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MOLECULAR TRANSMISSION BAND MODELS FOR THE UNIFORMLY MIXED AND THE TRACE GASES

Joseph H. Pierluissi
Christos E. Maragoudakis

The University of Texas at El Paso
Electrical Engineering Department
El Paso, TX 79968-0523

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The report includes the theory, development, and validation of molecular transmittance band models for the uniformly mixed (N_2O, CH_4, CO, O_2 and CO_2), and for the trace (NO, NO_2, NH_3, and SO_2) gases in the infrared. The models are specifically designed for direct incorporation into the LOWTRAN atmospheric transmission code.

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Molecular Transmission Band Models for the Uniformly Mixed and the Trace Gases

Summary

This report deals with the theory, development and validation of molecular transmission band models for the uniformly mixed (N_2O, CH_4, CO, O_2, and CO_2), and for the trace (NO, NO_2, NH_3, and SO_2) gases. The models were specifically designed for direct incorporation into the LOWTRAN atmospheric transmission code. The transmission function adopted for each gas, acting individually consists of a double exponential function defined by three gas dependent parameters and a single spectrally-dependent parameter. All of these parameters were determined optimally through a numerical procedure that generally incorporates line-by-line and measured transmittance spectra. The resulting nine models were defined at 5 cm^{-1} intervals throughout their absorber bands, for transmittance calculations of 20 cm^{-1} spectral resolution at typical atmospheric conditions. Averaged vertical mixing ratio profiles for these gases were obtained for direct use with the 33-level standard atmospheric models in the calculation of slant-path transmittance. Comparisons are presented between line-by-line and measured transmittance spectra, and between these spectra and model calculations using LOWTRAN 6.

1. Introduction

Since the discovery of the infrared region of the solar spectrum by Herschel[1], an ever increasing number of instruments and systems have been conceived which depend on a knowledge of atmospheric transmittance for their design and implementation. As far as the physical and chemical processes involved in the absorption of energy by the molecules of the atmospheric gases are concerned, they are generally well understood. That is, the monochromatic absorption is governed by Beer's[2] law, and the broadening of the absorption lines is reasonably-well described by functions such as Doppler[3], Lorentz[4], and Voigt[5] shapes. Hence, the method of synthesizing atmospheric molecular absorption along a specified path reduces, in principle, to the application of those functions to assumed information on the gas types, their concentration profiles, the atmospheric conditions, the path geometry, the instrument spectral response, and the spectral line parameters. In actuality, such calculations quickly become exceedingly laborious and time consuming for the ordinary user, and efforts are normally made to replace them with analytically simpler, computationally faster and reasonably accurate band transmittance models.

The equation for the mean transmittance over a narrow spectral interval within a band has been evaluated repeatedly over the years for intervals containing from one[6] to a large number of lines, assuming a variety of line shapes and distributions of line intensities and positions. Of these, the regular[7] and the random[8,9] models are the best known. Using a conglomerate of existing theoretical and empirical models and the available data, Altshuler in 1961[10] originated the first comprehensive graphical method for easily estimating atmospheric transmission in the infrared. This pioneering effort was followed by the work of the

AFCRL[11] group, who conceived the idea and generated the backbone of what later became the LOWTRAN 2[12] computer code.

The original AFCRL method for the calculation of atmospheric transmission depended on a nomographic solution involving graphs of the transmission functions, and of the spectral parameters for the individual gases. Of particular attention is the fact that a single transmission function and parameter graph represented the total transmisttance for all the uniformly mixed gases together. At the inception of LOWTRAN 2, the functions and spectral parameters curves for all the gases were digitized for inclusion in the computer code. The temperature dependence of the data, originally neglected in the development of the transmission functions and parameters, was introduced in a later version of the code[13,14]. Considering all the constraints associated with the availability, form, inhomogeneity, and broad spectral coverage of the data, it seems doubtful that more optimal models could have been developed at the time. At the present time it is still reasonable to justify the preservation of the basic transmittance calculation scheme[15], and only bring forth changes required to allow for extensions of the code capabilities into man-made atmospheric absorbers, into spatially variable absorber concentrations, and for the use of modern numerical procedures as well as recent transmittance measurements.

It is generally recognized by the scientific community that the present, most serious limitation of the molecular absorption models in LOWTRAN is the inseparability of the uniformly mixed gases. The existing combined model does not allow for the use of absorber concentrations that depart from the original values assumed for these gases in the model development. A somewhat less serious limitation, albeit highly desirable, is the absence of band models for estimating the transmittance impact of the trace gases in polluted environments. These needs are addressed in the work reported here, where individual molecular absorption band models are presented for the uniformly mixed gases N_2O, CH_4, CO, O_2, and CO_2, and the trace gases NO, NO_2, NH_3, and SO_2. These models were developed for the most part with a combination of line-by-line transmittance data and laboratory measurements. Both of these data sets were degraded to the 20 cm^{-1} spectral resolution of the LOWTRAN gaseous transmittance models, before they were incorporated into the modeling procedure. Vertical mixing ratio profiles for these gases are also proposed here, as they were derived from recently available data on atmospheric measurements[16,17].

2. The Transmittance Function

The transmittance function adopted in this work has its origin in Beer's law[2], which states that the monochromatic transmittance τ_ν at wavenumber ν along a path of length Z within an inhomogenous medium with pressure and temperature distributions P(Z) and T(Z), respectively, is

$$\tau_\nu = \exp\left[-\int K(P,T)\,dU(Z)\right] \quad , \tag{1}$$

where the integration is to be carried over the path length, K is the absorption coefficient for all contributing lines of a given absorber, and U, is its absorber amount expressable as

$$dU = \rho(Z)\,dZ \quad , \tag{2}$$

where ρ is the absorber density. For broadband radiation detected by an instrument of spectral response ϕ_ν, the quantity of interest is the weighted mean transmittance τ defined as

$$\tau = \int \tau_\nu \phi_\nu d\nu \Big/ \int \phi_\nu d\nu \quad , \tag{3}$$

in which the integration is to be carried over the limits of ϕ. In line-by-line monchromatic calculations of τ_ν in Eq. (1), the approximation is commonly made of a horizontally stratified atmosphere, throughout each layer of which uniformity of all parameters may be assumed, such that Eq. (1) becomes

$$\tau_\nu = \exp\left[-\int K(P,T)U(Z)\right]. \qquad (4)$$

Numerous analytical evaluations of and empirical approximations to Eq. (3) may be found in the literature[18], most of which express τ in terms of absorber and spectral parameters, as well as of meteorological variables. A notable form of these is the model of King[19] given by

$$\tau = g\ [C(P/P_o)^n(T_o/T)^m U] \qquad (5)$$

where g is a continuous function to be determined empirically, C is a spectral parameter defined over a spectral interval $\Delta\nu$, n and m are absorber parameters, and the subscript "o" denotes standard conditions of the associated variables for computational convenience Eq. (5) is expressed in LOWTRAN as

$$\tau = f\{X\}\ , \qquad (6)$$

where

$$X = C' + \log_{10} W \quad , \qquad (7)$$

$$C' = \log_{10} C \quad , \qquad (8)$$

$$W = (P/P_o)^n(T_o/T)^m U \quad , \qquad (9)$$

and f is the transmittance function, C' is a spectral parameter, and W is the equivalent absorber amount. In the current version of LOWTRAN look up tables of τ versus X are provided for the single function for water vapor and the uniformly mixed gases, and for the function for ozone.

From among the numerous analytical forms of f in Eq. (6) available in the literature a function that has been found[20] to approximate reasonably well the transmittance of a variety of gases over a wide range of meteorological conditions and spectral bands, is the double exponential

$$\tau = \exp\left(-10^{aX}\right) \quad , \tag{10}$$

where a is another absorber parameter. This function is appealing for use as a universal transmission function because it is analytically simple and reasonably accurate, has only a few parameters, and it is asymptotic to one and to zero, as the argument ranges from minus infinity to infinity (i.e. as the absorber amount increases from zero to infinity). With Eqs. (7) through (9) it provides a general band model function defined by three absorber parameters (a,n,m) and a single spectral parameter (C'). It has been shown in the literature[14] that Eq. (10) leads to a transmittance polynomial proposed earlier[21] for carbon dioxide and water vapor, which in turn arose from the strong-line limit to the classical random model. However, because of the substantive number of empirical adjustments made to the theory, not much physical significance may be attributed to the values for the parameters set in Eq. (10).

3. Numerical Modeling Method

The parameters a,n, and m for the spectral bands of each absorber, as well as the C' for each spectral interval within such bands, were obtained numerically from the transmittance data and the meteorological conditions. The numerical optimization was performed by first minimizing the error function ε, as given by

$$\varepsilon = \sum_{i=1}^{I} \sum_{j=1}^{J} \left[\tau_{ij} - \tau_{mij}\right]^2 \quad , \tag{11}$$

where τ_{ij} and τ_{mij} represent line-by-line and model transmittances, respectively, $i = 1,2,\ldots,I$ is the number of spectral intervals, and $j = 1,2,\ldots,J$ is the number of data values. The minimization was carried out by setting the partial derivatives of the error function with respect to the spectral parameters C' to zero, and calculating the C' at every frequency interval for a given set of values of the absorber parameters a,n, and m. Using Eq. (11) the partial derivatives become

$$\frac{\partial\varepsilon}{\partial C'} = 2a\ \ln(10) \sum_{j=1}^{J} D_{ij} \quad , \tag{12}$$

where:

$$D_{ij} = (\tau_{ij} - \tau_{mij})\ \tau_{mij}\ 10^{F_{ij}} \quad , \tag{13}$$

$$F_{ij} = a\ (C'_i + nP'_j + mT'_j + U'_j) \quad , \tag{14}$$

$$P'_j = \log\left(\frac{P}{P_o}\right) \quad , \tag{15}$$

$$T'_j = \log\left(\frac{T_o}{T}\right) \quad , \tag{16}$$

$$U'_j = \log U \quad . \tag{17}$$

In the second stage of the minimization of the error function in Eq. (11), the partial derivatives were taken with respect to the model parameters a,n, and m. From Eq. (11) the partial derivatives become

$$\frac{\partial\varepsilon}{\partial a} = 2\ \ln(10) \sum_{i=1}^{I} \sum_{j=1}^{J} D_{ij}\ (n\ P'_{wij} + m\ T'_{wij} + U'_{wij}) \quad , \tag{18}$$

$$\frac{\partial\varepsilon}{\partial n} = 2\ln(10) \sum_{i=1}^{I} \sum_{j=1}^{J} D_{ij}\ P'_{wij} \quad , \tag{19}$$

$$\frac{\partial \varepsilon}{\partial m} = 2\ln(10) \sum_{i=1}^{I} \sum_{j=1}^{J} D_{ij}\, T'_{wij} \quad , \tag{20}$$

where:

$$P'_{wij} = P'_j \frac{\sum_{j=1}^{J} W_{F_{ij}} P'_j}{\sum_{j=1}^{J} W_{F_{ij}}} \quad , \tag{21}$$

$$T'_{wij} = T'_j \frac{\sum_{j=1}^{J} W_{F_{ij}} T'_j}{\sum_{j=1}^{J} W_{F_{ij}}} \quad , \tag{22}$$

$$U'_{wij} = U'_j - \frac{\sum_{j=1}^{J} W_{F_{ij}} U'_j}{\sum_{j=1}^{J} W_{F_{ij}}} \quad , \tag{23}$$

$$W_{F_{ij}} = \tau^2 m_{ij}\, 10^{2F_{ij}} + D_{ij}\, (1-10^{F_{ij}}) \quad , \tag{24}$$

with P'_j, T'_j and U'_j as specified by Eqs. (15), (16), and (17), respectively.

The optimal model parameters were then computed by using the conjugate gradient algorithm[22] DFMCG available in the IBM SSP library. Three other numerical minimization procedures were also tested with the same data [23], but the one presented here (called "the weighted-average" method) gave the best results.

4. Developing Data

For the most part the parameters of the proposed band models were determined and/or validated through a combination of synthetic and measured transmittance spectra. The synthetic spectra were generated through line-by-line calculations with FASCOD1C[24], which in turn used the standard atmospheric profiles[25] and the AFGL line parameter compilation[26,27]. The measured spectra consisted of laboratory measurements available in part as digitized tables in magnetic tapes, and in part as spectral curves or figures in open literature publications and technical reports.

For each absorber in a given band, the transmittance calculations generally consisted of 10 monochromatic spectral curves along homogeneous paths at 10 different pressure levels within the standard atmospheric profiles. These were then degraded at 5 cm^{-1} intervals through Eq.(3), and the triangular filter function of 20 cm^{-1} full width at half intensity originally adopted in the development of the LOWTRAN molecular absorption models. The absorber vertical concentration for each one of the uniformly mixed gases consisted of the profiles proposed by M.S.H. Smith[17], extrapolated so as to match the 33 altitude increments of the standard atmospheric models of S.L. Valley[25]. Although the same reference for the vertical concentration profiles was used in connection with the trace gases, the mixing ratios were increased substantially such that polluted environments would be within the range of applicability of the respective band models. A plot of the concentration profiles adopted in LOWTRAN, without the increases for the trace gases, is shown in Fig.(1). In the absence of values beyond 50 km in the reference, the values at 50 km were assumed to remain constant at higher altitudes. Table I provides a numerical listing of the mixing ratios that accompany the models developed for LOWTRAN.

