00000	0.15300	1.00000	0.08090	0.15300	1.00000	0.08090	0.15300
P (atm)	0.769737	0.955263	0.384211	0.976316	0.477632	0.192105	0.488158	0.239474
P _e (atm)	1.000658	0.999110	0.499474	1.000011	0.499555	0.249737	0.500005	0.250466
u (#/cm ²)*	6.001E 22	1.139E 22	2.995E 22	6.152E 21	5.697E 21	1.498E 22	3.079E 21	2.856E 21

ν (cm ⁻¹)	H2O1	H2O2	H2O3	H2O4	H2O5	H2O6	H2O7	H2O8
780.00	0.	0.	0.	0.	0.	0.	0.	0.
782.00	1.206	0.407	0.637	0.219	0.202	0.357	0.112	0.102
784.00	2.270	0.752	1.276	0.402	0.370	0.653	0.209	0.134
786.00	3.184	1.032	1.765	0.554	0.507	0.857	0.289	0.255
788.00	3.951	1.247	2.158	0.676	0.612	1.089	0.355	0.317
790.00	4.624	1.435	2.507	0.790	0.711	1.276	0.424	0.378
792.00	5.633	1.975	3.284	1.192	1.073	1.830	0.750	0.675
794.00	7.166	2.926	4.473	1.692	1.740	2.666	1.214	1.102
796.00	8.239	3.376	5.124	2.168	2.009	3.003	1.377	1.237
798.00	8.970	3.555	5.492	2.297	2.130	3.190	1.448	1.302
800.00	9.690	3.826	5.957	2.433	2.253	3.382	1.513	1.370
802.00	10.443	4.079	6.241	2.582	2.385	3.584	1.589	1.447
804.00	11.215	4.353	6.638	2.741	2.524	3.793	1.672	1.531
806.00	11.988	4.638	7.032	2.903	2.665	4.004	1.754	1.614
808.00	12.740	4.918	7.417	3.067	2.803	4.210	1.836	1.699
810.00	13.466	5.183	7.783	3.219	2.930	4.408	1.914	1.788
812.00	14.160	5.434	8.133	3.359	3.048	4.588	1.992	1.865
814.00	14.834	5.662	8.453	3.486	3.152	4.756	2.062	1.936
816.00	15.395	5.966	8.741	3.599	3.246	4.910	2.129	1.994
818.00	15.920	6.039	9.000	3.691	3.332	5.046	2.187	2.046
820.00	16.381	6.191	9.226	3.765	3.405	5.167	2.238	2.095
822.00	16.777	6.319	9.422	3.827	3.464	5.271	2.283	2.133
824.00	17.105	6.420	9.582	3.882	3.515	5.353	2.321	2.168
826.00	17.379	6.502	9.712	3.929	3.555	5.424	2.344	2.200
828.00	17.672	6.590	9.863	3.979	3.601	5.510	2.370	2.230
830.00	18.081	6.707	10.039	4.040	3.663	5.632	2.408	2.272
832.00	18.416	6.815	10.267	4.093	3.709	5.722	2.437	2.307
834.00	18.590	6.870	10.352	4.118	3.742	5.765	2.458	2.337
836.00	18.719	6.915	10.416	4.158	3.776	5.798	2.471	2.367
838.00	18.832	6.947	10.464	4.188	3.796	5.823	2.487	2.389
840.00	18.934	6.983	10.512	4.213	3.823	5.850	2.508	2.405
842.00	19.029	7.019	10.552	4.233	3.854	5.876	2.525	2.432
844.00	19.117	7.050	10.593	4.253	3.884	5.901	2.542	2.456
846.00	19.207	7.082	10.638	4.276	3.914	5.924	2.566	2.484
848.00	19.300	7.120	10.696	4.302	3.946	5.954	2.593	2.510
850.00	19.389	7.160	10.731	4.325	3.978	5.981	2.619	2.537

* The units of u are molecules/cm², abbreviated here by (#/cm²)

TABLE 19 $\tilde{L}^v Adv$ [illegible]

TABLE 20 $\int_A dV$

Sam. No.	ZH02	ZH04	ZH06	ZH08	ZI01	ZI03	ZI05	ZI07	ZI09	ZJ01	ZJ02	ZJ04	ZJ06	ZJ08	ZJ10
Temp (°C)	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.	174.
Path (cm)	0.00000	0.01910	0.03820	0.05730	0.07640	0.09550	0.11460	0.13370	0.15280	0.17190	0.19100	0.21010	0.22920	0.24830	0.26740
Conc.	0.00000	0.0124342	0.0248684	0.0373026	0.0497368	0.0621710	0.0746052	0.0870394	0.0994736	0.1119078	0.1243420	0.1367762	0.1492104	0.1616446	0.1740788
ρ (g/cc)	0.00000	0.0124342	0.0248684	0.0373026	0.0497368	0.0621710	0.0746052	0.0870394	0.0994736	0.1119078	0.1243420	0.1367762	0.1492104	0.1616446	0.1740788
μ (1/cm)	1.104E 80	1.049E 80	1.000E 80	1.018E 80	1.036E 80	1.054E 80	1.072E 80	1.090E 80	1.108E 80	1.126E 80	1.144E 80	1.162E 80	1.180E 80	1.198E 80	1.216E 80
$\nu \cdot 10^3$ (cm ⁻¹)															
610.00	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
612.00	0.099	0.085	0.066	0.031	0.055	0.069	0.054	0.032	0.	0.069	0.066	0.053	0.035	0.019	0.011
614.00	0.209	0.164	0.081	0.061	0.119	0.140	0.104	0.053	0.	0.137	0.132	0.111	0.075	0.045	0.030
616.00	0.344	0.257	0.125	0.094	0.195	0.214	0.159	0.085	0.007	0.218	0.210	0.182	0.125	0.088	0.053
618.00	0.595	0.443	0.271	0.185	0.343	0.367	0.262	0.150	0.049	0.455	0.411	0.351	0.250	0.170	0.110
620.00	0.792	0.564	0.404	0.295	0.460	0.454	0.336	0.190	0.066	0.641	0.584	0.527	0.404	0.330	0.219
622.00	0.992	0.670	0.475	0.275	0.597	0.562	0.404	0.224	0.076	0.817	0.728	0.654	0.500	0.425	0.234
624.00	1.187	0.795	0.546	0.317	0.719	0.671	0.476	0.256	0.084	0.982	0.854	0.750	0.572	0.487	0.251
626.00	1.408	0.923	0.629	0.360	0.862	0.787	0.553	0.286	0.097	1.153	1.000	0.861	0.654	0.557	0.273
628.00	1.644	1.060	0.712	0.411	1.017	0.903	0.635	0.327	0.113	1.327	1.142	0.954	0.709	0.580	0.294
630.00	1.895	1.203	0.794	0.459	1.173	1.039	0.725	0.375	0.110	1.495	1.258	1.032	0.766	0.610	0.310
632.00	2.157	1.357	0.911	0.520	1.338	1.157	0.799	0.411	0.112	1.667	1.384	1.118	0.822	0.654	0.341
634.00	2.432	1.521	0.982	0.578	1.504	1.271	0.842	0.459	0.115	1.840	1.514	1.204	0.875	0.687	0.371
636.00	2.716	1.697	1.065	0.639	1.673	1.404	0.995	0.528	0.122	2.014	1.642	1.284	0.937	0.721	0.401
638.00	3.010	1.884	1.157	0.706	1.846	1.503	1.079	0.631	0.134	2.187	1.778	1.364	0.991	0.754	0.421
640.00	3.314	2.081	1.259	0.781	2.023	1.603	1.171	0.693	0.153	2.360	1.874	1.432	1.064	0.808	0.441
642.00	3.628	2.285	1.372	0.860	2.204	1.704	1.274	0.755	0.172	2.533	1.974	1.514	1.136	0.867	0.461
644.00	3.952	2.496	1.494	0.944	2.389	1.806	1.379	0.817	0.191	2.706	2.074	1.594	1.208	0.917	0.481
646.00	4.286	2.714	1.625	1.031	2.576	1.909	1.484	0.879	0.210	2.879	2.174	1.674	1.280	0.967	0.501
648.00	4.630	2.939	1.760	1.121	2.766	2.012	1.597	0.941	0.229	3.052	2.274	1.754	1.352	1.021	0.521
650.00	4.984	3.172	1.900	1.214	2.959	2.116	1.714	1.003	0.248	3.225	2.374	1.834	1.424	1.075	0.541
652.00	5.348	3.414	2.044	1.310	3.154	2.221	1.837	1.065	0.267	3.398	2.474	1.914	1.496	1.129	0.561
654.00	5.722	3.664	2.192	1.409	3.351	2.326	1.960	1.127	0.286	3.571	2.574	1.994	1.568	1.183	0.581
656.00	6.106	3.919	2.344	1.511	3.550	2.431	2.084	1.189	0.305	3.744	2.674	2.074	1.640	1.237	0.601
658.00	6.499	4.178	2.500	1.616	3.750	2.536	2.206	1.251	0.324	3.917	2.774	2.154	1.712	1.291	0.621
660.00	6.902	4.441	2.659	1.724	3.951	2.641	2.329	1.313	0.343	4.090	2.874	2.234	1.784	1.345	0.641
662.00	7.314	4.708	2.820	1.837	4.152	2.746	2.452	1.375	0.362	4.263	2.974	2.314	1.856	1.400	0.661
664.00	7.736	4.978	2.984	1.952	4.354	2.851	2.574	1.437	0.381	4.436	3.074	2.394	1.928	1.454	0.681
666.00	8.168	5.251	3.150	2.069	4.557	2.956	2.697	1.499	0.400	4.609	3.174	2.474	2.000	1.508	0.701
668.00	8.609	5.526	3.319	2.187	4.760	3.061	2.820	1.561	0.419	4.782	3.274	2.554	2.072	1.562	0.721
670.00	9.059	5.802	3.490	2.307	4.964	3.166	2.942	1.623	0.438	4.955	3.374	2.634	2.144	1.616	0.741
672.00	9.518	6.078	3.662	2.429	5.168	3.271	3.064	1.685	0.457	5.128	3.474	2.714	2.216	1.670	0.761
674.00	9.986	6.354	3.836	2.553	5.373	3.376	3.187	1.747	0.476	5.301	3.574	2.794	2.288	1.724	0.781
676.00	10.462	6.631	4.011	2.679	5.578	3.481	3.310	1.809	0.495	5.474	3.674	2.874	2.360	1.778	0.801
678.00	10.947	6.908	4.187	2.806	5.783	3.586	3.433	1.871	0.514	5.647	3.774	2.954	2.432	1.832	0.821
680.00	11.432	7.184	4.364	2.934	5.988	3.691	3.556	1.933	0.533	5.820	3.874	3.034	2.504	1.886	0.841
682.00	11.917	7.460	4.541	3.062	6.193	3.796	3.679	2.005	0.552	6.003	3.974	3.114	2.576	1.940	0.861
684.00	12.402	7.736	4.718	3.190	6.398	3.901	3.798	2.067	0.571	6.176	4.074	3.194	2.648	1.994	0.881
686.00	12.887	8.012	4.895	3.318	6.603	4.006	3.900	2.129	0.590	6.349	4.174	3.274	2.720	2.048	0.901
688.00	13.372	8.288	5.072	3.446	6.808	4.111	4.009	2.191	0.609	6.522	4.274	3.354	2.792	2.102	0.921
690.00	13.857	8.564	5.249	3.574	7.013	4.216	4.112	2.253	0.628	6.695	4.374	3.434	2.864	2.156	0.941
692.00	14.342	8.840	5.426	3.702	7.218	4.321	4.215	2.315	0.647	6.868	4.474	3.514	2.936	2.210	0.961
694.00	14.827	9.116	5.603	3.830	7.423	4.426	4.318	2.377	0.666	7.041	4.574	3.594	3.008	2.264	0.981
696.00	15.312	9.392	5.780	3.958	7.628	4.531	4.421	2.439	0.685	7.214	4.674	3.674	3.080	2.318	1.001
698.00	15.797	9.668	5.957	4.086	7.833	4.636	4.526	2.501	0.704	7.387	4.774	3.754	3.152	2.372	1.021
700.00	16.282	9.944	6.134	4.214	8.038	4.741	4.629	2.563	0.723	7.560	4.874	3.834	3.224	2.426	1.041
702.00	16.767	10.219	6.311	4.342	8.243	4.846	4.732	2.625	0.742	7.733	4.974	3.914	3.296	2.480	1.061
704.00	17.252	10.495	6.488	4.470	8.448	4.951	4.835	2.687	0.761	7.906	5.074	3.994	3.368	2.534	1.081
706.00	17.737	10.770	6.665	4.598	8.653	5.056	4.930	2.749	0.780	8.079	5.174	4.074	3.440	2.588	1.101
708.00	18.222	11.046	6.842	4.726	8.858	5.161	5.029	2.811	0.799	8.252	5.274	4.154	3.512	2.642	1.121
710.00	18.707	11.321	7.019	4.854	9.063	5.266	5.124	2.873	0.818	8.425	5.374	4.234	3.584	2.696	1.141
712.00	19.192	11.597	7.196	4.982	9.268	5.371	5.219	2.935	0.837	8.598	5.474	4.314	3.656	2.750	1.161
714.00	19.677	11.872	7.373	5.110	9.473	5.476	5.314	2.997	0.856	8.771	5.574	4.394	3.728	2.804	1.181
716.00	20.162	12.148	7.550	5.238	9.678	5.581	5.409	3.059	0.875	8.944	5.674	4.474	3.800	2.858	1.201
718.00	20.647	12.423	7.727	5.366	9.883	5.686	5.504	3.121	0.894	9.117	5.774	4.554	3.872	2.912	1.221
720.00	21.132	12.699	7.904	5.494	10.088	5.791	5.599	3.183	0.913	9.290	5.874	4.634	3.944	2.966	1.241
722.00	21.617	12.974	8.081	5.622	10.293	5.896	5.694	3.245	0.932	9.463	5.974	4.714	4.016	3.020	1.261
724.00	22.102	13.250	8.258	5.750	10.498	5.999	5.789	3.307	0.951	9.636	6.074	4.794	4.088	3.074	1.281
726.00	22.587	13.526	8.435	5.878	10.703	6.104	5.884	3.369	0.970	9.809	6.174	4.874	4.160	3.128	1.301
728.00	23.072	13.801	8.612	6.006	10.908	6.209	5.979	3.431	0.989	9.982	6.274	4.954	4.232	3.182	1.321
730.00	23.557	14.077	8.789	6.134	11.113	6.314	6.074	3.493	1.008	10.155	6.374	5.034	4.304	3.236	1.341
732.00	24.042	14.352	8.966	6.262	11.318	6.419	6.169	3.555	1.027	10.328	6.474	5.114	4.376	3.290	1.361
734.00	24.527	14.628	9.143	6.390	11.523	6.524	6.264	3.617	1.046	10.501	6.574	5.194	4.448	3.344	1.381
736.00	25.012	14.903	9.320	6.518	11.728	6.629	6.359	3.679	1.065	10.674	6.674	5.274	4.520	3.398	1.401
738.00	25.497	15.179	9.497	6.646	11.933	6.734	6.454	3.741	1.084	10.847	6.774	5.354	4.592	3.452	1.421
740.00	25.982	15.454	9.674	6.774	12.138	6.839	6.549	3.803	1.103	11.020	6.874	5.434	4.664	3.506	1.441
742.00	26.467	15.729	9.851</												