Transmittance calculation were also made using the same method, but for the conditions of the available measurements. In this latter type, the

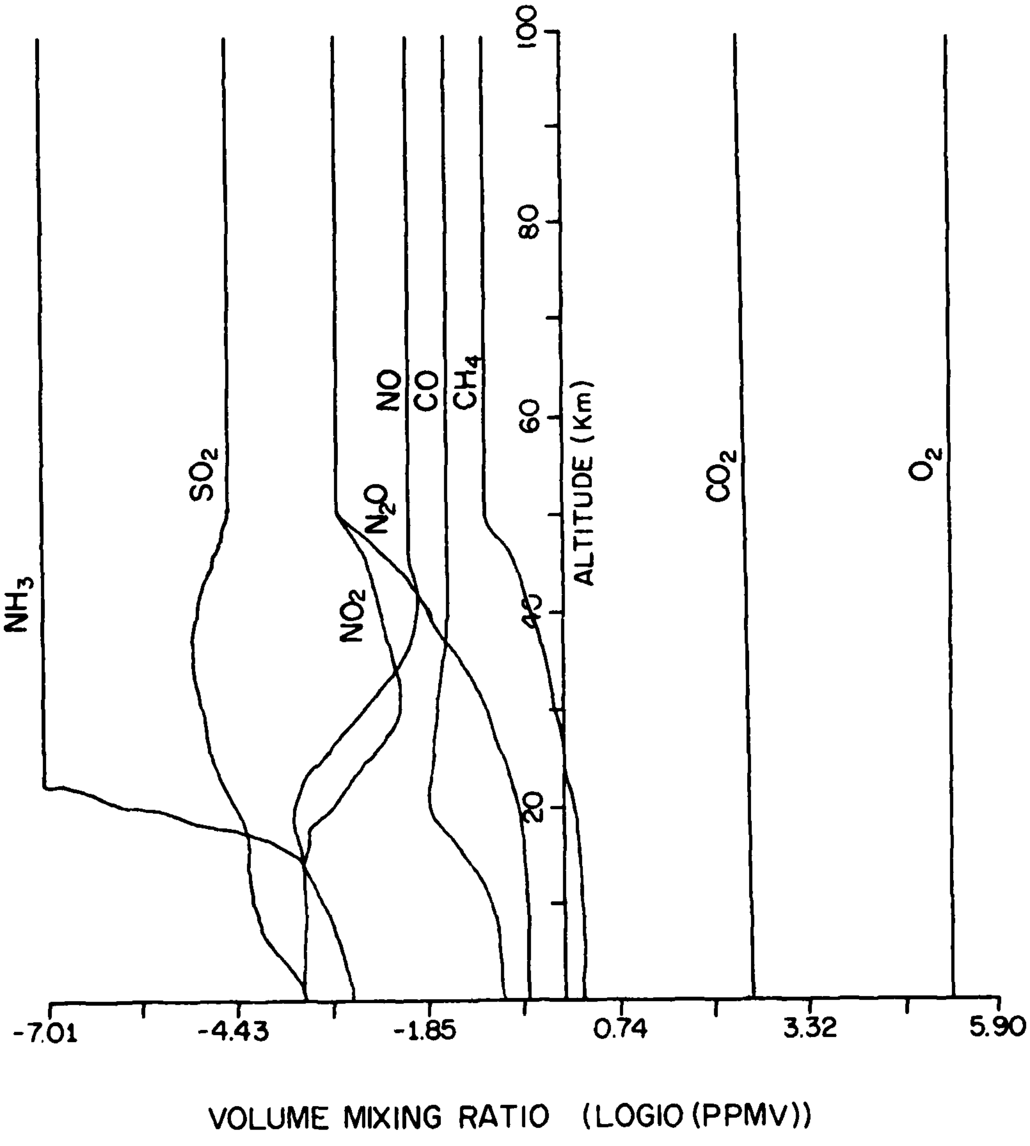

FIGURE 1

VERTICAL DISTRIBUTIONS OF THE UNIFORMLY MIXED AND TRACE GASES.

HT. KM	NO	NO2	NH3	SO2	CH4	N2O	O2	CO	CO2
	(PPMV)								
	$*10^{-2}$	$*10^{-2}$	$*10^{-3}$	$*10^{-4}$	$*10^{+0}$	$*10^{-1}$	$*10^{+5}$	$*10^{-1}$	$*10^{+2}$
0	0.0300	0.300	1.30000	3.000	1.700	3.200	2.09	1.500	3.14
1	0.0300	0.300	1.25000	2.750	1.700	3.200	2.09	1.450	3.14
2	0.0300	0.300	1.20000	2.500	1.700	3.200	2.09	1.400	3.14
3	0.0300	0.300	1.10000	1.950	1.700	3.200	2.09	1.350	3.14
4	0.0300	0.300	1.00000	1.400	1.700	3.200	2.09	1.330	3.14
5	0.0300	0.300	0.92500	1.180	1.700	3.200	2.09	1.300	3.14
6	0.0300	0.300	0.85000	0.950	1.700	3.200	2.09	1.300	3.14
7	0.0300	0.300	0.77500	0.825	1.650	3.200	2.09	1.250	3.14
8	0.0300	0.300	0.70000	0.700	1.650	3.200	2.09	1.200	3.14
9	0.0300	0.300	0.62500	0.650	1.650	3.200	2.09	1.100	3.14
10	0.0300	0.300	0.55000	0.600	1.650	3.200	2.09	1.000	3.14
11	0.0300	0.300	0.47500	0.575	1.650	3.150	2.09	0.900	3.14
12	0.0300	0.300	0.40000	0.550	1.650	3.100	2.09	0.800	3.14
13	0.0300	0.315	0.35000	0.555	1.550	3.050	2.09	0.650	3.14
14	0.0300	0.330	0.30000	0.560	1.500	3.000	2.09	0.500	3.14
15	0.0285	0.340	0.20000	0.580	1.500	2.950	2.09	0.400	3.14
16	0.0270	0.350	0.10000	0.600	1.500	2.900	2.09	0.300	3.14
17	0.0250	0.375	0.05500	0.550	1.450	2.800	2.09	0.250	3.14
18	0.0230	0.400	0.01000	0.500	1.400	2.700	2.09	0.200	3.14
19	0.0240	0.650	0.00550	0.415	1.350	2.550	2.09	0.175	3.14
20	0.0250	0.900	0.00100	0.310	1.300	2.400	2.09	0.150	3.14
21	0.0275	1.050	0.00055	0.265	1.200	2.200	2.09	0.155	3.14
22	0.0300	1.200	0.00010	0.220	1.100	2.000	2.09	0.160	3.14
23	0.0350	1.700	0.00010	0.205	1.050	1.800	2.09	0.165	3.14
24	0.0400	2.200	0.00010	0.190	1.000	1.600	2.09	0.170	3.14
25	0.0600	2.650	0.00010	0.180	0.965	1.450	2.09	0.175	3.14
30	0.2500	7.500	0.00010	0.130	0.800	0.900	2.09	0.200	3.14
35	0.8000	5.250	0.00010	0.110	0.615	0.410	2.09	0.255	3.14
40	1.0000	3.500	0.00010	0.130	0.400	0.160	2.09	0.300	3.14
45	1.0000	2.250	0.00010	0.205	0.225	0.055	2.09	0.300	3.14
50	1.0000	1.000	0.00010	0.350	0.100	0.010	2.09	0.300	3.14
70	1.0000	1.000	0.00010	0.350	0.100	0.010	2.09	0.300	3.14
100	1.0000	1.000	0.00010	0.350	0.100	0.010	2.09	0.300	3.14

Table I. Vertical mixing ratio profiles for the uniformly mixed and the trace gases as recommended for use with the 33-levels atmospheric models calculations were restricted to measured samples at conditions commonly found in atmospheric profiles. The resulting range of pressure, temperature and absorber amount are shown in Tables II and III under the column headings "CALC". For the gases in Table II both types of transmittance calculations were combined with the measurements during the development of the models. For the gases in Table III only the transmittance data from 100 atmospheric spectral curves were used in the development. The calculations at the conditions of the measurements were used strictly for the verifications of the line-by-line data, and for the validation of the models.

In dealing with measurements, use was made of the relation

$$P = (B - 1)p\, P_T \quad , \tag{24}$$

where P is the equivalent atmospheric pressure (used in FASCOD1C), B is a constant representing the ratio of the self-broadening ability of the gases to the broadening ability of N_2, p is the partial pressure of the absorber in the absorption cell, and P_T is the total gaseous pressure of the gas mixture in the cell. The values of B adopted for the transmitttance calculations involving N_2O, CH_4, CO, CO_2, NO, NO_2, NH_3, and SO_2 were, respectively, 1.24, 1.29, 1.02, 0.94, 1.31, 1.00, 1.00, 6.20, and 5.00[28-36]. Likewise, the absorber amount was calculated using the expression

$$U(\text{atm.cm}) = 0.00224M\, Z\, \frac{\rho_a}{m_a} \quad , \tag{25}$$

where ρ_a in g/m^3 is the air density, Z in km is the path length, m_a is the molecular weight of air, and M in parts per million by volume is the gas mixing ratio.

RANGE OF MODEL DATA

ABSORBER	SPECTRAL RANGE (CM^{-1})	PRESSURE (ATM) MEAS.	PRESSURE (ATM) CALC.	TEMPERATURE (K) MEAS.	TEMPERATURE (K) CALC.	ABSORBER (ATM.CM) MEAS.	ABSORBER (ATM.CM) CALC.	REFERENCE FOR MEASUREMENTS
	425-850							
	855-1460							
	1820-2830							
CARBON	3070-3755							
DIOXIDE	3760-4105	0.100E-1	0.117E-1	216	217	0.804E-1	0.856E-2	
(CO_2)	4535-5375	To	To	To	To	To	To	28,29,30,31
	5920-7025	1.000E+0	1.000E+0	310	288	0.235E+5	0.300E+5	
	7395-7820							
	8000-8345							
METHANE	1075-1775	0.100E-0	0.102E+0	302	217	0.922E-1	0.997E-1	
	2370-3230	To	To	To	To	To	To	28
(CH_4)	4105-4730	1.000E+0	1.000E+0	310	300	1.375E-1	1.359E+2	
NITROGEN	1540-1670	0.663E-1	0.551E-1	298	217	0.823E-2	0.948E-3	
DIOXIDE		To	To	To	To	To	To	32
(NO_2)	2840-2950	1.000E+0	1.000E+0	328	288	0.919E+0	0.119E+0	
NITROUS	500-755	0.515E-4	0.102E+0	296	217	0.686E-3	0.962E-3	
OXIDE	1100-1370	To	To	To	To	To	To	28
(N_2O)	2105-2630	0.484E+0	1.000E+0	301	300	0.387E+3	0.829E+2	
SULPHUR	420-635	0.500E-1	0.102E+0	296	217	0.186E-1	0.987E-2	
DIOXIDE	1050-1440	TO	To	To	To	To	To	33
(SO_2)	2430-2565	1.000E+0	1.000E+0	298	300	0.584E+1	0.290E+2	

Table II. Range of the calculated and measured transmittance data used in the development and validation of the band models for the indicated gaseous absorbers.

RANGE OF MODEL DATA

ABSORBER	SPECTRAL RANGE (CM^{-1})	PRESSURE (ATM) MEAS.	PRESSURE (ATM) CALC.	TEMPERATURE (K) MEAS.	TEMPERATURE (K) CALC.	ABSORBER (ATM.CM) MEAS.	ABSORBER (ATM.CM) CALC.	REFERENCE FOR MEASUREMENTS
AMMONIA	660-1260	0.163E+0	0.102E+0	300	217	0.935E-2	0.962E-2	
(NH_3)	1300-1900	To	To		To	To	To	34
		0.824E+0	1.000E+0		300	0.308E+0	0.180E+1	
CARBON	1955-2280	0.304E+0	0.102E+0	300	230	0.730E-1	0.350E-1	
MONOXIDE		To	To		To	To	To	28
(CO)	4055-4365	1.000E+0	1.000E+0		300	0.143E+3	0.275E+3	
NITRIC	1700-1995	0.136E-1	0.546E-1	300	217	0.772E-1	0.619E-3	
OXIDE		To	To		To	To	To	35
(NO)		0.966E+0	1.000E+0		288	0.310E-0	0.310E+0	
OXYGEN	7760-8020	0.940E+0	0.102E+0		217	0.274E+4	0.489E+3	
			To	300	To	To	To	36
(O_2)	12930-13190		1.000E+0		300	0.219E+6	0.256E+9	

Table III. Range of the calculated and measured transmittance data used in the validation of the band models for the indicated gaseous absorbers.

Two types of measured laboratory transmittance spectra were available during the development of the band models. One type consisted of tape provided by AFGL, and the other data measured by the authors of the references listed in Tables II and III. These data were available for CO_2, CH_4, NO_2, N_2O, and SO_2. The spectral range, pressure, temperature and absorber amount characterizing the data samples adopted from the tapes for these gases, are also shown in Table II. These high resolution data were first degraded to the 20 cm^{-1} resolution, and then combined with the calculated transmittance data, during the determination of the model parameters. For the most part the spectral range for a given band model was dictated by the boundaries of the absorption band, as observed in either the measurements or the calculations. However, for CO_2 several spectral ranges had to be specified within the infrared region because of the large amount of data involved, and because of the desire of keeping the modeling accuracy within one or two percent. The spectral coverage that was found reasonable for use with the numerical determination of a given set of model parameters was 500 cm^{-1}. Using this criterion, CO_2 was modeled through nine different models, as specified in Table II.

The other type of laboratory measured transmittance spectra was available in the form of graphs in research reports and in open literature articles. These data existed for NH_3, CO, NO and O_2. Because of their nature they were unsuitable for inclusion in the model development and, hence, they were used for model validation only.

5. Band Model Development

The numerical procedures discussed in a previous section were adopted and used with the available transmittance data in order to determine the band model parameters, a, n, m and the C's for the eleven gases.

The main results of the analyses are summarized in Table IV and V and in the appendices. Table IV presents the modeling results for all those gases for which there were both calculated, and digitized transmittance specta. Table V presents the modeling results for all those gases for which there were only calculated spectra for inclusion in the numerical method. The available graphical data were later used in the model validation. Figures (2) and (3) are composite plots of the transmission curves for the uniformly mixed and for the trace gases, respectively. Individual plots of the transmission functions for these gases may be found in Appendix A. The spectral parameters C' at 5 cm^{-1} for all the absorber, both in tables and graphical forms, are also provided in Appendix A.

6. Transmittance Comparisons

Before the model parameters were determined comparisons were made between line-by-line calculations and measured transmittance spectra. The transmittance calculations were made with FASCOD1C, which used Eq. (4) for homogeneous paths, together with the absorption coefficient most suitable to the atmospheric height of interest. Magnetic tapes containing high resolution measured data were available from AFGL for each one of the five gases CO_2, CH_4, NO_2 N_2O, and SO_2. Only graphical representations were available for the measured spectra of the remaining gases NH_3, CO, NO, and O_2. The types of comparisons and model developments that were accomplished are summarized in Table VI.

In connection with the gases for which measured transmittance data were available in tapes, extensive sets of comparisons with line-by-line data were made. Firstly, the monochromatic calculations were degraded

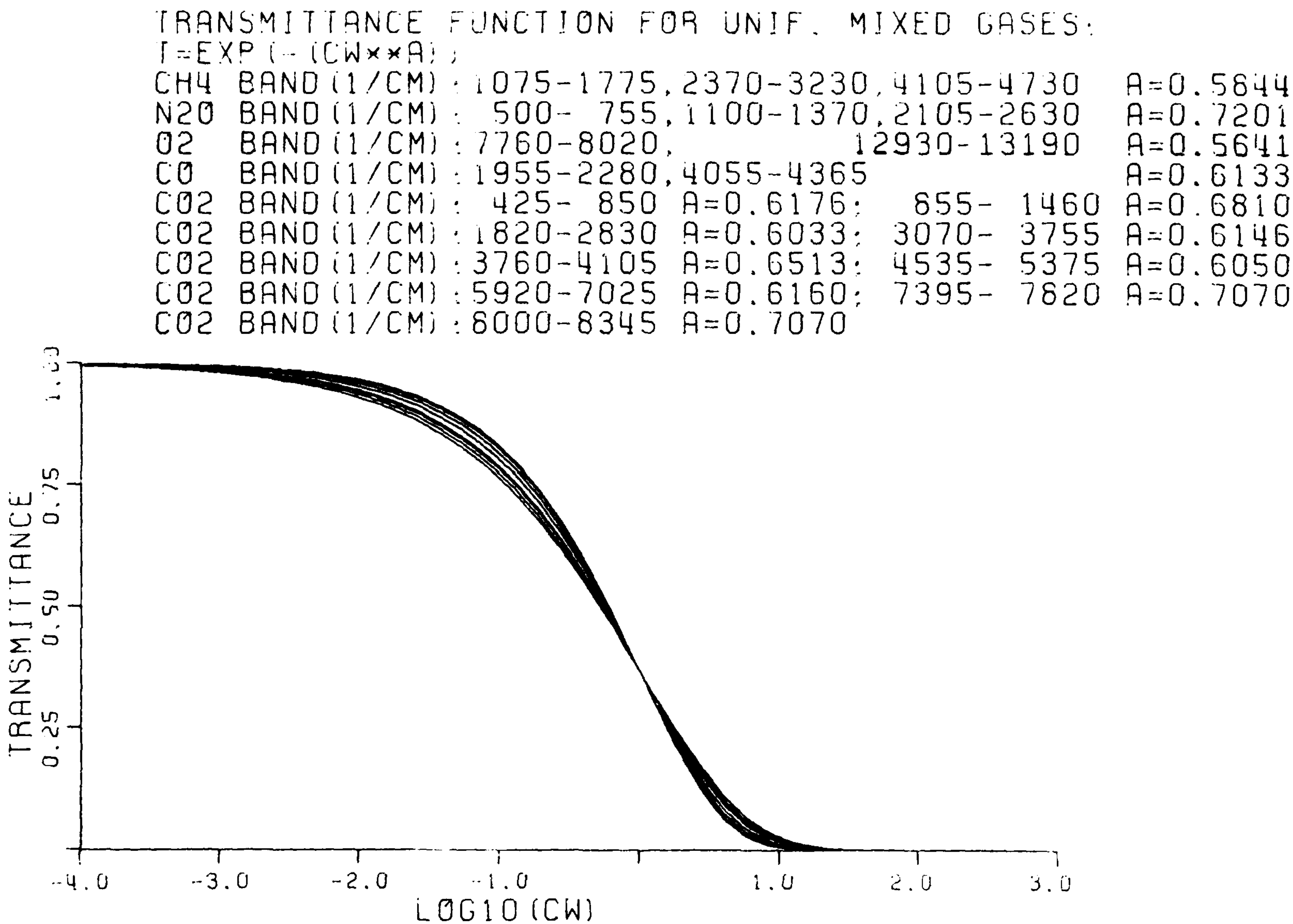

Fig. 2. Composite plot of the transmission functions for the uniformly mixed gases using Eqs. (7) through (10). The upper curve is for N_2O with a=0.7201.

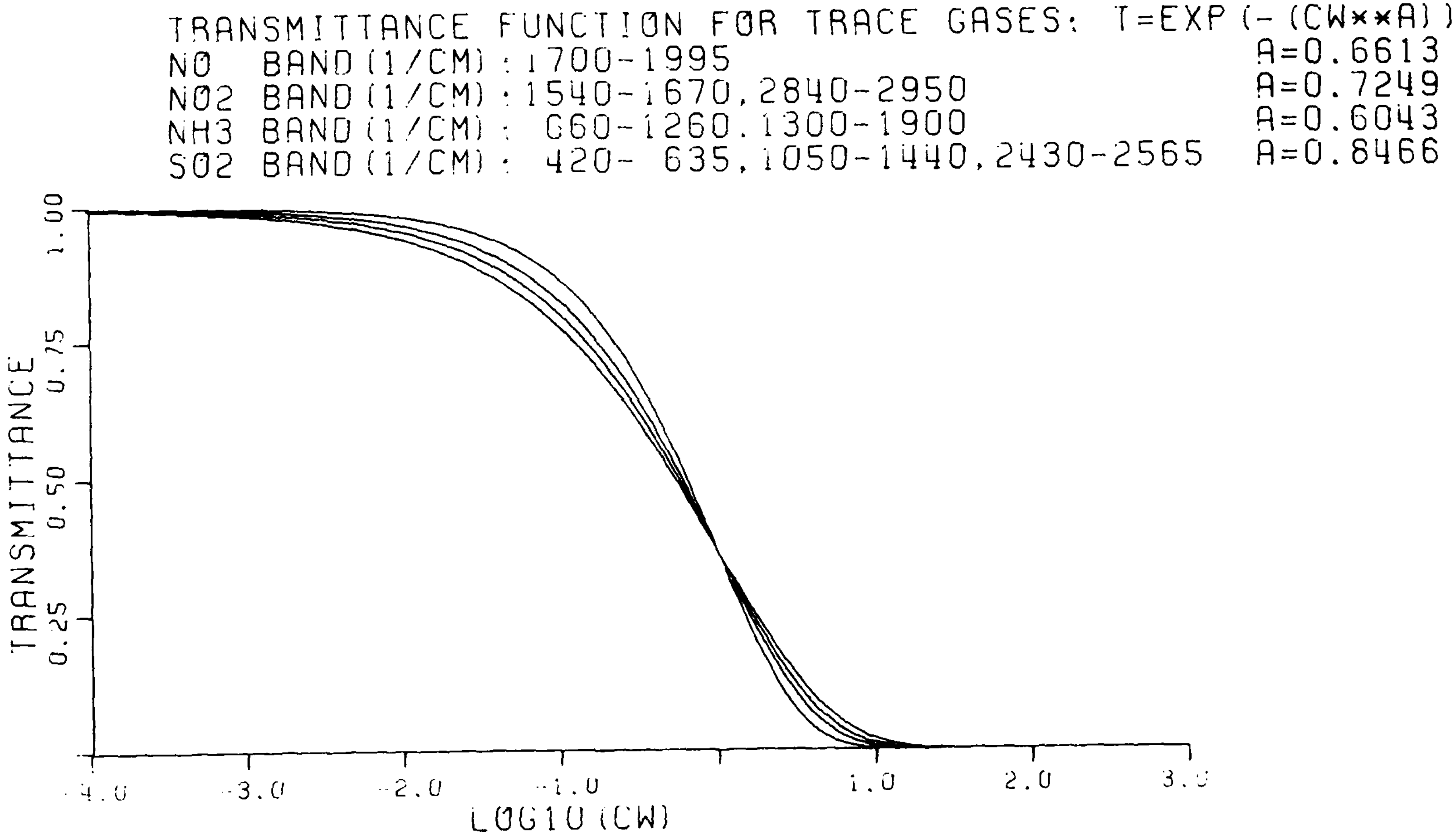

Fig. 3. Composite plot of the transmission functions for the trace gases using Eqs.(7) through (10). The upper curve is for SO_2 with a=0.8466.

ABSORBER	SPECTRAL RANGE (CM^{-1})	ABSORBER MODEL PARAMETERS a	n	m	RMS TRANSMITTANCE DEVIATION (%)
CARBON DIOXIDE (CO_2)	425-850	0.6176	0.6705	-2.2560	1.84
	855-1460	0.6810	0.7038	-5.0768	2.18
	1820-2830	0.6033	0.7258	-1.6740	2.27
	3070-3755	0.6146	0.6982	-1.8107	1.95
	3760-4105	0.6513	0.8867	-0.5327	2.49
	4535-5375	0.6050	0.7883	-1.320	3.33
	5920-7025	0.6160	0.6899	-0.8152	1.28
	7395-7820 8000-8345	0.7070	0.6035	0.6026	0.30
METHANE (CH_4)	1075-1775 2370-3230 4175-4730	0.5844	0.7139	-0.4185	1.56
NITROGEN DIOXIDE (NO_2)	1540-1670 2840-2950	0.7249	0.3956	-0.0545	2.40
NITROUS OXIDE (NO_2)	500-755 1100-1370 2105-2630	0.7201	0.7203	-0.1836	1.49
SULPHUR DIOXIDE (SO_2)	420-635 1050-1440 2430-2565	0.8466	0.2135	0.0733	2.38

Table IV. Band model parameters as obtained with the numerical methods presented in the text, and mixture of calculated and laboratory measured transmittance data.

ABSORBER	SPECTRAL RANGE (CM^{-1})	ABSORBER MODEL PARAMETERS			RMS TRANSMITTANCE DEVIATION (%)
		a	n	m	
AMMONIA (NH_3)	660-1260 1300-1900	0.6043	0.8272	0.5768	0.76
CARBON MONOXIDE (CO)	1955-2280 4055-4365	0.6133	0.9267	0.1716	0.71
NITRIC OXIDE (NO)	1700-1995	0.6613	0.5265	-0.4702	0.31
OXYGEN (O_2)	7760-8020 12930-13190	0.5641	0.9353	0.1936	0.96

Table V. Band model parameters as obtained with the numerical methods presented in the text, and strictly line-by-line calculated transmittance data.

ABSORBER	NUMBER OF BANDS MODELED	NUMBER OF BAND MODELS	COMPARISONS WITH MEASUREMENTS	FINAL MODEL DEVELOPMENT		REFERENCE FOR MEASUREMENTS
				LINE-BY-LINE	MIXED	
AMMONIA (NH_3)	1	1	YES	YES	NOT POSSIBLE	34
CARBON DIOXIDE (CO_2)	17	9	YES	YES	YES	28,29,30,31
CARBON MONOXIDE (CO)	2	1	YES	YES	NOT POSSIBLE	28
METHANE (CH_4)	3	1	YES	YES	YES	28
NITRIC OXIDE (NO)	1	1	YES	YES	NOT POSSIBLE	35
NITROGEN DIOXIDE (NO_2)	3	1	YES	YES	YES	32
NITROUS OXIDE (N_2O)	3	1	YES	YES	YES	28
OXYGEN (O_2)	2	1	YES	YES	NOT POSSIBLE	36
SULPHUR DIOXIDE (SO_2)	3	1	YES	YES	YES	33

Table VI. Summary of the types of model development and validation conducted in the band model generation for the uniformly mixed and the trace gases.

to approximately the resolution of the measurements, and compared for all cases in which the conditions of the measurements were close to typical atmospheric environments. The purpose of these comparisons was to establish the source of any observed discrepancies, as possibly originating in the line parameter compilation. These were published in a series of internal progress reports to AFGL (see References 37 through 45). Secondly, both the transmittance calculations and the measurements were degraded to the spectral resolution of LOWTRAN and compared again. For this purpose use was made of Eqs. (3) and (4), with a triangular filter function ϕ of 20 cm^{-1} full-width at half-intensity. The results of these comparisons were incorporated in the cited references. Samples of these comparisons for CO_2, CH_4, NO_2, N_2O, and SO_2 are shown in Appendix B. For each figure number part "a" compares monochromatic line-by-line calculations with high resolution measurements, while part "b" compares their degraded counterparts.

Once the transmittance comparisons were accomplished, both the tape measurements and the calculated transmittances were put together in a transmittance data bank. The data were then substituted in Eqs. (11) through (24) for the purpose of determining the absorber and spectral model parameters. The model parameters were then used in Eqs. (7) through (10) in order to compare the resulting band models with the degraded line-by-line and/or measured transmittance data. While the complete results of these final comparisons were included in References 37 through 45, some sample comparisons are shown in Appendix C.

In connection with the gases for which measured transmittance spectra were available only in graphical form, the comparisons with line by line calculations were more restrictive. For this purpose the resolution of the calculations was reduced to approximately those of the measurements.

This was followed by an attempt to plot the calculations on the same dimensional scale as the measurements. Appendix D shows some typical cases of such comparisons. Because of this limitation, the models for CO, NH_3, NO and O_2 were developed strictly using line-by-line calculated transmittance data.

Once the measured and the calculated transmittances for these latter gases were compared, calculations were made using the developed model at the conditions of the measurements. The purpose of this was to determine how well the model predicted the measurements, even though the measurements were not used in the determination of the model parameters. Appendix E contain some typical cases of such comparisons.

7. Discussion and Conclusions

The principal purpose of the work reported here was to develop and validate molecular transmittance band models, with line-by-line calculated and measured transmittance spectra, for the uniformly mixed gases N_2O, CH_4, CO, O_2 and CO_2, and for the trace gases NO, NO_2, NH_3 and SO_2. Since the models were intended for inclusion in LOWTRAN, they are for 20 cm^{-1} resolution spectra and are represented by a simple double exponential function characterized at 5 cm^{-1} intervals by a single spectral parameter. Use was made of well established, nonlinear optimization techniques in the parmeterization of the transmission function. An overall rms average transmittance deviation of 1.68% was obtained between the developing data and the data reproduced with the models.

Because of the availability of two basic forms for the measured data, the process of developement and validation took different approaches. Digitized data were available in magnetic tapes for CO_2, CH_4, NO_2, N_2O, and SO_2. Hence, the models for these gases were developed with a mixture of line-by-line data computed with FASCOD1C, and the measured data. In these cases transmittance comparisons were made between the original high-resolution measurements and line-by-line calculations at similar resolutions, between 20 cm^{-1} degraded measurements and line-by-line calculations, between degraded line-by-line and band model calculations, and between degraded measurements and band model calculations. Samples of these comparisons are included in the appendices, and show generally excellent agreement.

Graphical data in the forms of spectral curves were available in the literature for NH_3, CO, NO and O_2. Since these data were not in digital form the corresponding models were developed using line-by-line calculated transmittances only. In these cases transmittance comparisons were made between the original high resolution measurements and line-by-line calculations at similar resolutions, between degraded line-by-line and band model calculations, and between degraded line-by-line at the conditions of the measurements and band model calculation. Samples of these comparisons are included in the Appendix, and show generally excellent agreement.