690.00	35.591	25.142	15.734	10.355	31.355	23.342	15.679	9.533	5.539	22.034	19.203	13.392	8.726	5.332	3.074
692.00	35.519	25.012	15.677	10.315	31.285	23.270	15.612	9.493	5.499	21.964	19.132	13.322	8.686	5.292	3.034
694.00	35.447	24.883	15.614	10.275	31.215	23.199	15.542	9.453	5.460	21.892	19.061	13.251	8.647	5.252	2.994
696.00	35.375	24.754	15.551	10.235	31.145	23.128	15.472	9.413	5.420	21.820	18.990	13.180	8.607	5.212	2.954
698.00	35.303	24.625	15.488	10.195	31.075	23.057	15.402	9.373	5.380	21.749	18.919	13.110	8.567	5.172	2.914
700.00	35.231	24.496	15.425	10.155	31.005	22.986	15.332	9.333	5.340	21.678	18.848	13.040	8.527	5.132	2.874
702.00	35.159	24.367	15.362	10.115	30.935	22.915	15.262	9.293	5.300	21.607	18.777	12.970	8.487	5.092	2.834
704.00	35.087	24.238	15.299	10.075	30.865	22.844	15.192	9.253	5.260	21.536	18.706	12.900	8.447	5.052	2.794
706.00	35.015	24.109	15.236	10.035	30.795	22.773	15.122	9.213	5.220	21.465	18.635	12.830	8.407	5.012	2.754
708.00	34.943	23.980	15.173	9.995	30.725	22.702	15.052	9.173	5.180	21.394	18.564	12.760	8.367	4.972	2.714
710.00	34.871	23.851	15.110	9.955	30.655	22.631	14.982	9.133	5.140	21.323	18.493	12.690	8.327	4.932	2.674
712.00	34.799	23.722	15.047	9.915	30.585	22.560	14.912	9.093	5.100	21.252	18.422	12.620	8.287	4.892	2.634
714.00	34.727	23.593	14.984	9.875	30.515	22.489	14.842	9.053	5.060	21.181	18.351	12.550	8.247	4.852	2.594
716.00	34.655	23.464	14.921	9.835	30.445	22.418	14.772	9.013	5.020	21.110	18.280	12.480	8.207	4.812	2.554
718.00	34.583	23.335	14.858	9.795	30.375	22.347	14.702	8.973	4.980	21.039	18.209	12.410	8.167	4.772	2.514
720.00	34.511	23.206	14.795	9.755	30.305	22.276	14.632	8.933	4.940	20.968	18.138	12.340	8.127	4.732	2.474
722.00	34.439	23.077	14.732	9.715	30.235	22.205	14.562	8.893	4.900	20.897	18.067	12.270	8.087	4.692	2.434
724.00	34.367	22.948	14.669	9.675	30.165	22.134	14.492	8.853	4.860	20.826	17.996	12.200	8.047	4.652	2.394
726.00	34.295	22.819	14.606	9.635	30.095	22.063	14.422	8.813	4.820	20.755	17.925	12.130	8.007	4.612	2.354
728.00	34.223	22.690	14.543	9.595	30.025	21.992	14.352	8.773	4.780	20.684	17.854	12.060	7.967	4.572	2.314
730.00	34.151	22.561	14.480	9.555	29.955	21.921	14.282	8.733	4.740	20.613	17.783	11.990	7.927	4.532	2.274
732.00	34.079	22.432	14.417	9.515	29.885	21.850	14.212	8.693	4.700	20.542	17.712	11.920	7.887	4.492	2.234
734.00	34.007	22.303	14.354	9.475	29.815	21.779	14.142	8.653	4.660	20.471	17.641	11.850	7.847	4.452	2.194
736.00	33.935	22.174	14.291	9.435	29.745	21.708	14.072	8.613	4.620	20.400	17.570	11.780	7.807	4.412	2.154
738.00	33.863	22.045	14.228	9.395	29.675	21.637	14.002	8.573	4.580	20.329	17.499	11.710	7.767	4.372	2.114
740.00	33.791	21.916	14.165	9.355	29.605	21.566	13.932	8.533	4.540	20.258	17.428	11.640	7.727	4.332	2.074
742.00	33.719	21.787	14.102	9.315	29.535	21.495	13.862	8.493	4.500	20.187	17.357	11.570	7.687	4.292	2.034
744.00	33.647	21.658	14.039	9.275	29.465	21.424	13.792	8.453	4.460	20.116	17.286	11.500	7.647	4.252	2.000
746.00	33.575	21.529	13.976	9.235	29.395	21.353	13.722	8.413	4.420	20.045	17.215	11.430	7.607	4.212	1.960
748.00	33.503	21.400	13.913	9.195	29.325	21.282	13.652	8.373	4.380	19.974	17.144	11.360	7.567	4.172	1.920
750.00	33.431	21.271	13.850	9.155	29.255	21.211	13.582	8.333	4.340	19.903	17.073	11.290	7.527	4.132	1.880
752.00	33.359	21.142	13.787	9.115	29.185	21.140	13.512	8.293	4.300	19.832	17.002	11.220	7.487	4.092	1.840
754.00	33.287	21.013	13.724	9.075	29.115	21.069	13.442	8.253	4.260	19.761	16.931	11.150	7.447	4.052	1.800
756.00	33.215	20.884	13.661	9.035	29.045	20.998	13.372	8.213	4.220	19.690	16.860	11.080	7.407	4.012	1.760
758.00	33.143	20.755	13.598	8.995	28.975	20.927	13.302	8.173	4.180	19.619	16.789	11.010	7.367	3.972	1.720
760.00	33.071	20.626	13.535	8.955	28.905	20.856	13.232	8.133	4.140	19.548	16.718	10.940	7.327	3.932	1.680
762.00	33.000	20.497	13.472	8.915	28.835	20.785	13.162	8.093	4.100	19.477	16.647	10.870	7.287	3.892	1.640
764.00	32.928	20.368	13.409	8.875	28.765	20.714	13.092	8.053	4.060	19.406	16.576	10.800	7.247	3.852	1.600
766.00	32.856	20.239	13.346	8.835	28.695	20.643	13.022	8.013	4.020	19.335	16.505	10.730	7.207	3.812	1.560
768.00	32.784	20.110	13.283	8.795	28.625	20.572	12.952	7.973	3.980	19.264	16.434	10.660	7.167	3.772	1.520
770.00	32.712	19.981	13.220	8.755	28.555	20.501	12.882	7.933	3.940	19.193	16.363	10.590	7.127	3.732	1.480

* The units of u are molecules/cm², abbreviated here by (u/cm²).

TABLE 21 $\int_{\mathbb{A}} \mathbf{A} \, dv$ [illegible]

^a The units of ν are molecules/cm², abbreviated here by (ν /cm²).

TABLE 23 $\int_{v_i}^v A dv$

* The units of u are molecules/cm², abbreviated here by (#/cm²).