Upon the completion of the band models, these were incorporated into LOWTRAN 6, together with a corresponding set of average vertical mixing ratio profiles. Numerous types of calculations were then made for several types of atmospheric paths, which included the uniformly mixed gases both as separate models and combined, the trace gases for a simulated polluted environment, the model for the uniformly mixed gases presently in LOWTRAN, and all the standard atmosphere models. Appendix F includes samples of transmittance calculations using the models for the uniformly mixed gases, both separately and combined, for a path tangent to the earth's surface from one end of the U.S. Standard atmosphere to the other, using the proposed vertical mixing ratio profiles. The set of figures also include a comparison between the present model and the proposed models for the uniformly mixed gases, along a vertical path in which use was made in both cases of uniform concentrations of 0.28, 1.6, 0.075, 2.095 x 10^5, and 330 ppmv for N_2O, CH_4, CO, O_2 and CO_2, respectively. The mean rms deviation over the entire spectrum between the existing and proposed models are 6.51 and 1.24%, for the tangent and vertical paths, respectively.

Transmittance calculations using the models for the trace gases were also made for several types of atmospheric paths and all the standard atmospheres. Samples of these calculations for the case of a slant path in the U.S. Standard atmosphere are included in Appendix G. These calculations were made with the proposed mixing ratio profiles. However, because of the small amount of absorption with the use of the standard profiles, the models for these gases are primarily proposed for use in polluted environments. In such cases the user would insert his/her own mixing ratio profile in LOWTRAN, through the proper change in the control cards for this code.

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APPENDIX A

Data on the Uniformly Mixed and the Trace Gases

1. Plots of the Transmission Functions
2. Spectral Plots of the Spectral Parameter C'
3. Tables of the Spectral Paramener C'

Figure A 1

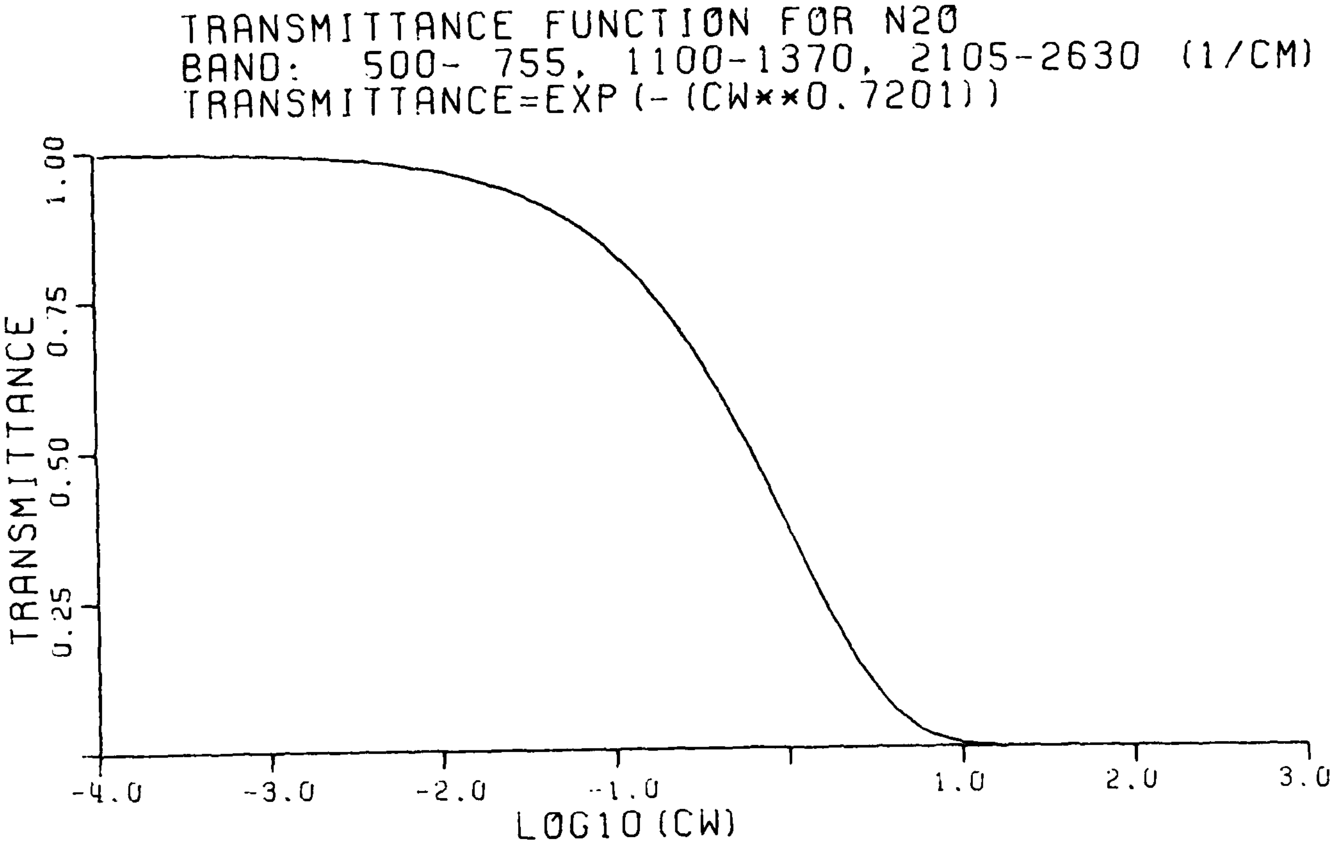

TRANSMITTANCE FUNCTION FOR N2O
BAND: 500- 755, 1100-1370, 2105-2630 (1/CM)
TRANSMITTANCE=EXP(-(CW**0.7201))
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LOG10(CW)

Figure A2

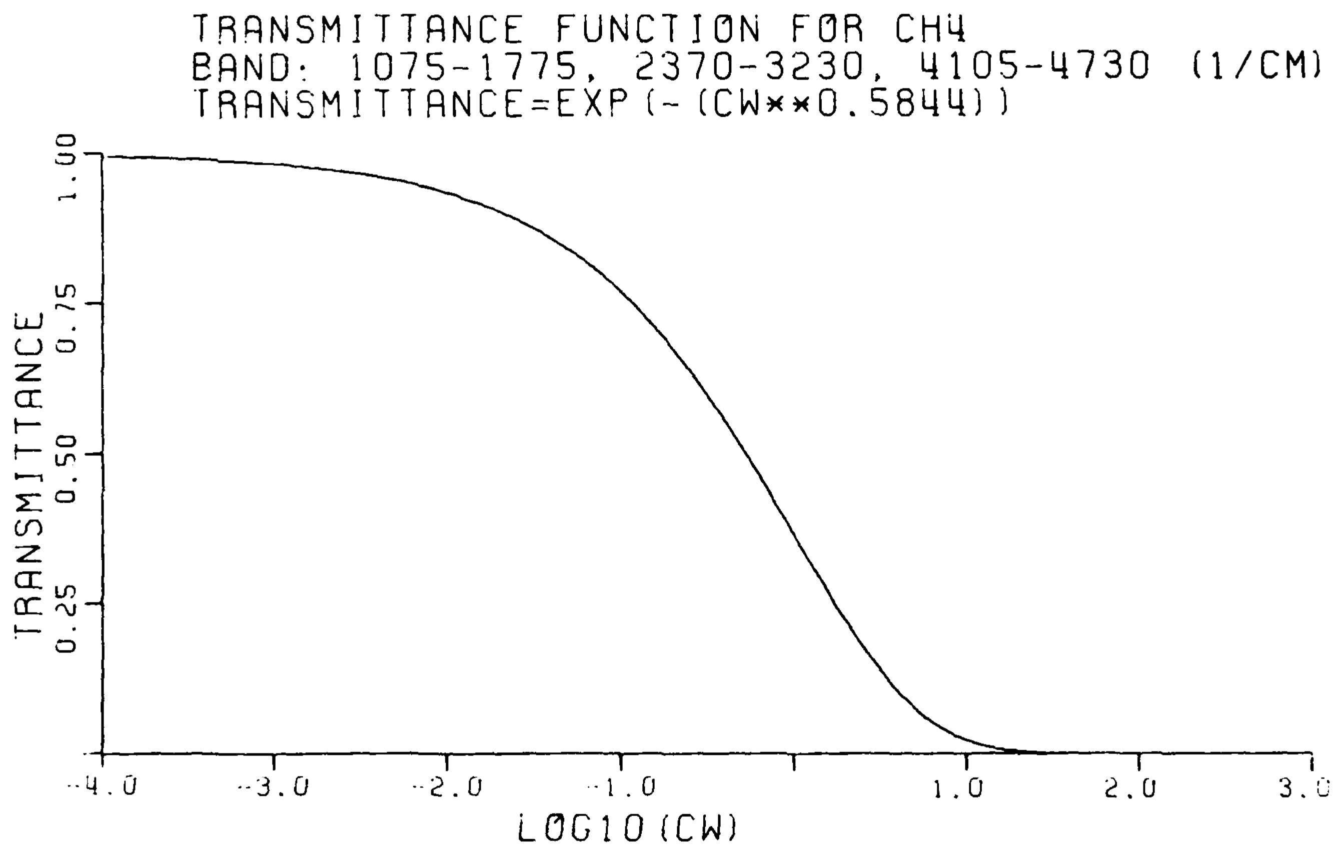

TRANSMITTANCE FUNCTION FOR CH4
BAND: 1075-1775, 2370-3230, 4105-4730 (1/CM)
TRANSMITTANCE=EXP(-(CW**0.5844))
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LOG10(CW)

Figure A3

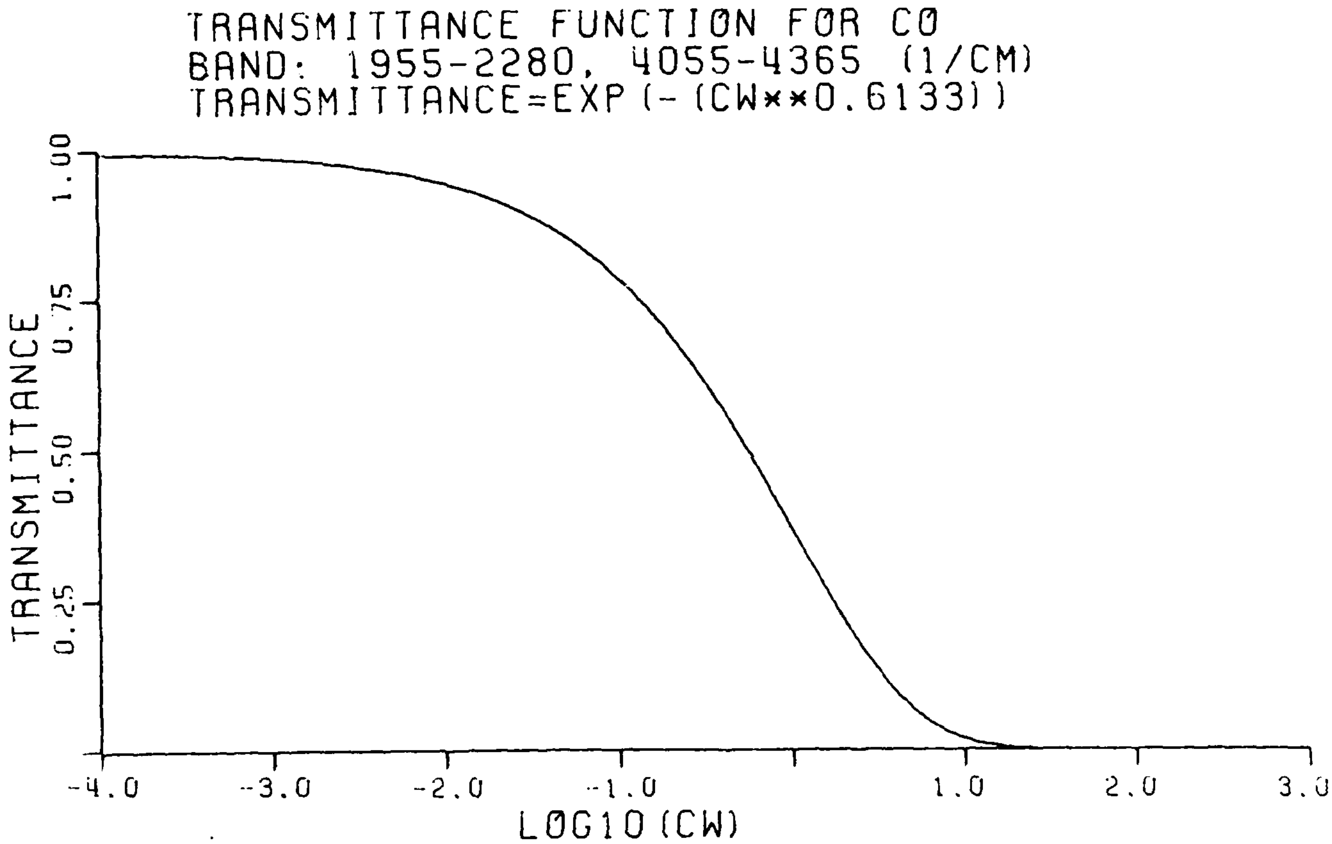

TRANSMITTANCE FUNCTION FOR CO
BAND: 1955-2280, 4055-4365 (1/CM)
TRANSMITTANCE=EXP(-(CW**0.6133))
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LOG10(CW)

Figure A4

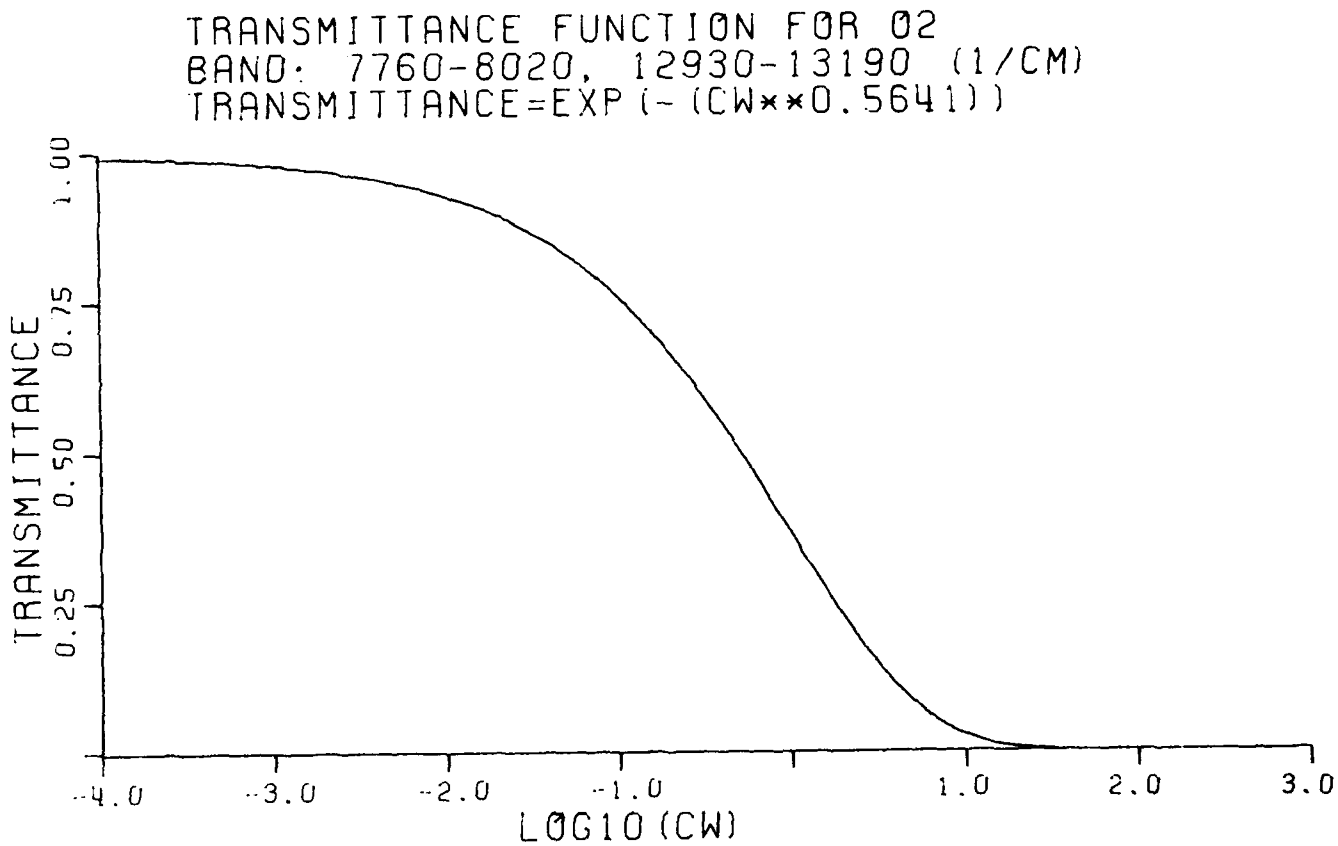
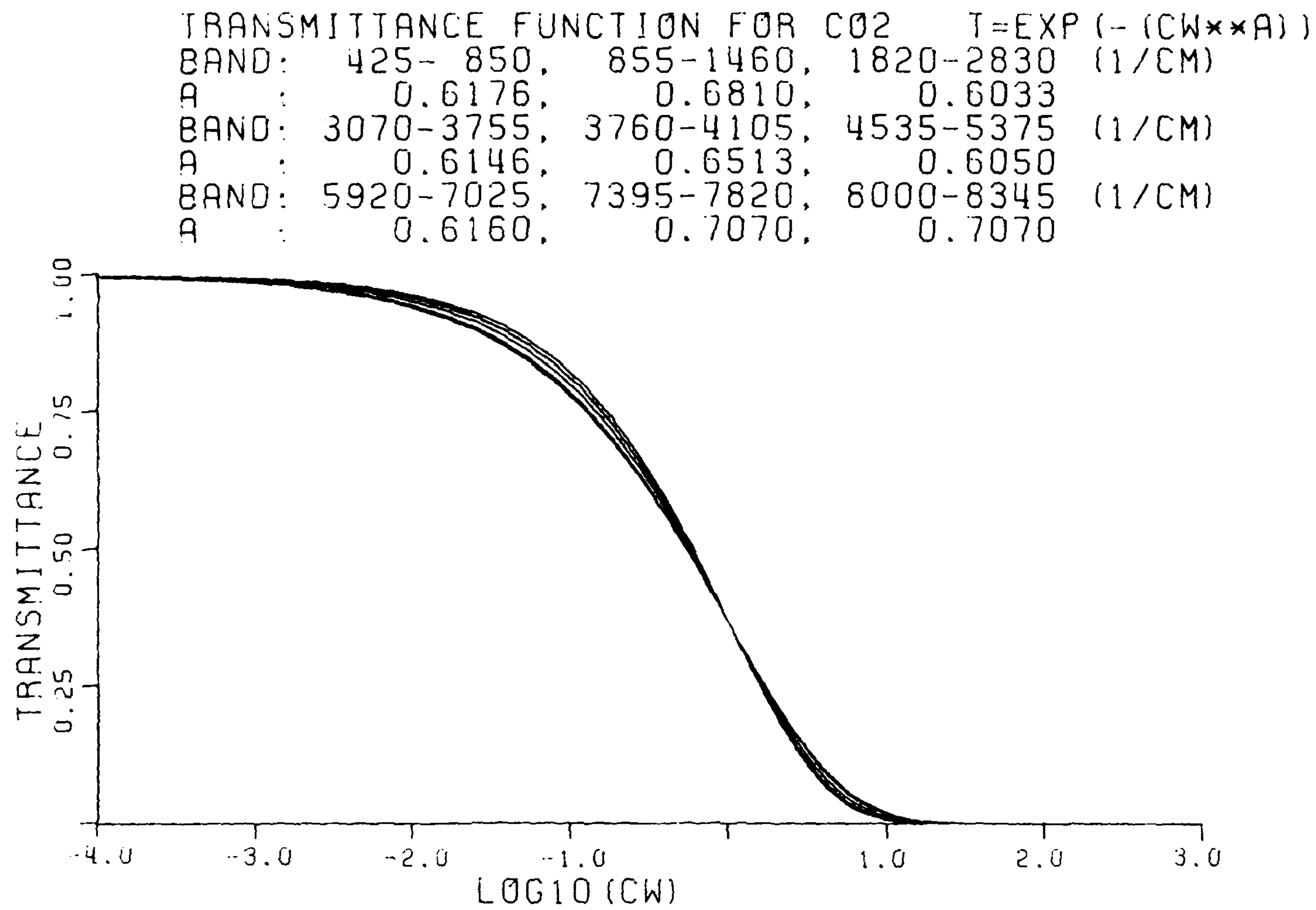

TRANSMITTANCE FUNCTION FOR O2
BAND: 7760-8020, 12930-13190 (1/CM)
TRANSMITTANCE=EXP(-(CW**0.5641))
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LOG10(CW)

Figure A5



TRANSMITTANCE FUNCTION FOR CO2 T=EXP(-(CW**A))
BAND: 425- 850, 855-1460, 1820-2830 (1/CM)
A : 0.6176, 0.6810, 0.6033
BAND: 3070-3755, 3760-4105, 4535-5375 (1/CM)
A : 0.6146, 0.6513, 0.6050
BAND: 5920-7025, 7395-7820, 8000-8345 (1/CM)
A : 0.6160, 0.7070, 0.7070
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LOG10(CW)

Figure A6

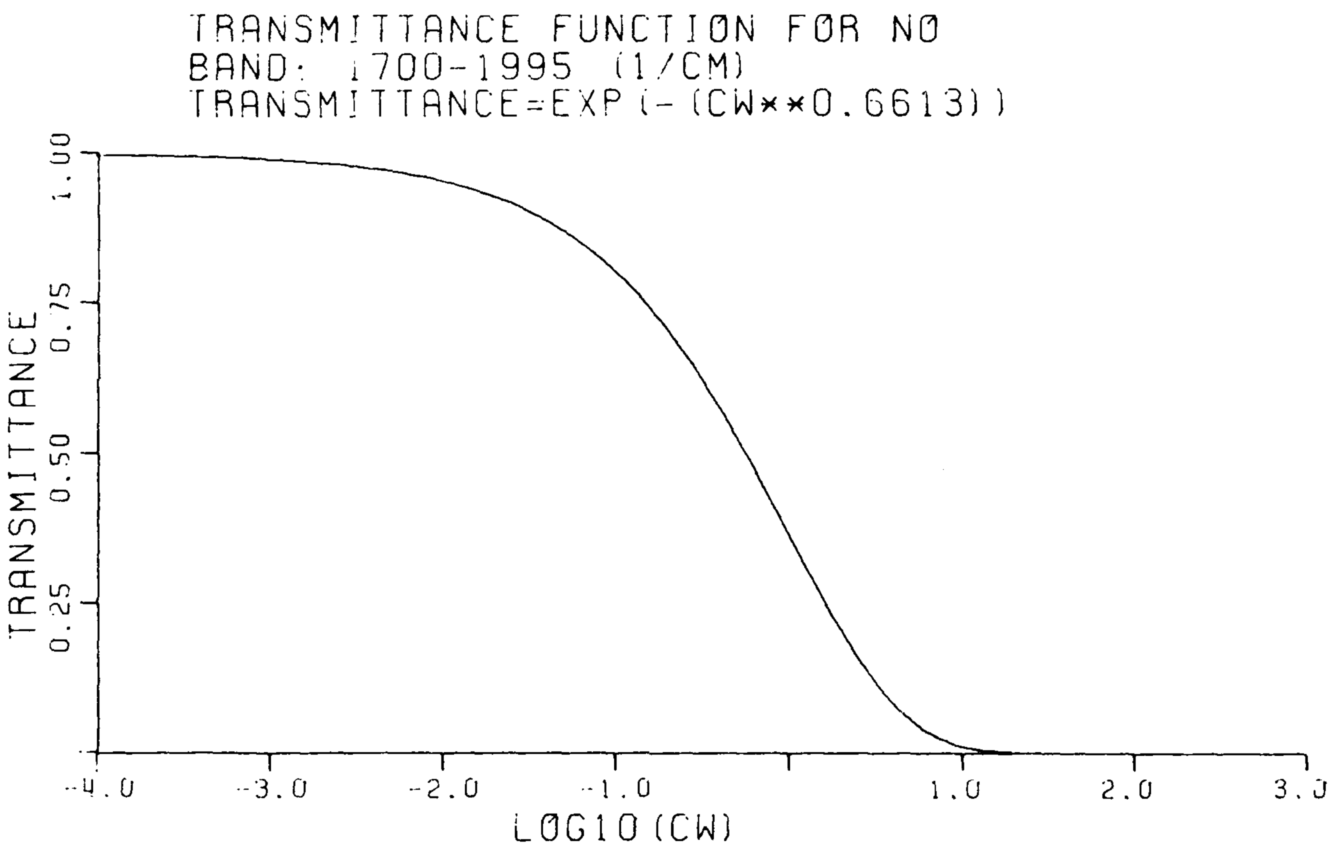
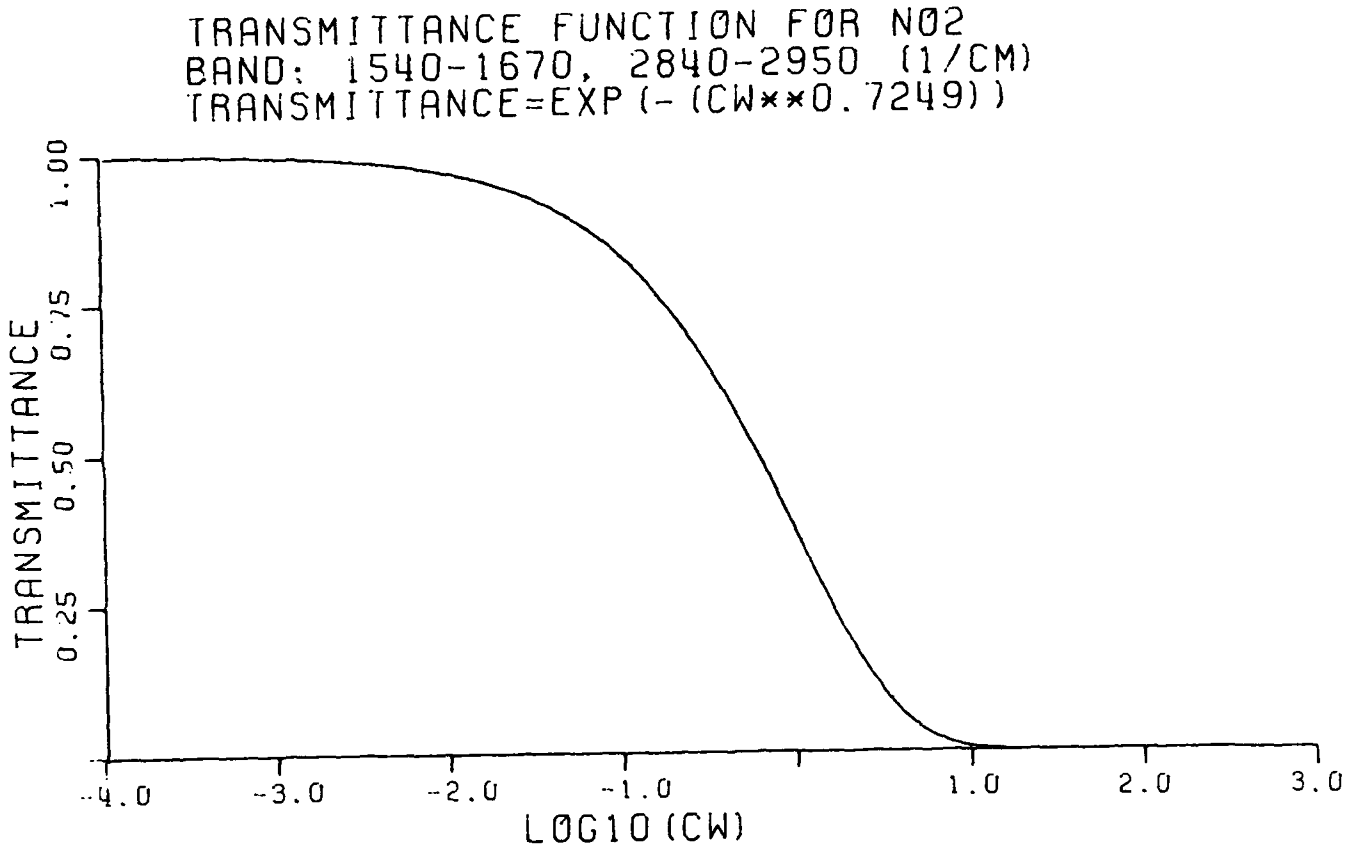

TRANSMITTANCE FUNCTION FØR NO
BAND: 1700-1995 (1/CM)
TRANSMITTANCE=EXP(-(CW**0.6613))
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LØG10(CW)