TABLE 24 $\int_{v'}^v \text{Ad} v$

Sat. No.	LA01	LR02	LC03	LD02	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02	LF04	LF06	LE01	LE03	LE05	LF02
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660.00	25.748	17.317	10.958	6.431	26.493	15.928	10.275	5.432	3.372	15.815	13.801	8.556	5.242	2.971	1.602
662.00	27.599	18.578	11.738	6.589	26.227	17.164	11.069	5.629	3.599	17.281	14.135	9.291	5.343	3.179	1.712
664.00	29.315	19.933	12.761	7.061	25.916	18.436	11.964	6.013	3.941	18.649	15.261	10.068	6.154	3.494	1.891
666.00	31.117	21.288	13.588	7.677	27.597	18.586	12.600	6.288	4.227	19.646	16.255	10.868	6.548	3.730	2.027
668.00	32.997	22.631	14.598	8.482	29.411	20.968	13.768	7.598	4.803	21.584	17.625	11.613	7.216	4.254	2.454
670.00	34.979	24.540	16.316	9.489	31.305	22.868	15.555	9.446	5.944	23.443	19.513	13.332	8.661	5.378	3.210
672.00	36.966	26.168	17.938	10.696	33.293	24.436	16.572	10.713	6.391	25.114	20.985	14.446	9.389	5.814	3.537
674.00	38.788	27.516	19.488	11.938	35.182	25.831	17.308	11.861	6.658	26.624	22.224	15.218	9.334	6.051	3.562
676.00	40.624	28.375	19.251	11.613	36.923	27.116	18.217	11.874	6.982	28.168	23.497	15.992	18.279	6.286	3.681
678.00	42.487	29.242	21.138	12.097	38.759	28.559	19.058	11.532	7.156	29.739	24.791	16.796	18.731	6.520	3.802
680.00	44.348	31.595	20.909	12.573	41.593	29.895	19.898	11.988	7.411	31.307	26.086	17.593	11.179	6.751	3.925
682.00	46.198	32.948	21.825	13.038	44.415	28.780	20.738	12.429	7.657	32.653	27.358	18.378	11.614	6.977	4.046
684.00	48.035	34.195	22.619	13.481	46.218	32.588	21.481	12.889	7.898	33.557	28.565	19.108	12.027	7.193	4.154
686.00	49.885	35.379	23.848	13.885	47.961	33.788	22.183	13.236	8.106	35.798	29.711	19.788	12.406	7.397	4.254
688.00	51.558	36.498	24.803	14.268	47.646	34.834	22.792	13.581	8.305	37.157	30.772	20.488	12.752	7.579	4.346
690.00	53.163	37.546	24.643	14.689	49.255	35.980	23.393	13.916	8.506	38.425	31.759	20.969	13.050	7.757	4.440
692.00	54.762	38.534	25.258	15.048	50.771	36.873	23.951	14.238	8.689	39.595	32.661	21.495	13.356	7.931	4.525
694.00	56.248	39.429	25.782	15.259	52.165	37.768	24.447	14.496	8.859	40.645	33.465	21.959	13.616	8.076	4.596
696.00	57.564	40.241	26.254	15.474	53.438	38.564	24.888	14.728	8.975	41.572	34.176	22.386	13.842	8.283	4.635
698.00	58.798	40.956	26.668	15.690	54.554	39.270	25.278	14.929	9.091	42.372	34.791	22.764	14.042	8.314	4.709
700.00	59.878	41.580	27.023	15.868	55.538	39.879	25.608	15.185	9.193	43.045	35.318	23.048	14.213	8.411	4.757
702.00	60.825	42.127	27.336	16.021	56.393	40.466	25.884	15.258	9.277	43.596	35.765	23.309	14.361	8.493	4.801
704.00	61.653	42.683	27.616	16.159	57.093	40.858	26.132	15.488	9.356	44.036	36.115	23.511	14.589	8.566	4.839
706.00	62.357	43.085	27.851	16.288	57.674	41.241	26.344	15.523	9.428	44.476	36.355	23.719	14.599	8.638	4.873
708.00	62.958	43.337	28.048	16.374	58.139	41.562	26.522	15.622	9.484	44.838	36.625	23.877	14.688	8.667	4.902
710.00	63.458	43.523	28.215	16.456	58.509	41.834	26.677	15.788	9.538	45.035	36.884	24.018	14.766	8.734	4.925
712.00	63.883	43.678	28.362	16.523	58.804	42.059	26.812	15.781	9.572	45.198	37.044	24.119	14.835	8.780	4.945
714.00	64.234	43.808	28.469	16.588	59.035	42.241	26.927	15.844	9.589	45.327	37.182	24.213	14.898	8.819	4.966
716.00	64.519	43.928	28.596	16.628	59.219	42.398	27.028	15.899	9.643	45.431	37.295	24.289	14.938	8.853	4.985
718.00	64.759	44.025	28.701	16.674	59.375	42.513	27.123	15.953	9.684	45.528	37.287	24.353	14.965	8.898	5.007
720.00	65.229	44.022	28.956	16.809	59.738	42.732	27.374	16.093	9.765	45.488	37.486	24.522	15.121	8.969	5.057
722.00	66.223	45.635	29.543	17.154	60.539	43.555	27.921	16.426	9.955	46.827	37.982	24.993	15.488	9.159	5.157
724.00	66.583	46.078	29.744	17.253	60.818	43.772	28.177	16.539	10.045	46.248	38.185	25.145	15.532	9.238	5.202
726.00	66.614	46.956	29.881	17.278	61.984	44.828	28.127	16.587	10.074	46.288	38.139	25.178	15.557	9.269	5.217
728.00	66.847	46.061	29.883	17.298	61.814	44.566	28.188	16.596	10.182	46.334	38.182	25.225	15.586	9.269	5.238
730.00	67.018	46.179	29.916	17.319	61.143	44.008	28.256	16.627	10.186	46.482	38.237	25.278	15.618	9.291	5.242
732.00	67.288	46.315	30.011	17.333	61.266	44.195	28.325	16.666	10.169	46.476	38.256	25.341	15.654	9.313	5.254
734.00	67.453	46.424	30.104	17.357	61.436	44.216	28.396	16.704	10.197	46.554	38.363	25.404	15.688	9.344	5.269
736.00	67.679	46.588	30.164	17.398	61.582	44.329	28.465	16.739	10.226	46.592	38.357	25.434	15.785	9.344	5.269
738.00	67.886	46.681	30.251	17.414	61.724	44.432	28.535	16.774	10.254	46.592	38.357	25.434	15.785	9.344	5.269
740.00	68.082	46.798	30.328	17.443	61.859	44.534	28.598	16.889	10.283	46.592	38.357	25.434	15.785	9.344	5.269
742.00	68.293	46.944	30.438	17.498	61.954	44.686	28.674	16.833	10.327	46.592	38.357	25.434	15.785	9.344	5.269
744.00	68.486	47.078	30.532	17.558	62.118	44.751	28.746	16.984	10.378	46.592	38.357	25.434	15.785	9.344	5.269
746.00	68.612	47.159	30.599	17.573	62.288	44.819	28.792	16.934	10.397	46.592	38.357	25.434	15.785	9.344	5.269
748.00	68.711	47.238	30.638	17.598	62.268	44.871	28.831	16.956	10.428	46.592	38.357	25.434	15.785	9.344	5.269
750.00	68.798	47.291	30.683	17.607	62.325	44.915	28.863	16.975	10.440	46.592	38.357	25.434	15.785	9.344	5.269

* The units of u are molecules/cm², abbreviated here by (θ/cm^2) .

TABLE 27 $\int_{\nu'}^{\nu} A d\nu$

Sam. No.	LP01	Sam. No.	LQ01
Temp (K)	249.	Temp (K)	249.
Path (cm)	3291.	Path (cm)	3291.
Conc.	1.00000	Conc.	1.00000
P (atm)	0.769737	P (atm)	0.769737
P (atm)	1.000658	P (atm)	1.000658
u^e (#/cm ²)*	7.471E 22	u^e (#/cm ²)*	7.471E 22

ν
(cm⁻¹)

500.00	0.
502.00	0.015
504.00	0.049
506.00	0.071
508.00	0.114
510.00	0.168
512.00	0.197
514.00	0.230
516.00	0.269
518.00	0.328
520.00	0.402
522.00	0.485
524.00	0.584
526.00	0.706
528.00	0.862
530.00	1.012
532.00	1.171
534.00	1.334
536.00	1.500
538.00	1.665
540.00	1.798
542.00	1.914
544.00	2.089
546.00	3.256
548.00	3.756
550.00	3.960
552.00	4.183
554.00	4.426
556.00	4.709
558.00	5.019
560.00	5.356

* The units of u are molecules/cm²,
abbreviated here by (#/cm²).

ν
(cm⁻¹)

780.00	0.
782.00	0.552
784.00	1.056
786.00	1.498
788.00	1.884
790.00	2.230
792.00	2.859
794.00	3.971
796.00	4.669
798.00	5.091
800.00	5.532
802.00	5.997
804.00	6.470
806.00	6.940
808.00	7.382
810.00	7.796
812.00	8.177
814.00	8.507
816.00	8.799
818.00	9.051
820.00	9.257
822.00	9.431
824.00	9.580
826.00	9.708
828.00	9.833
830.00	9.966
832.00	10.066
834.00	10.140
836.00	10.222
838.00	10.292
840.00	10.368
842.00	10.446
844.00	10.521
846.00	10.590
848.00	10.644
850.00	10.703