Figure A7



TRANSMITTANCE FUNCTION FOR NO2
BAND: 1540-1670, 2840-2950 (1/CM)
TRANSMITTANCE=EXP(-(CW**0.7249))
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LOG10(CW)

Figure A8

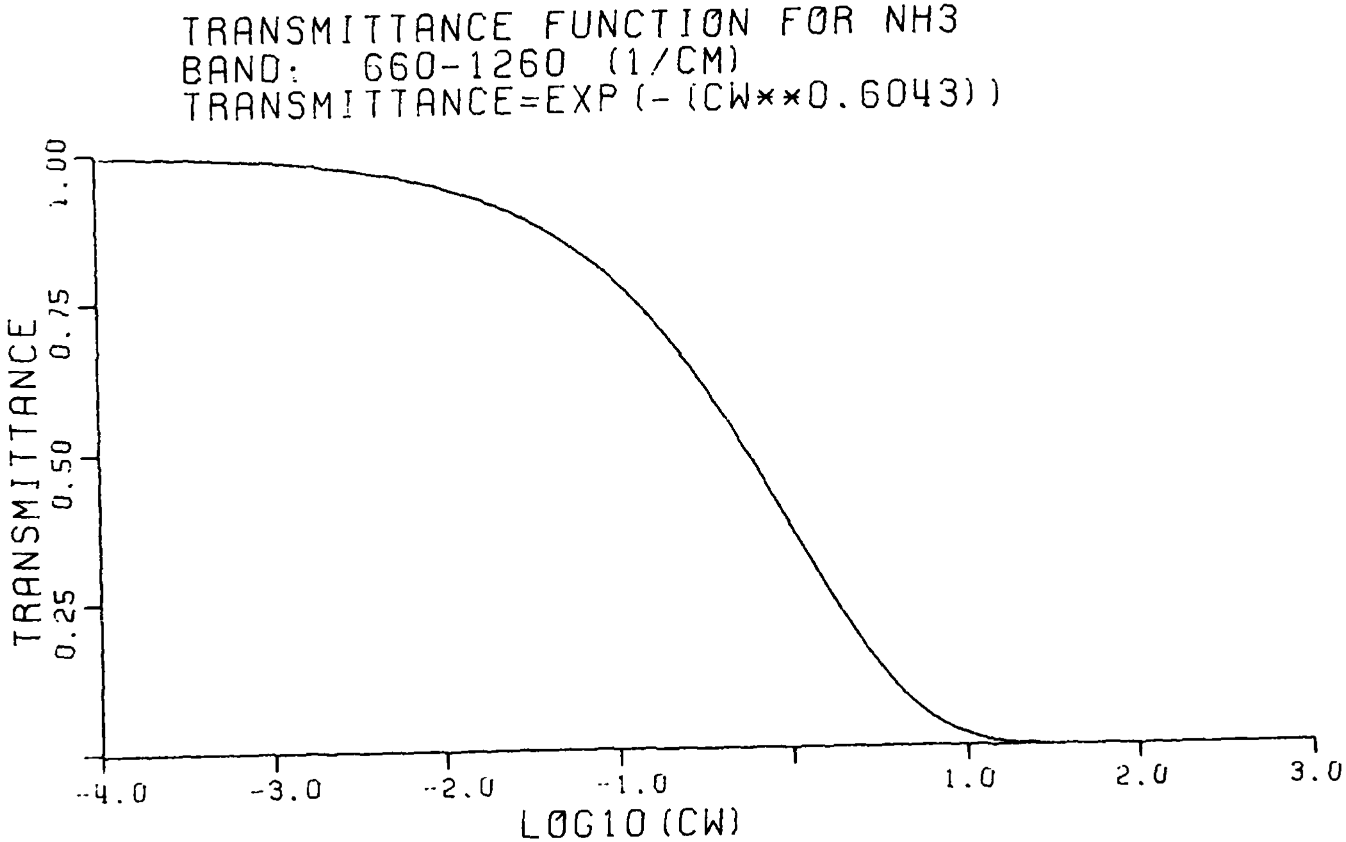

TRANSMITTANCE FUNCTION FØR NH3
BAND: 660-1260 (1/CM)
TRANSMITTANCE=EXP(-(CW**0.6043))
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LØG10(CW)

Figure A9

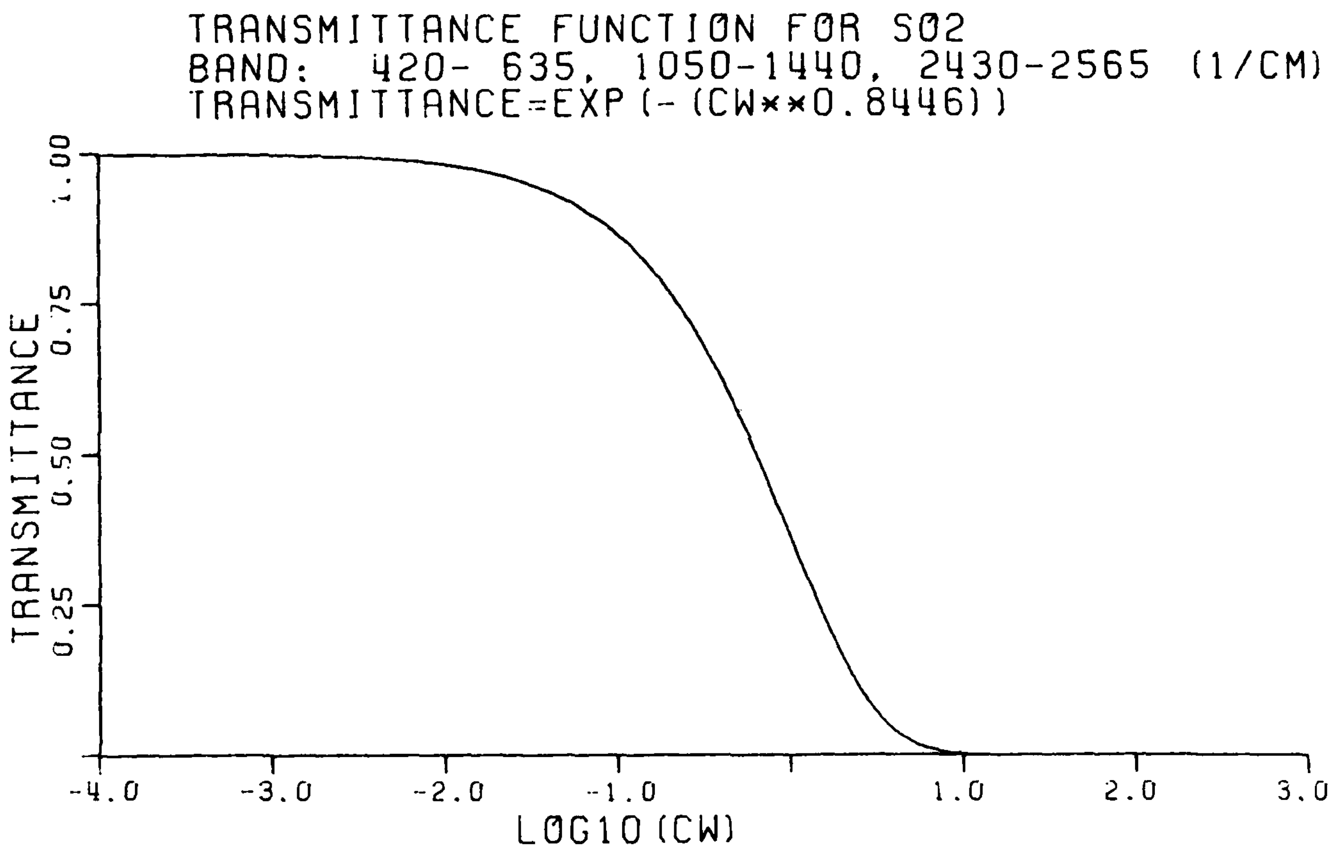

TRANSMITTANCE FUNCTION FOR SO2
BAND: 420- 635, 1050-1440, 2430-2565 (1/CM)
TRANSMITTANCE=EXP(-(CW**0.8446))
TRANSMITTANCE
1.00
0.75
0.50
0.25
-4.0
-3.0
-2.0
-1.0
1.0
2.0
3.0
LOG10(CW)

Figure A10

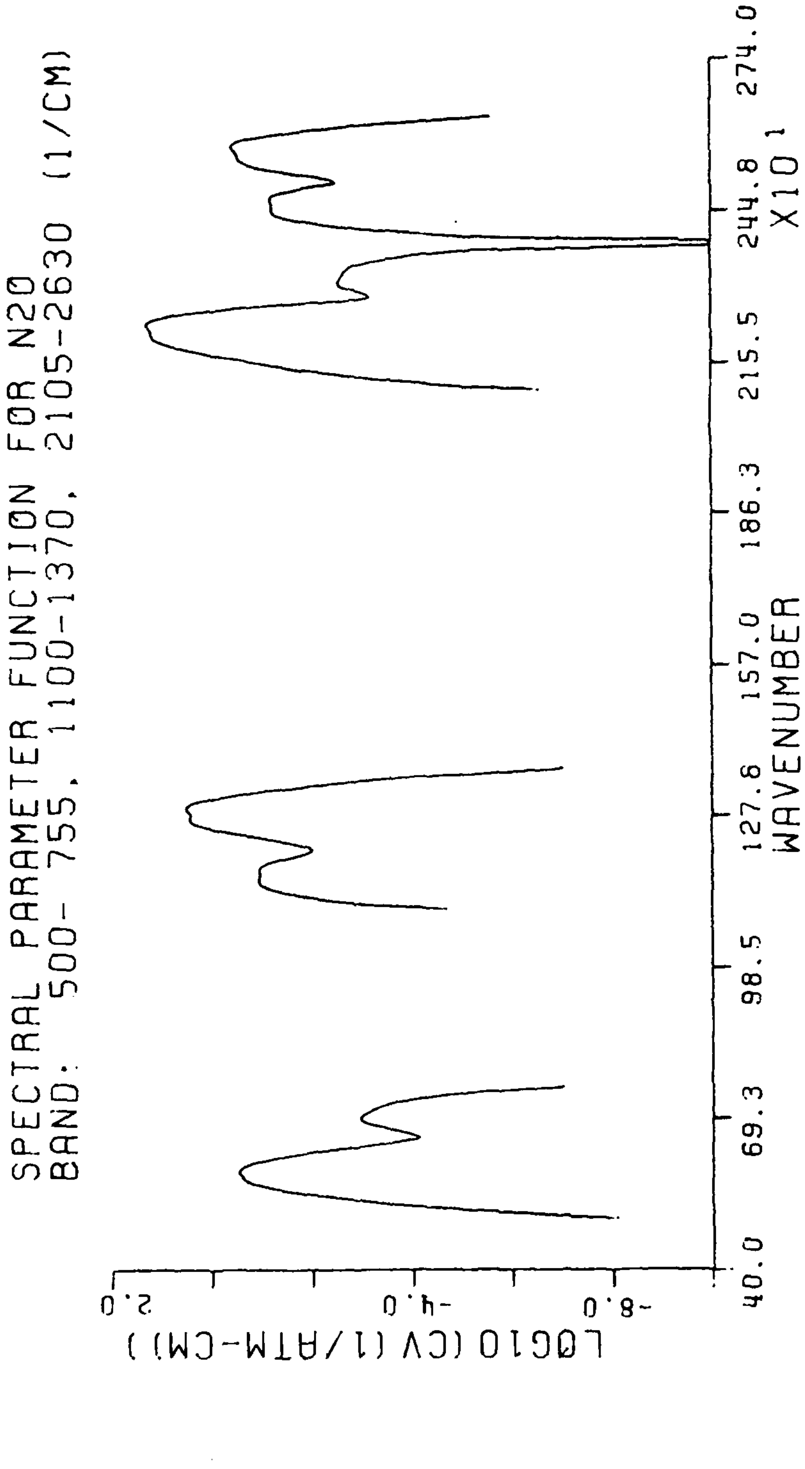

SPECTRAL PARAMETER FUNCTION FOR N2O
BAND: 500- 755, 1100-1370, 2105-2630 (1/CM)
LOG10(CV(1/ATM-CM))
2.0
-4.0
-8.0
40.0
69.3
98.5
127.8
157.0
186.3
215.5
244.8
274.0
X10 1
WAVENUMBER

Figure A11

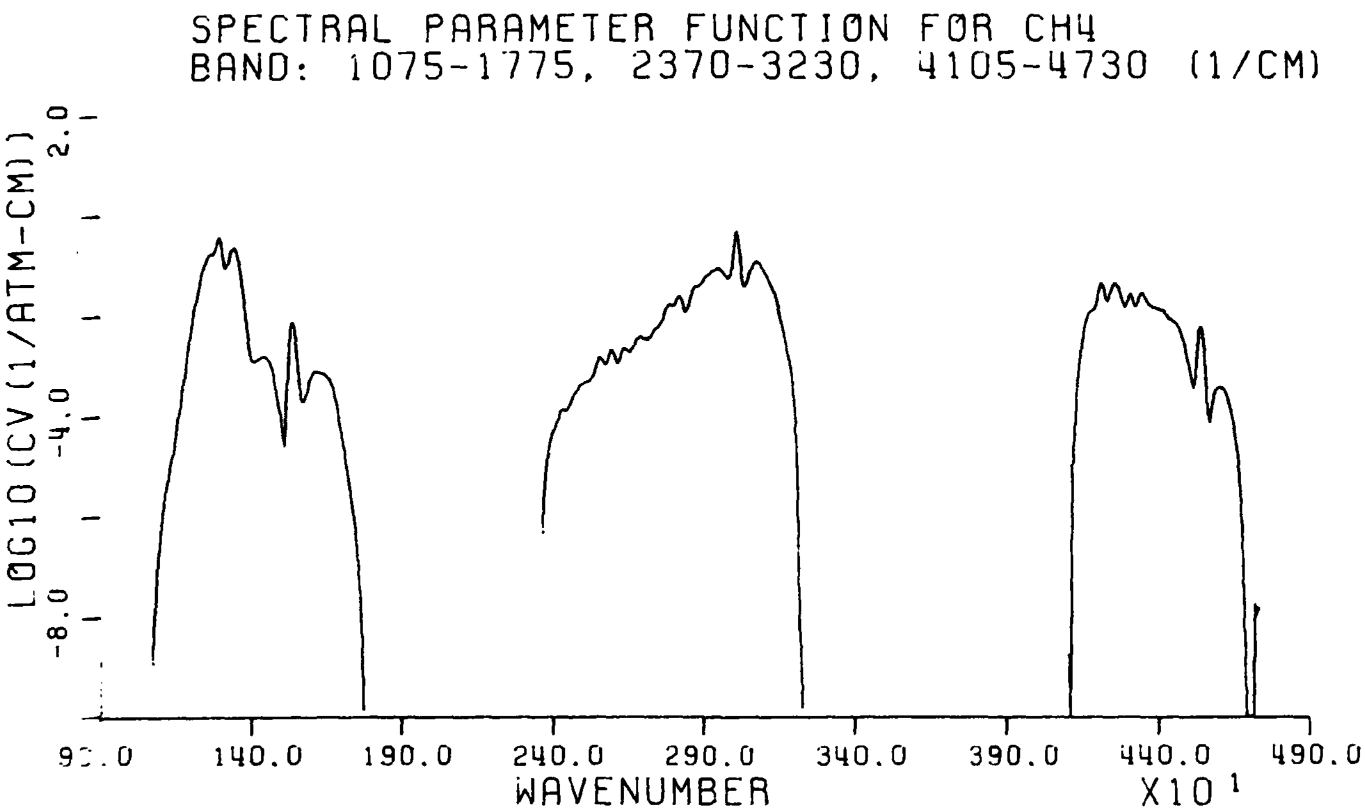

SPECTRAL PARAMETER FUNCTION FOR CH4
BAND: 1075-1775, 2370-3230, 4105-4730 (1/CM)
LOG10(CV(1/ATM-CM))
2.0
-4.0
-8.0
140.0
190.0
240.0
290.0
340.0
390.0
440.0
490.0
WAVENUMBER
X10 1