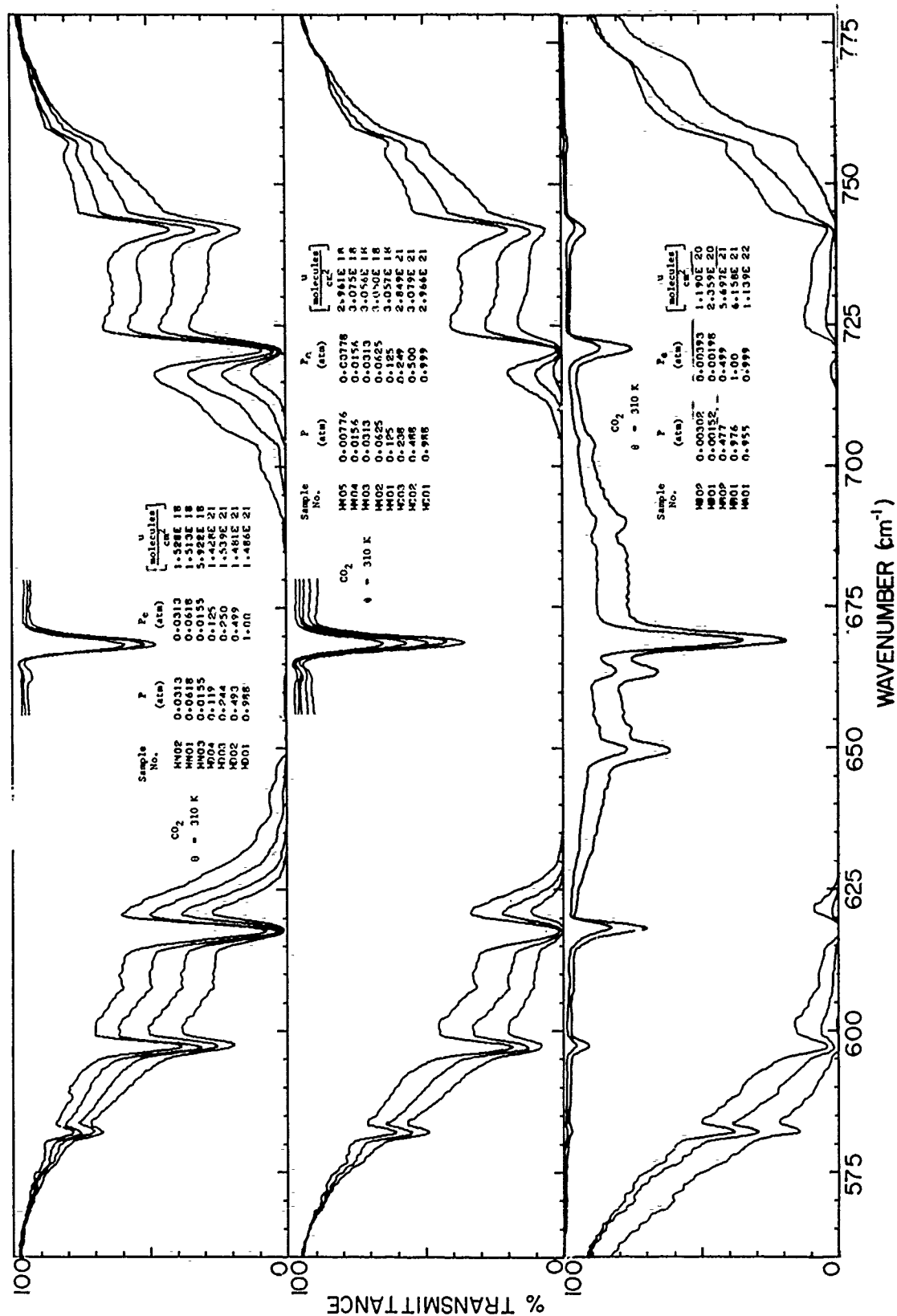


Figure 10. Spectral plots of transmittance of several CO₂ samples near 310 K.

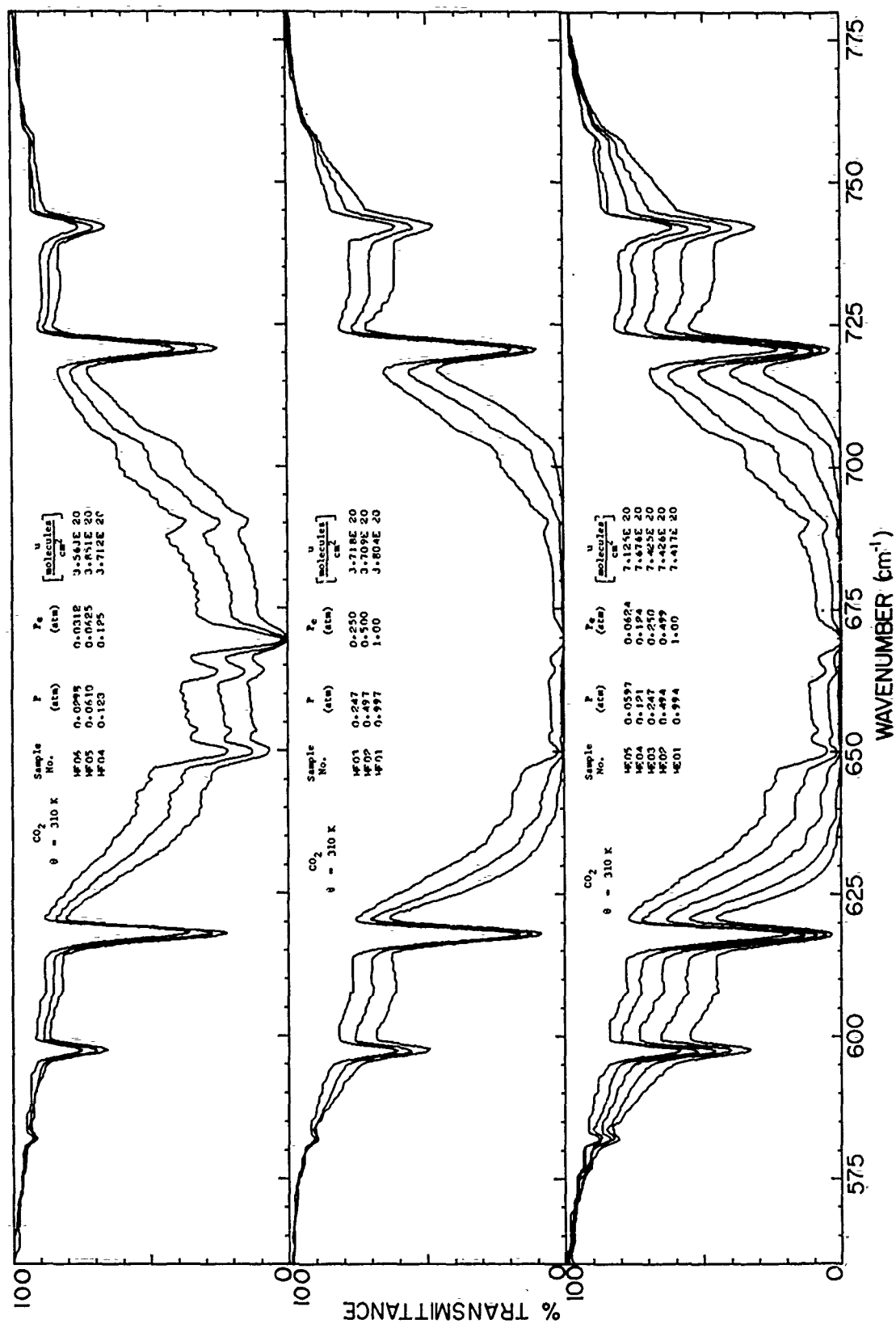


Figure 11. Spectral plots of transmittance of several CO₂ samples near 310 K.

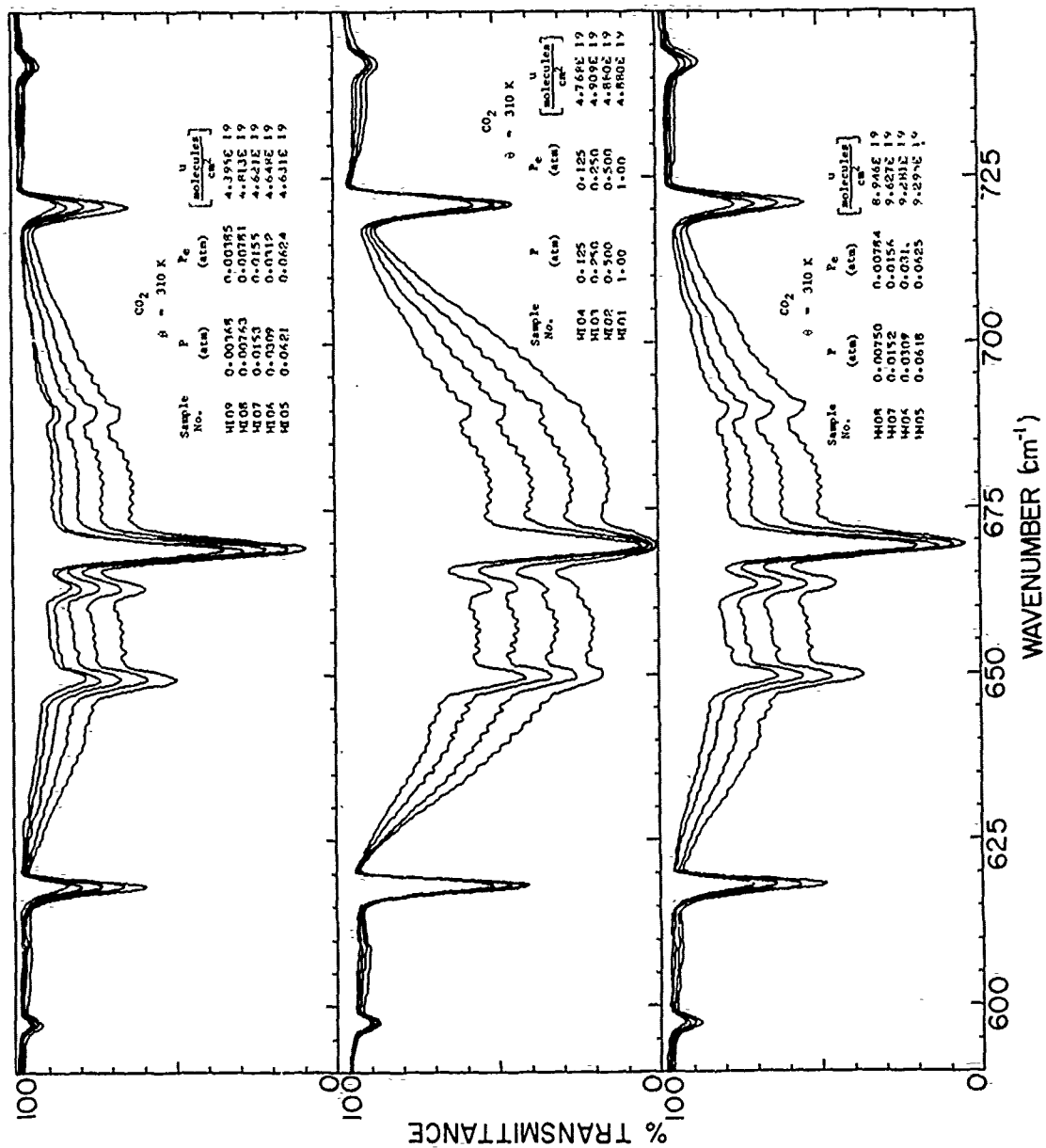


Figure 12. Spectral plots of transmittance of several CO_2 samples near 310 K.