Figure A12

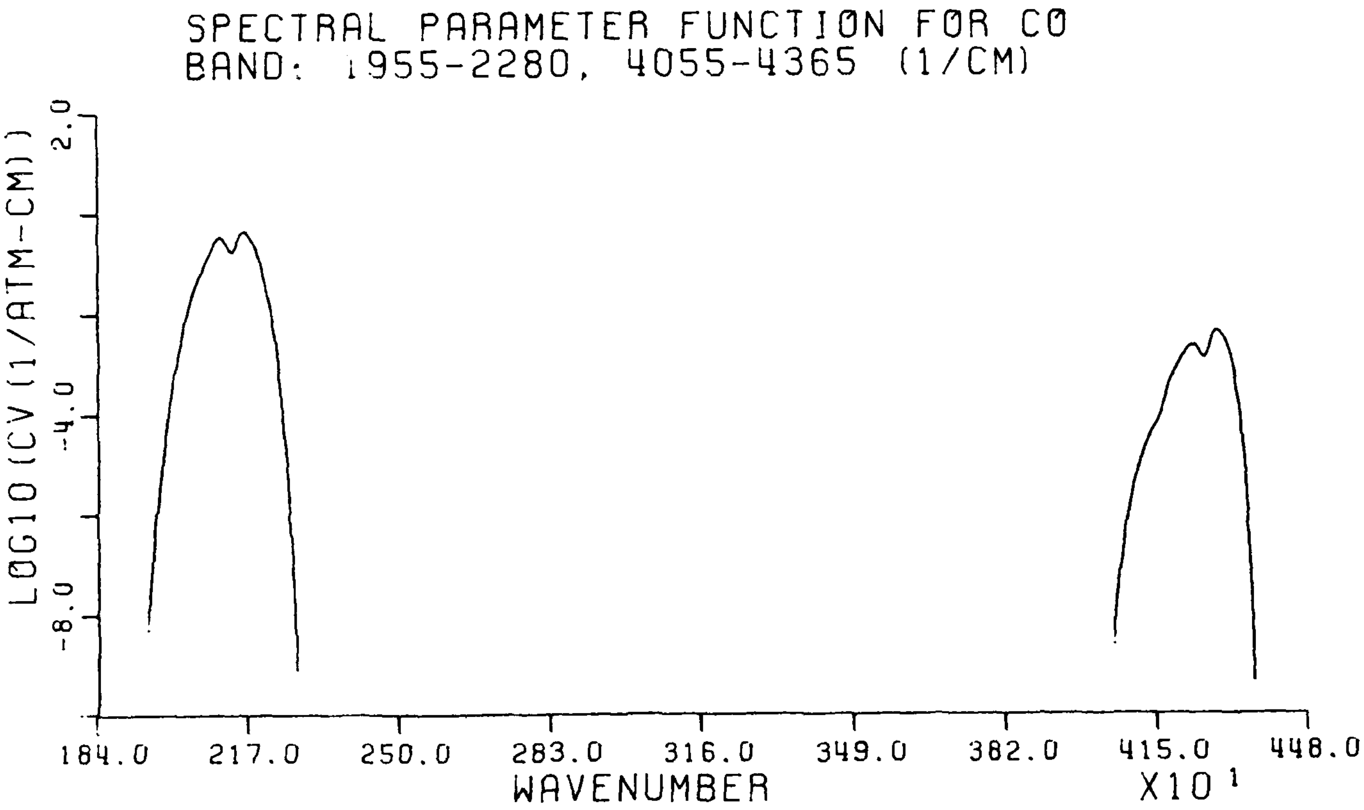
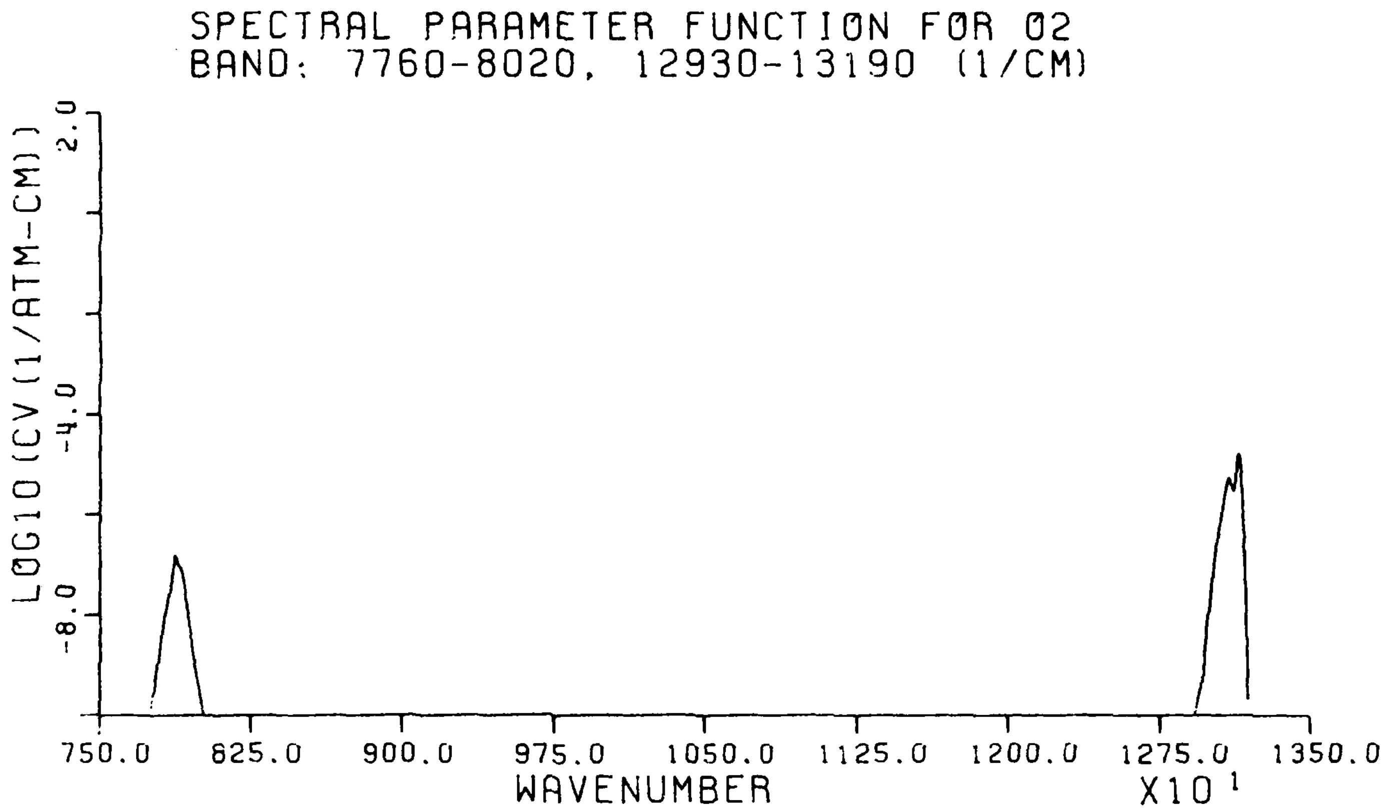

SPECTRAL PARAMETER FUNCTION FOR CO
BAND: 1955-2280, 4055-4365 (1/CM)
LOG10 (CV (1/ATM-CM))
2.0
-4.0
-8.0
184.0
217.0
250.0
283.0
316.0
349.0
382.0
415.0
448.0
WAVENUMBER
X10 1

Figure A13



SPECTRAL PARAMETER FUNCTION FØR O2
BAND: 7760-8020, 12930-13190 (1/CM)
LOG10(CV(1/ATM-CM))
2.0
-4.0
-8.0
750.0
825.0
900.0
975.0
1050.0
1125.0
1200.0
1275.0
1350.0
WAVENUMBER
X10 1