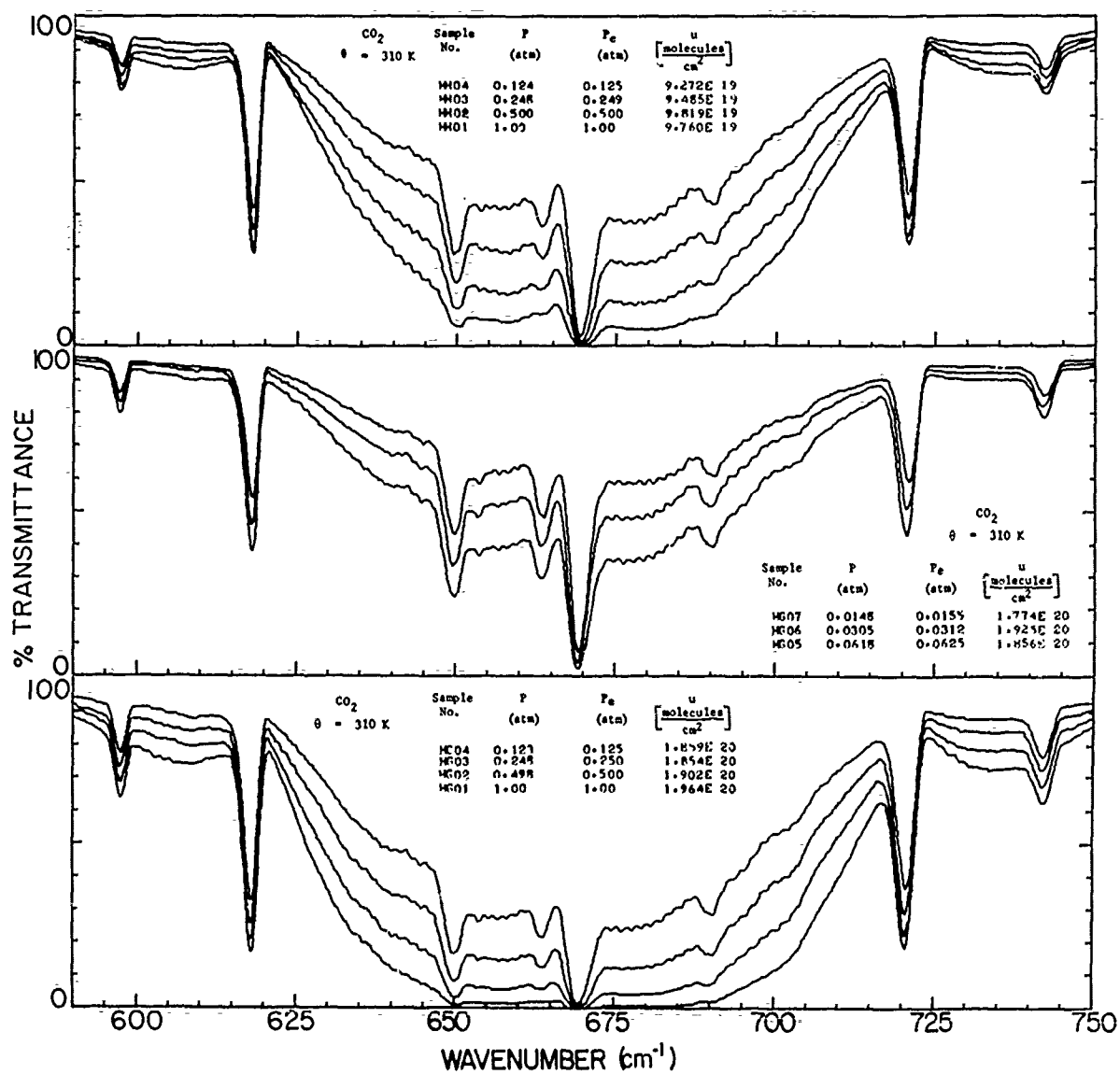


Figure 13. Spectral plots of transmittance of several CO₂ samples near 310 K.

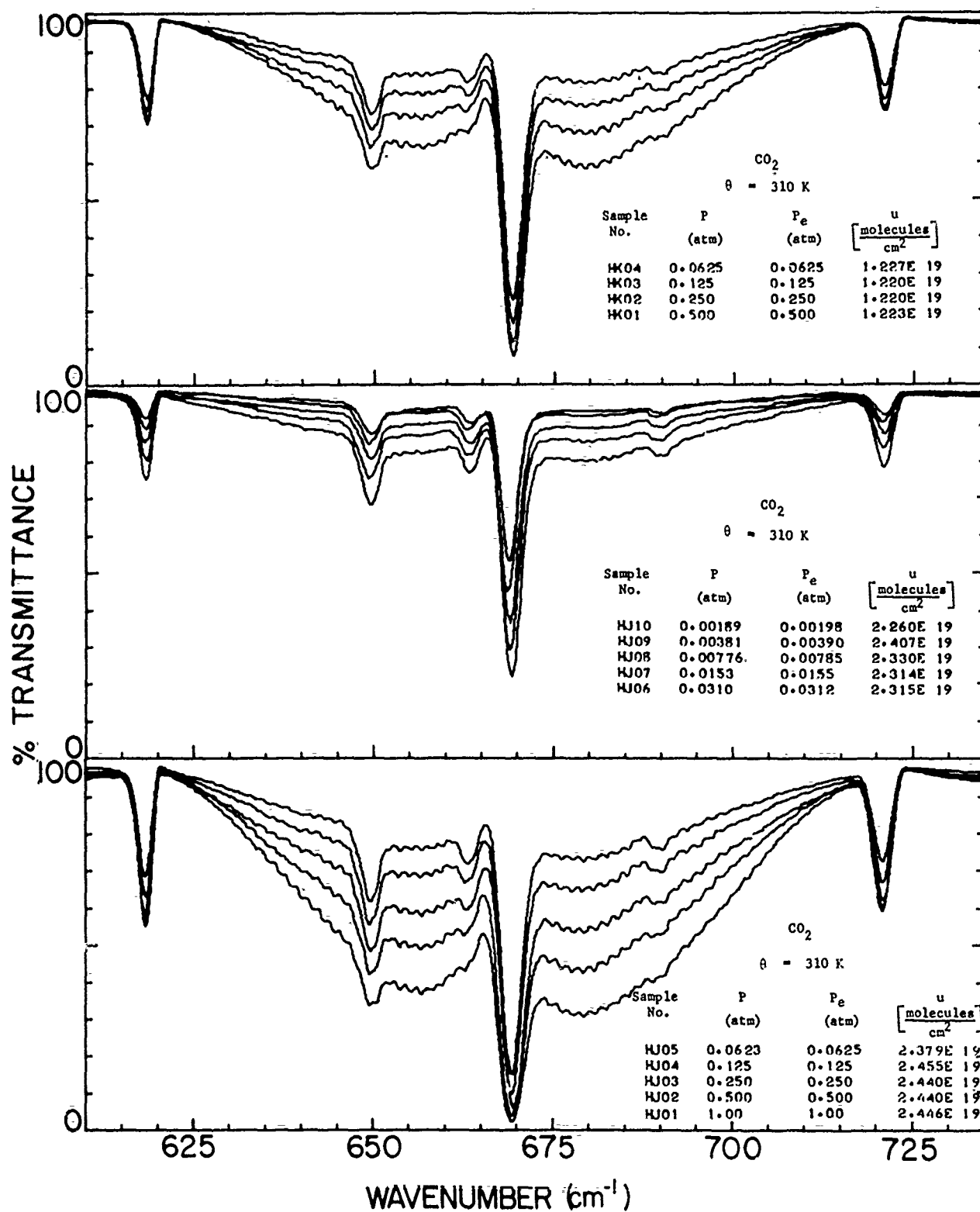


Figure 14. Spectral plots of transmittance of several CO₂ samples near 310 K.

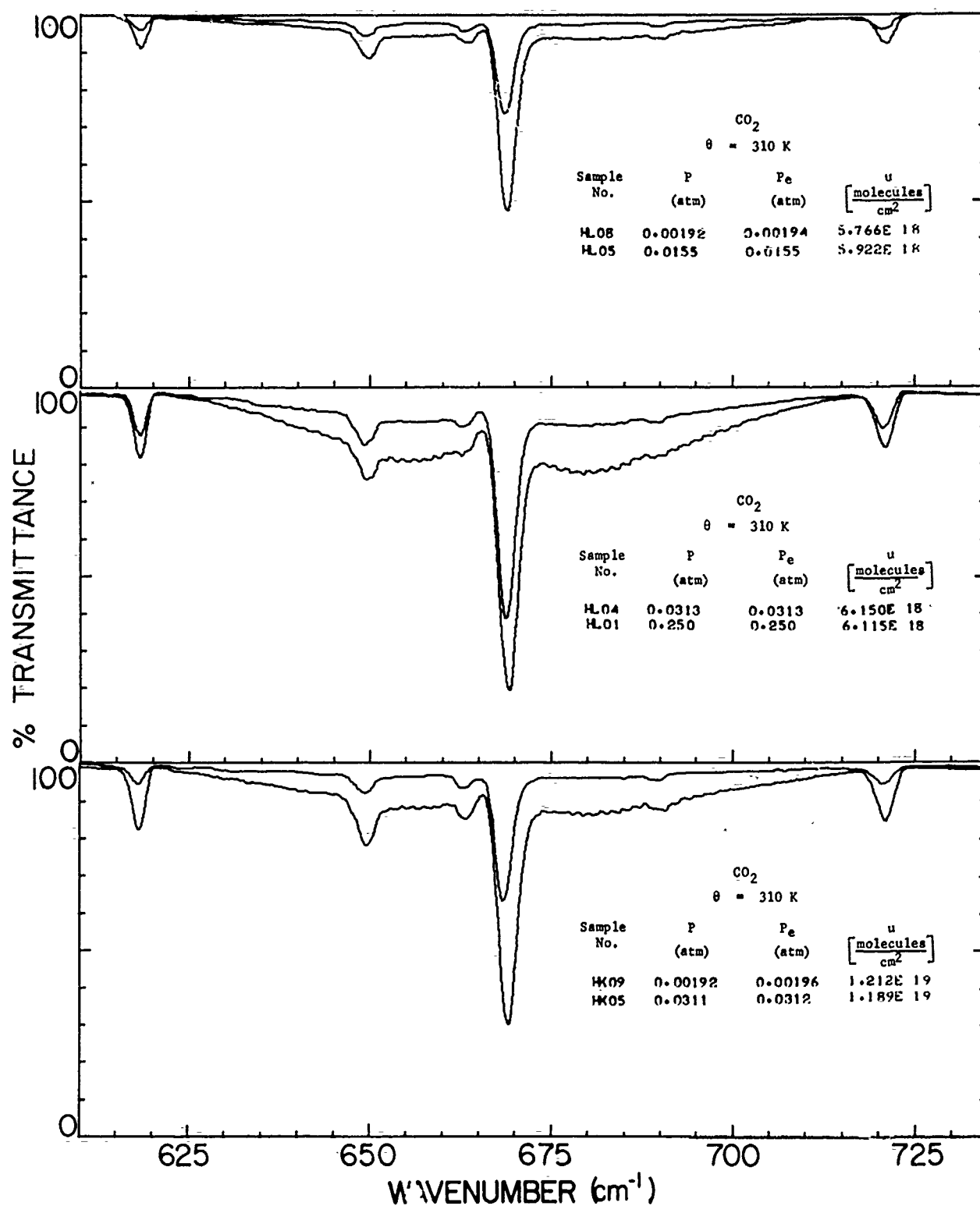


Figure 15. Spectral plots of transmittance of several CO₂ samples near 310 K.

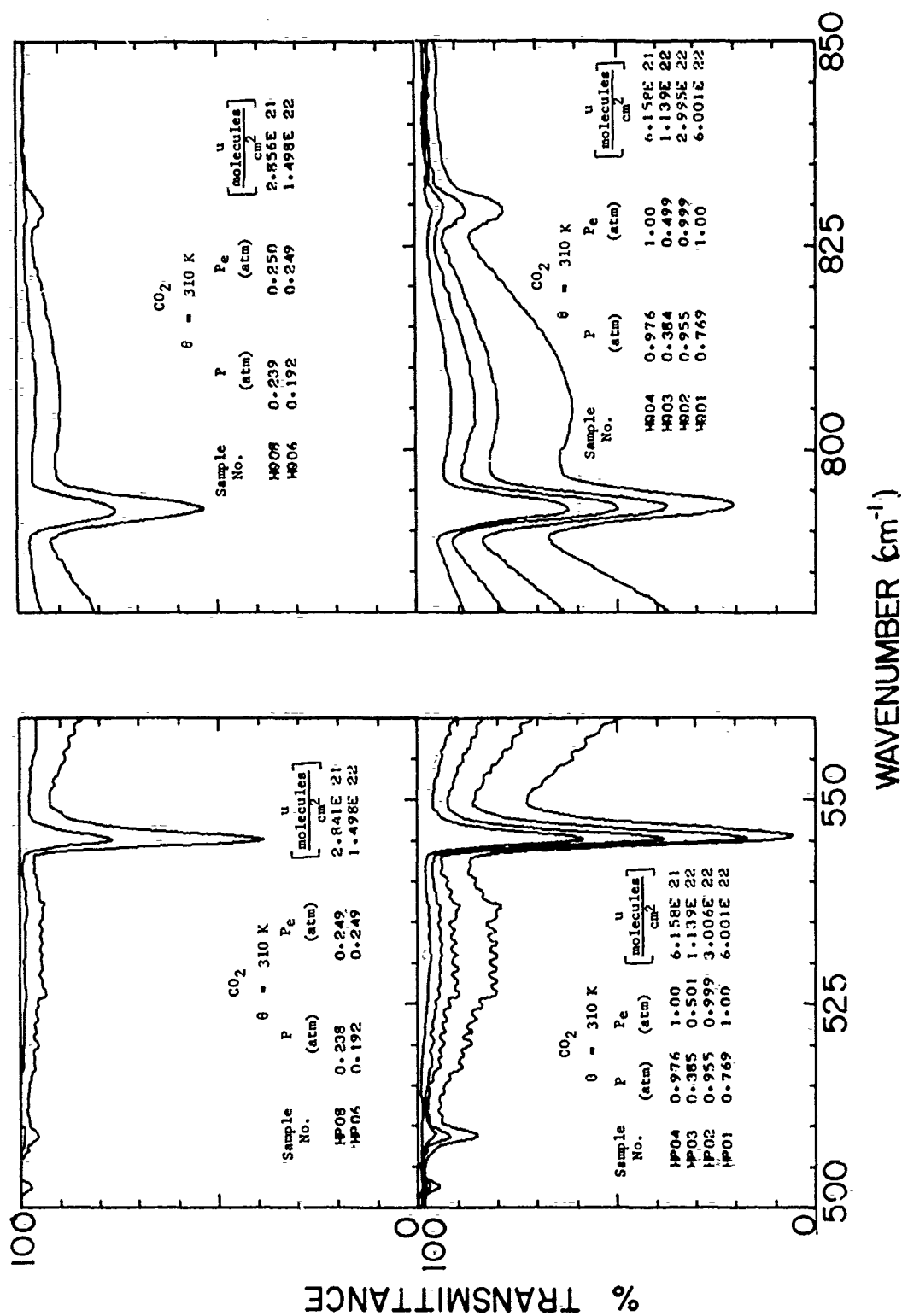


Figure 16. Spectral plots of transmittance of several CO₂ samples near 310 K.

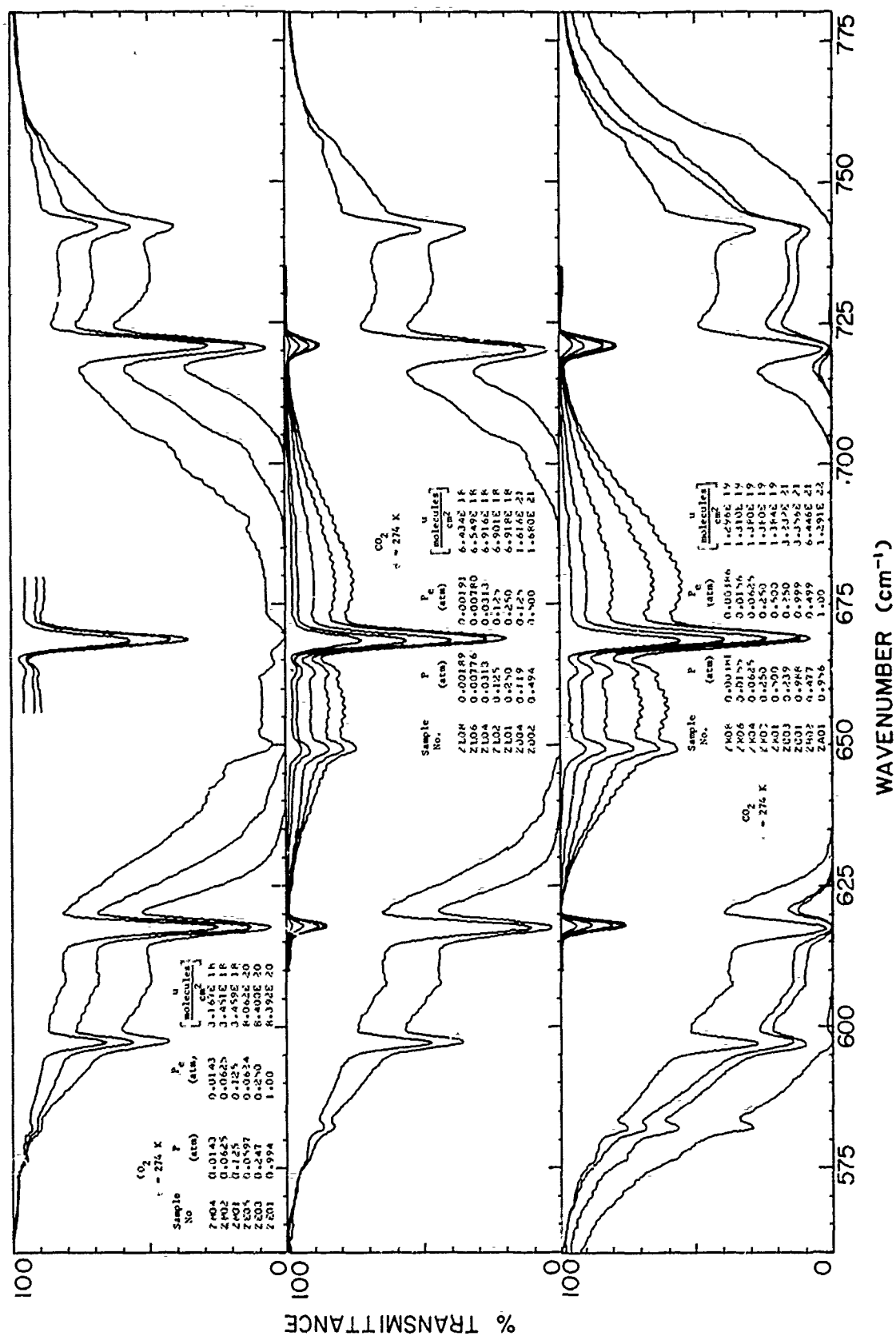


Figure 17. Spectral plots of transmittance of several CO₂ samples near 274 K.

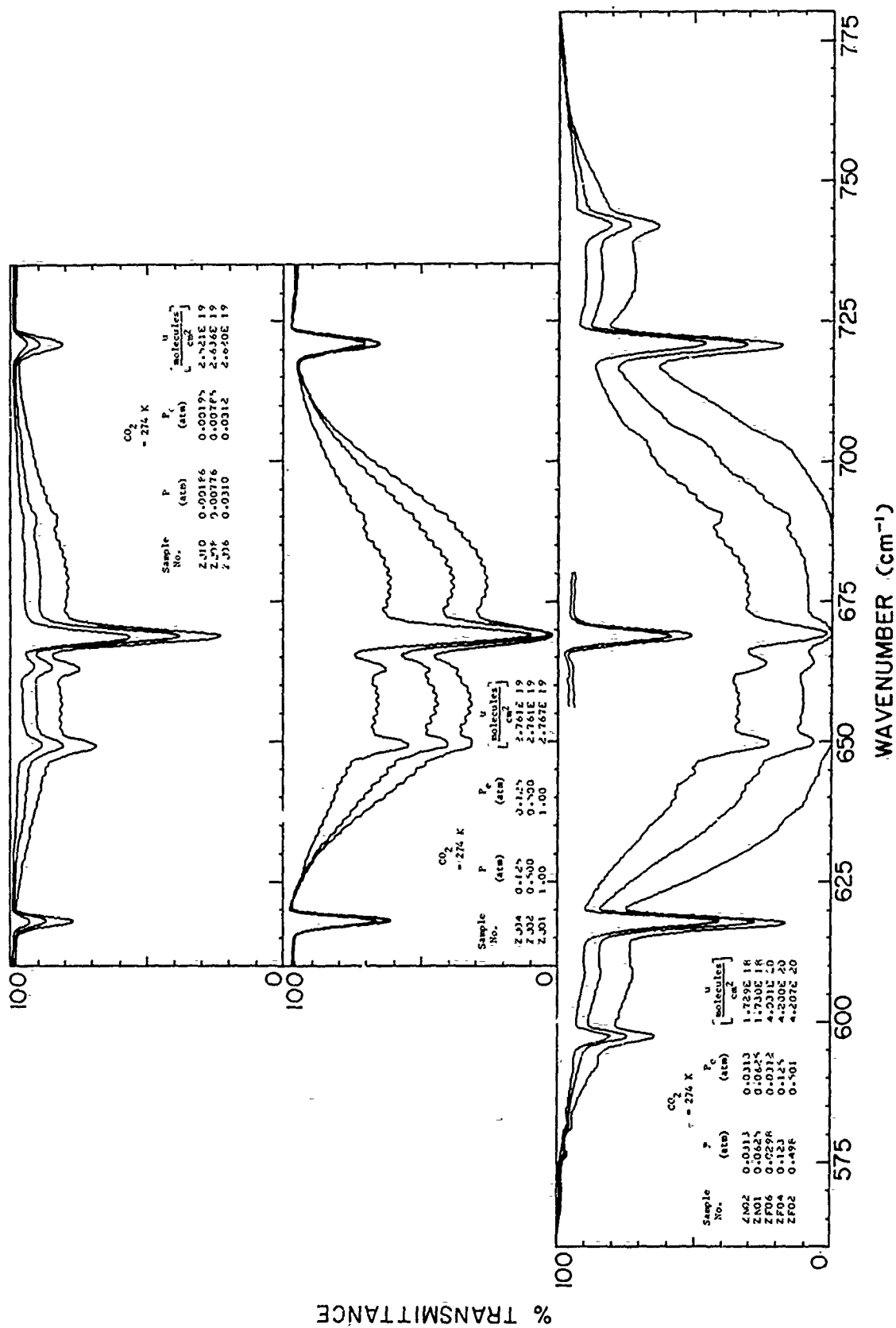


Figure 18. Spectral plots of transmittance of several CO₂ samples near 274 K.

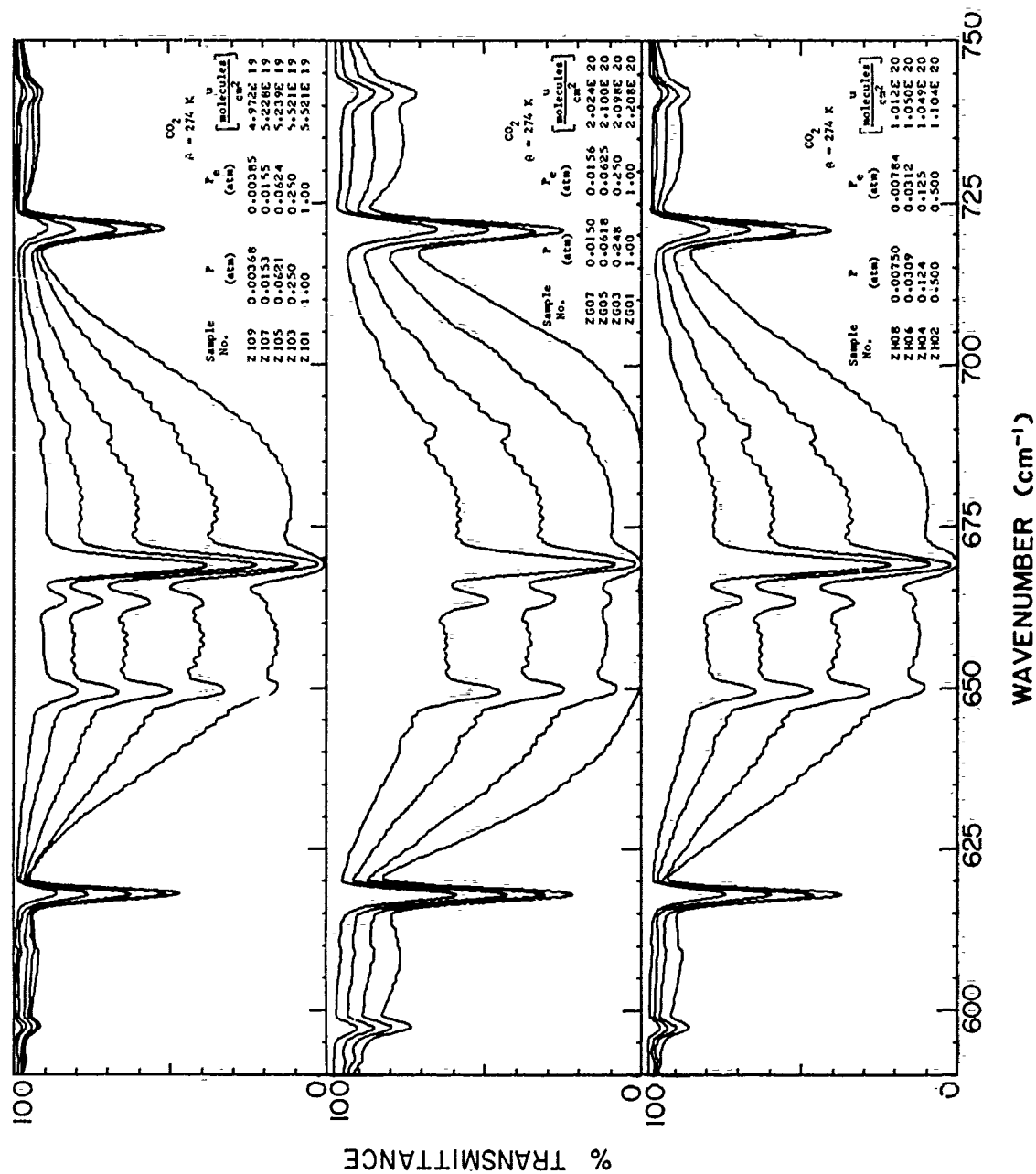


Figure 19. Spectral plots of transmittance of several CO₂ samples near 274 K.

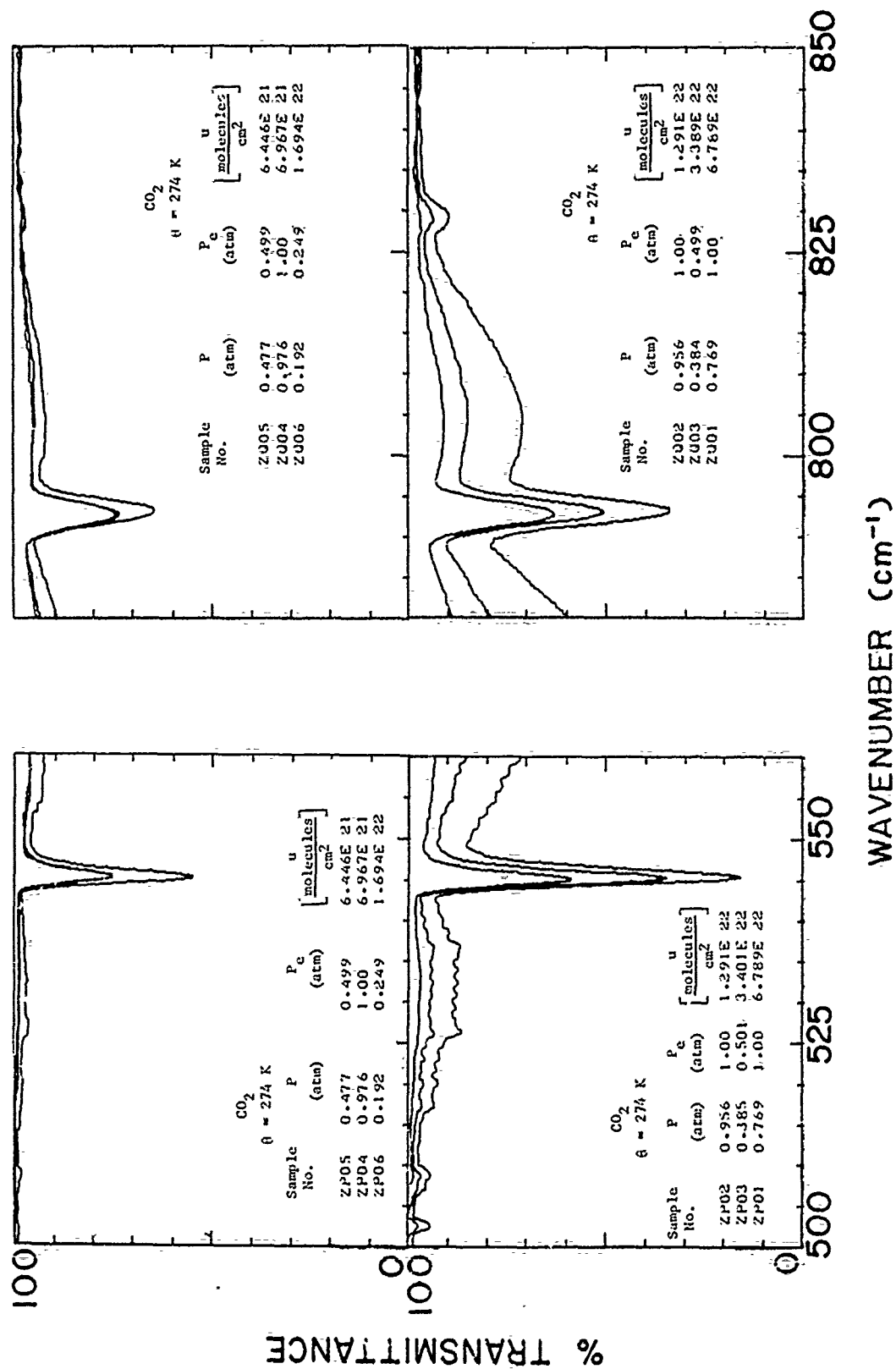


Figure 20. Spectral plots of transmittance of several CO₂ samples near 274 K.

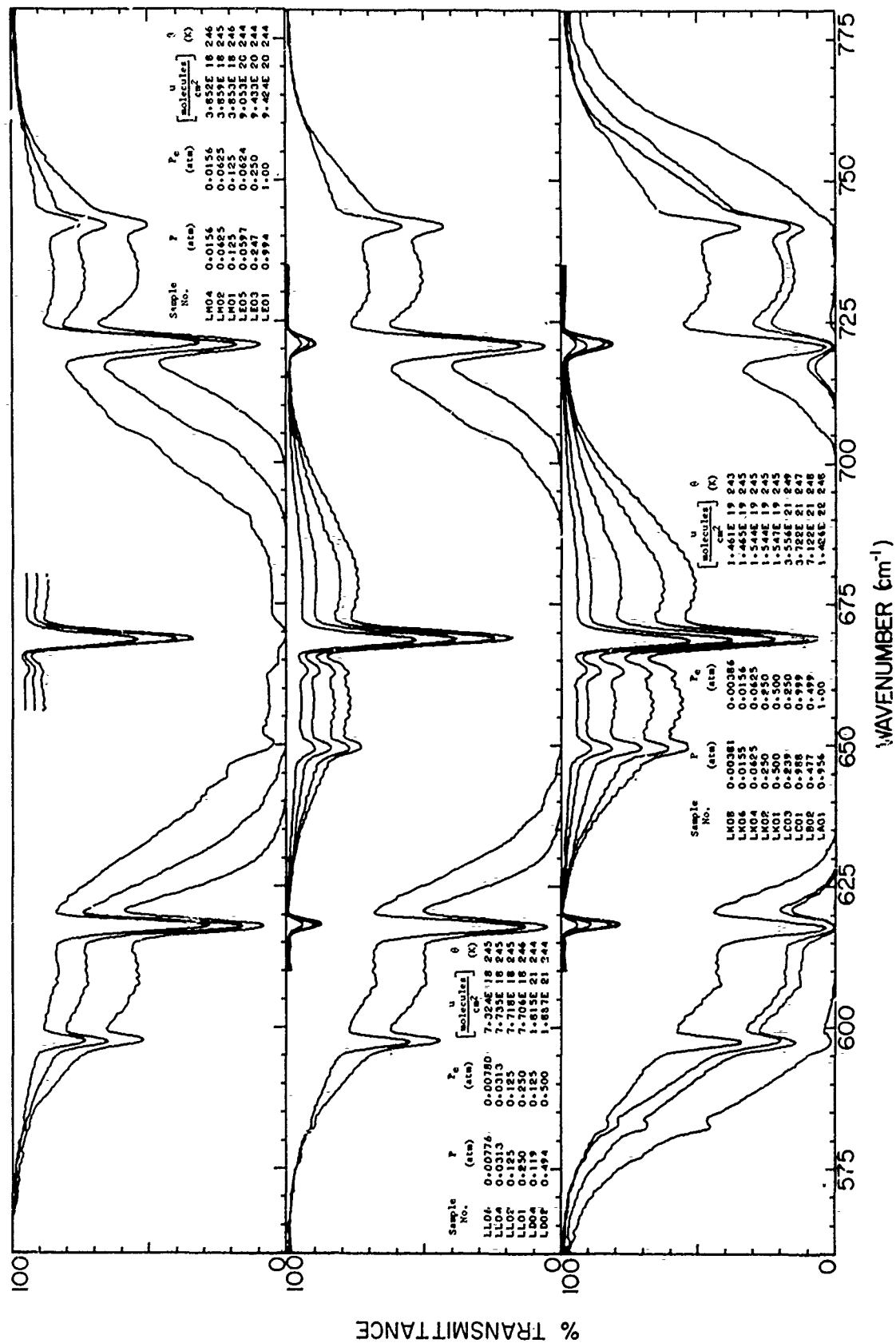


Figure 21. Spectral plots of transmittance of several CO₂ samples near 245°K.

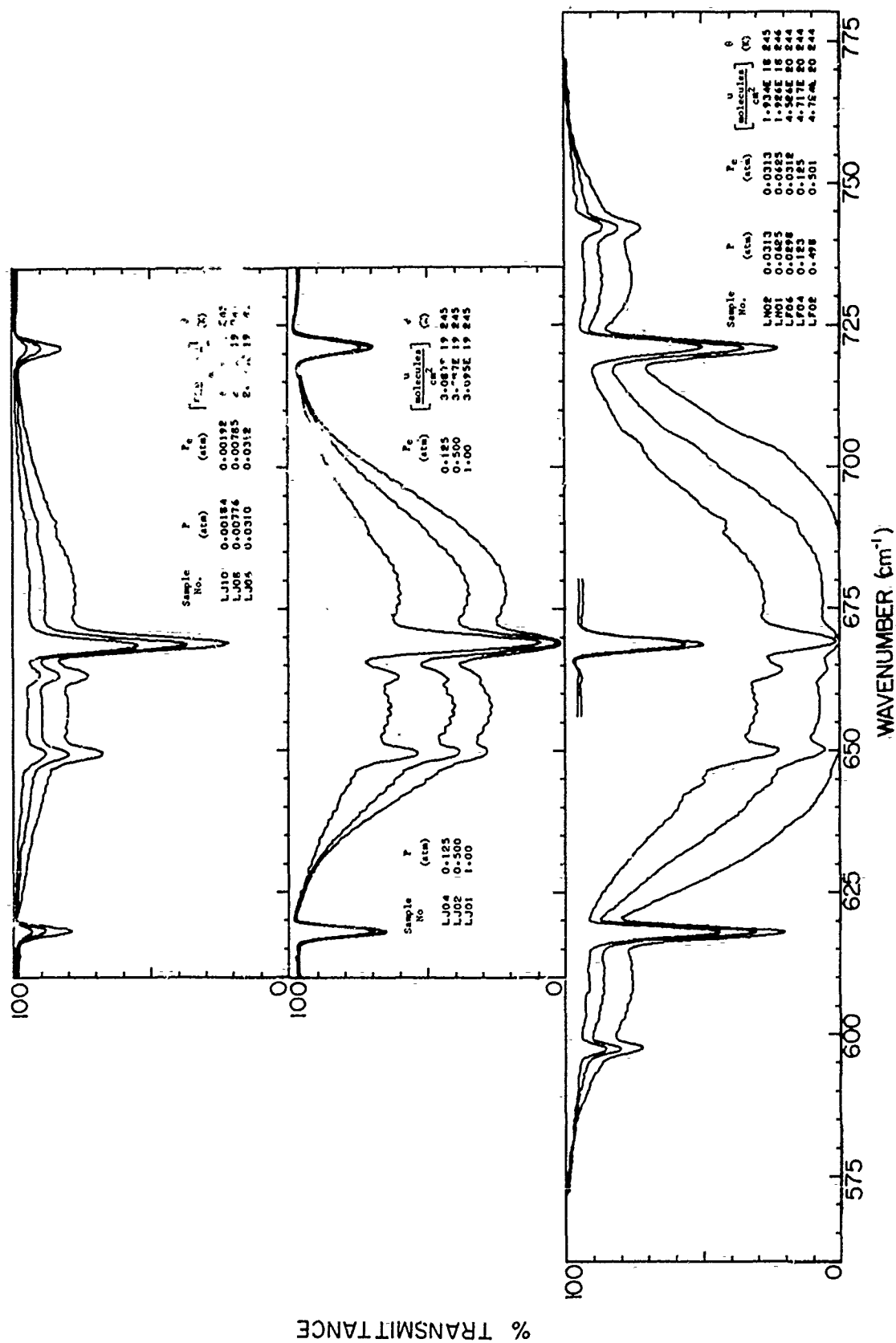


Figure 22. Spectra of transmittance of several CO₂ samples near 245 K.

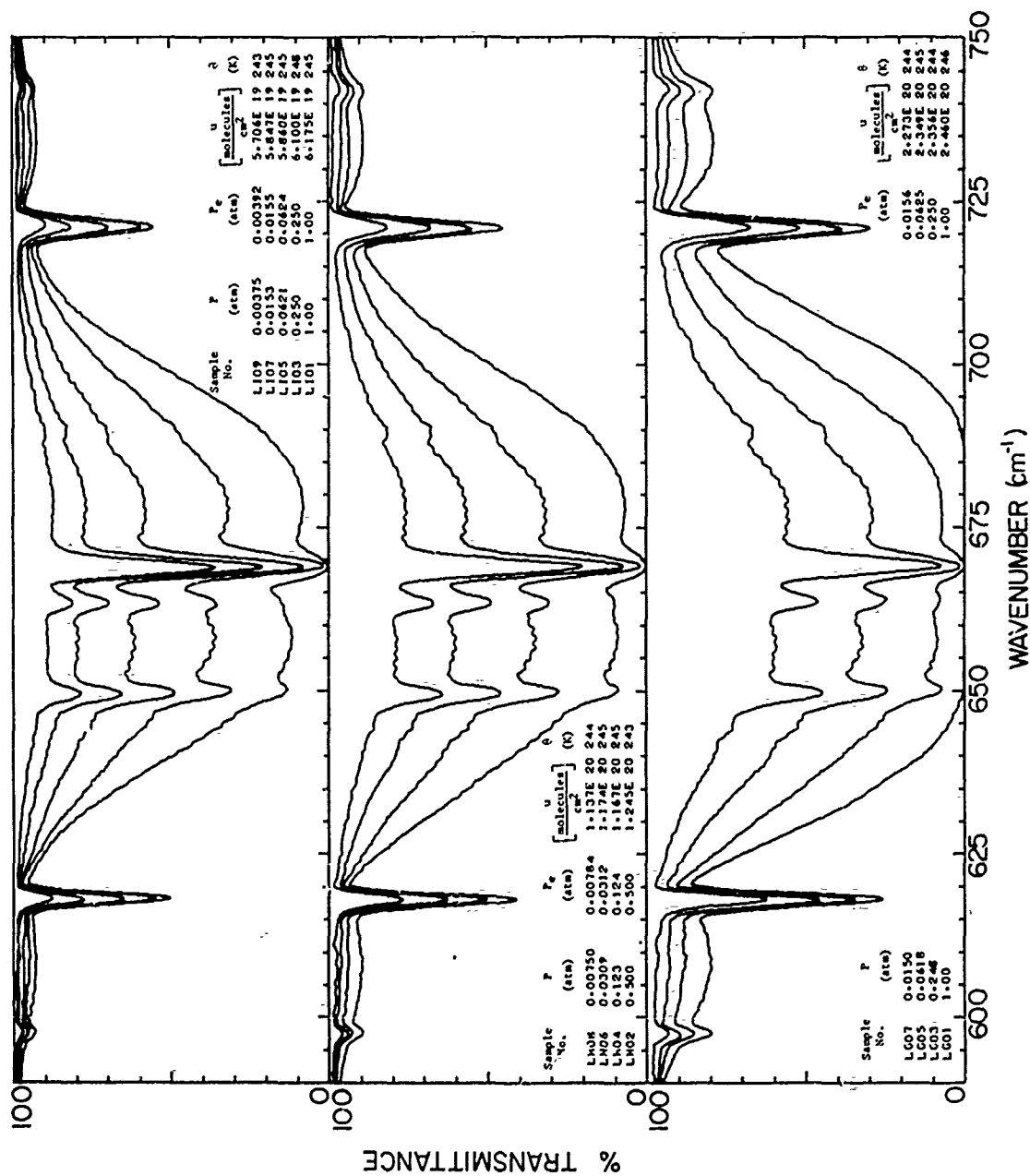


Figure 23. Spectral plots of transmittance of several CO₂ samples near 245 K.

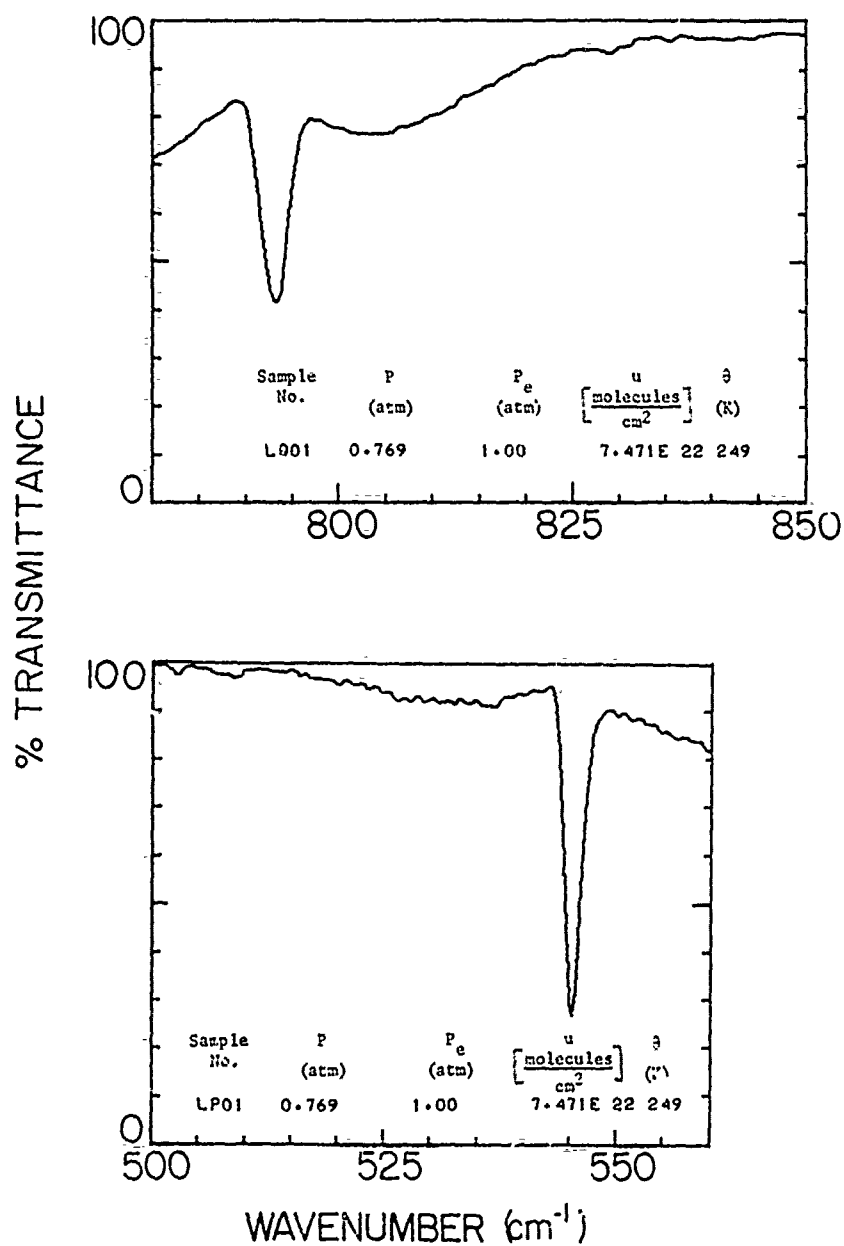


Figure 24. Spectral plots of transmittance of several CO₂ samples near 245 K.

SECTION 6

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