Figure A14

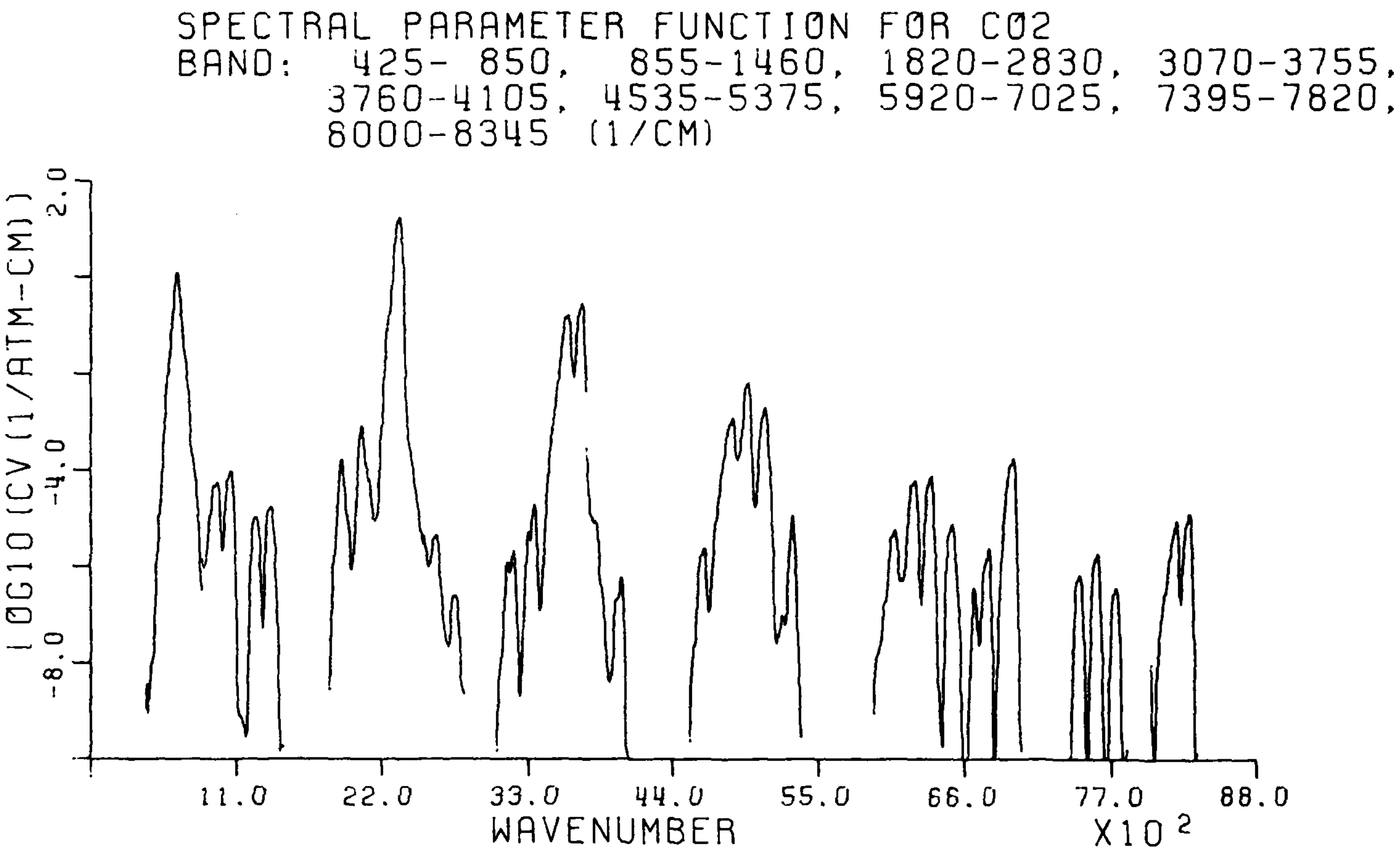
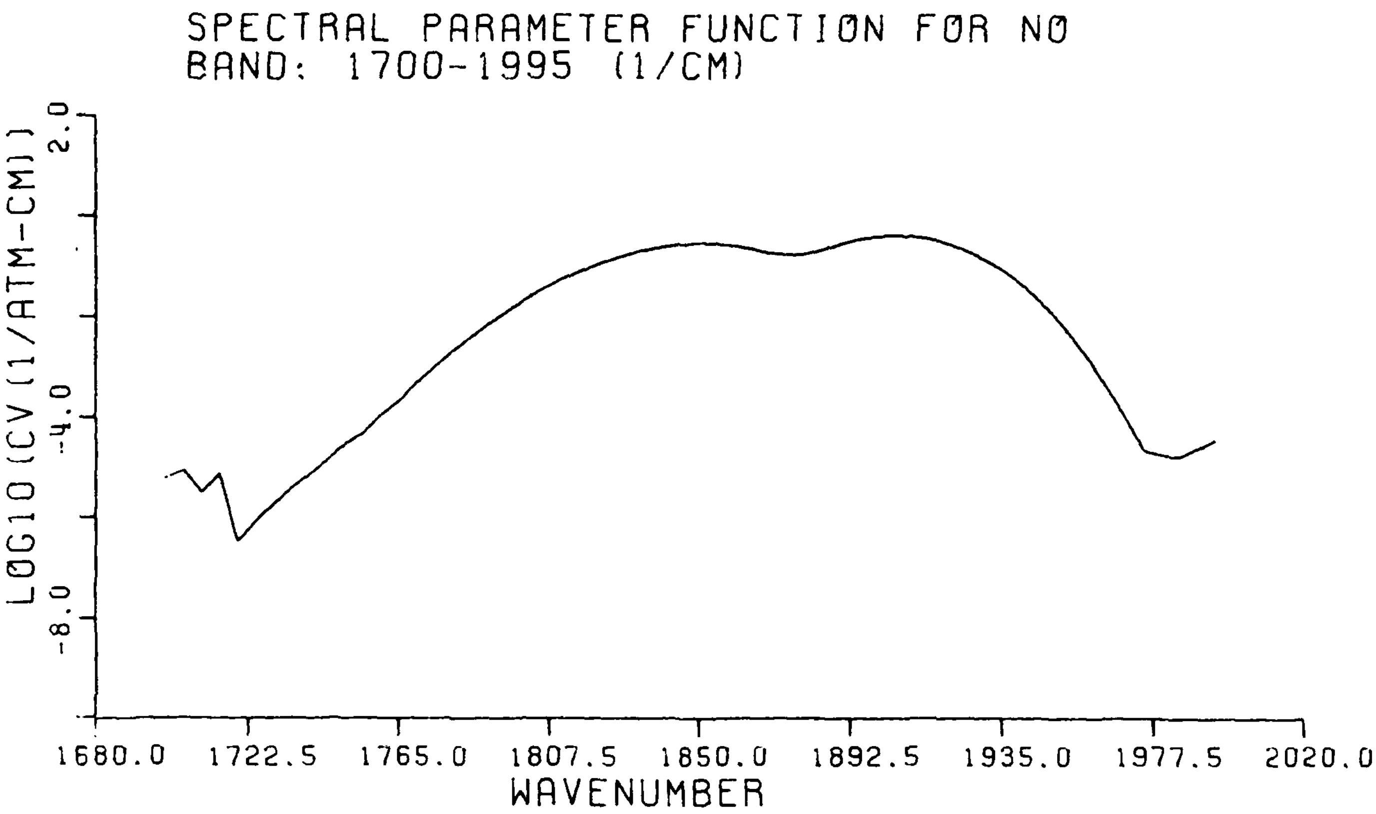
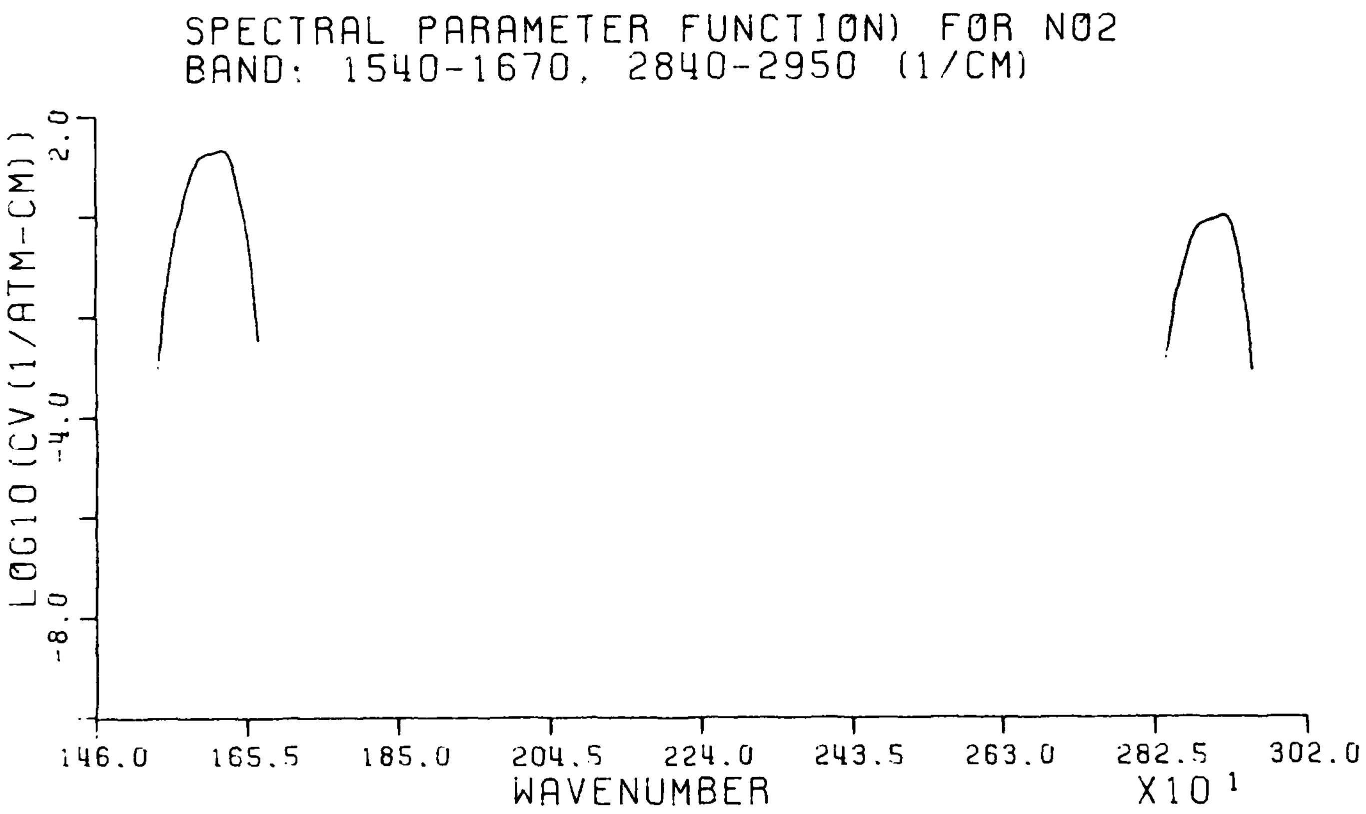

SPECTRAL PARAMETER FUNCTION FOR CØ2
BAND: 425- 850, 855-1460, 1820-2830, 3070-3755, 3760-4105, 4535-5375, 5920-7025, 7395-7820, 8000-8345 (1/CM)
LOG10(CV(1/ATM-CM))
2.0
-4.0
-8.0
11.0
22.0
33.0
44.0
55.0
66.0
77.0
88.0
WAVENUMBER
X10 2

Figure A15



SPECTRAL PARAMETER FUNCTION FØR NØ
BAND: 1700-1995 (1/CM)
LØG10(CV(1/ATM-CM))
2.0
-4.0
-8.0
1680.0
1722.5
1765.0
1807.5
1850.0
1892.5
1935.0
1977.5
2020.0
WAVENUMBER

Figure A16



SPECTRAL PARAMETER FUNCTION) FOR NO2
BAND: 1540-1670, 2840-2950 (1/CM)
LOG10(CV(1/ATM-CM))
2.0
-4.0
-8.0
146.0
165.5
185.0
204.5
224.0
243.5
263.0
282.5
302.0
WAVENUMBER
X10 1

Figure A17

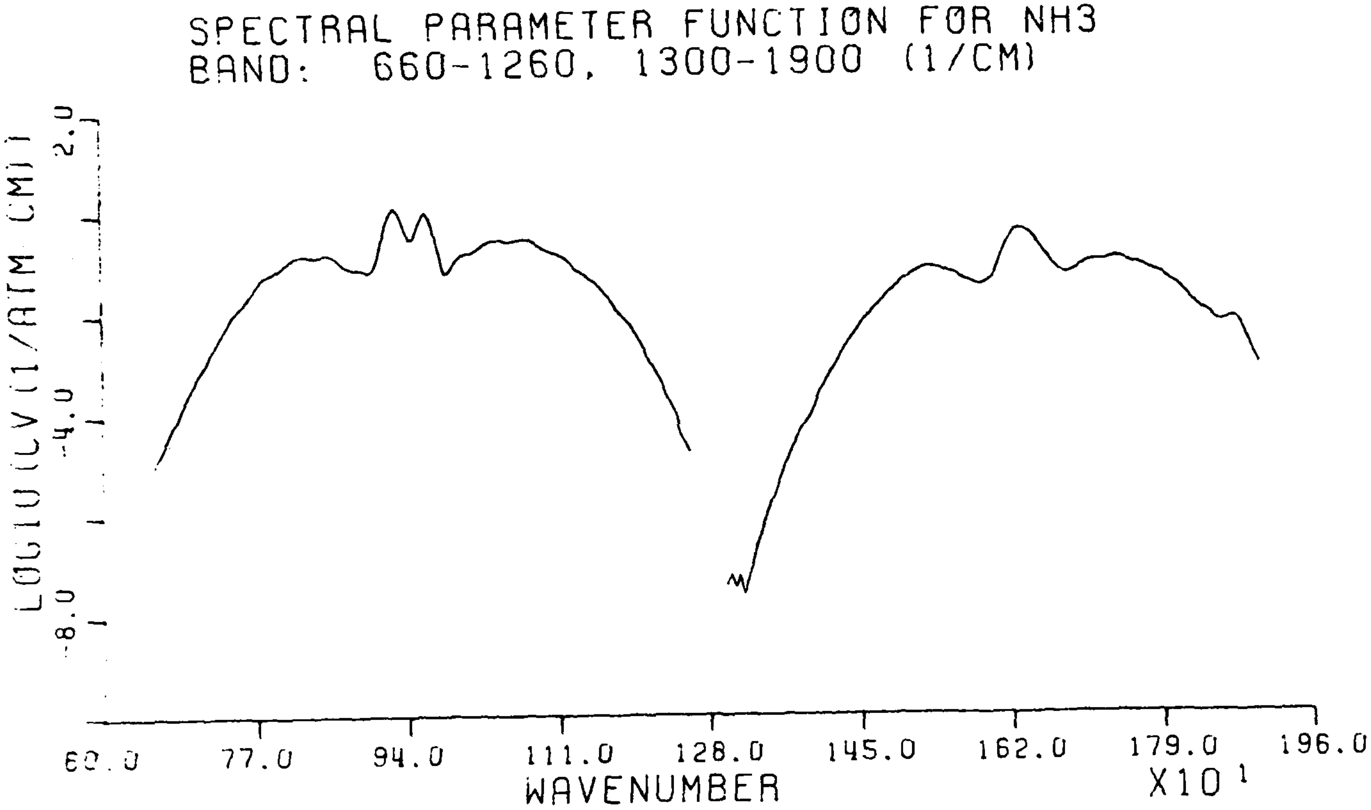

SPECTRAL PARAMETER FUNCTION FOR NH3
BAND: 660-1260, 1300-1900 (1/CM)
LOG10(CV(1/ATM CM))
2.0
-4.0
-8.0
60.0
77.0
94.0
111.0
128.0
145.0
162.0
179.0
196.0
WAVENUMBER
X10 1

Figure A18

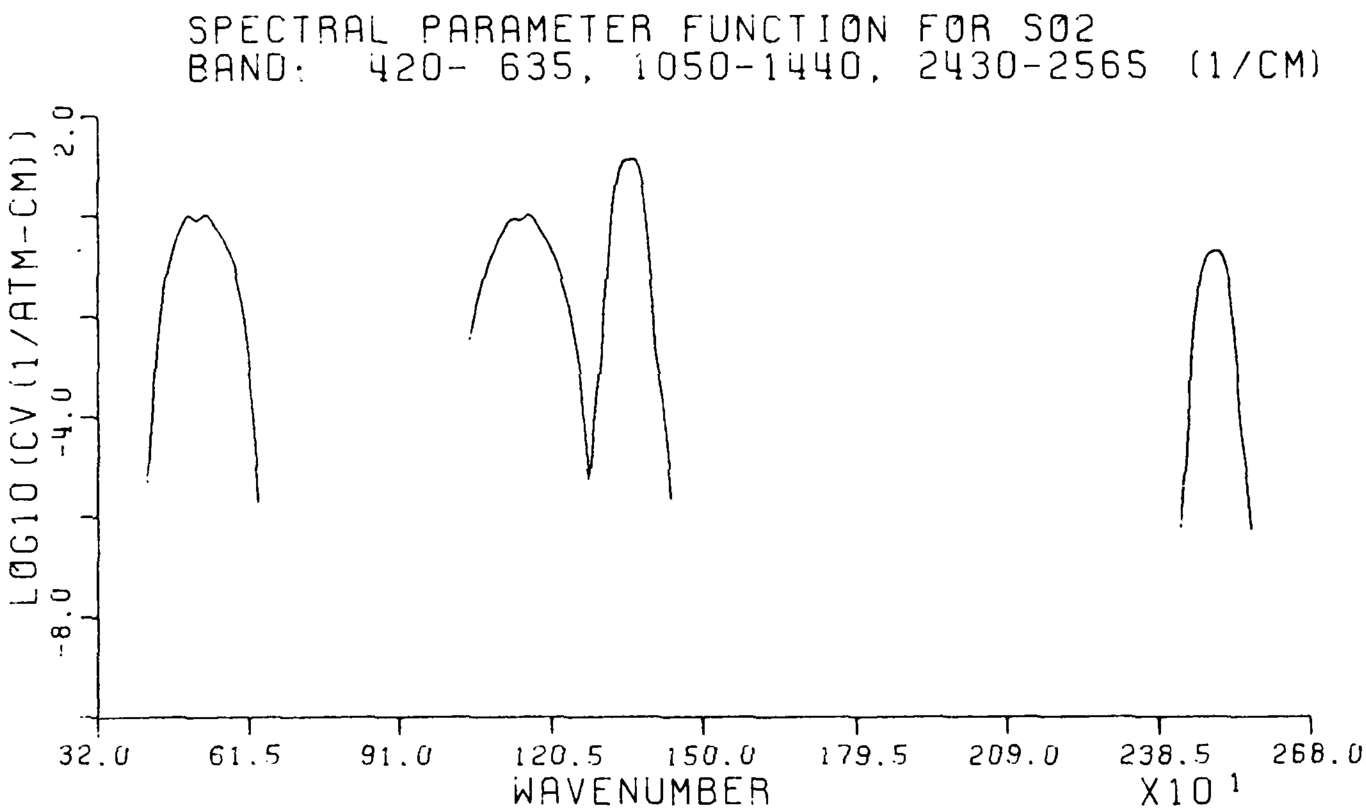

SPECTRAL PARAMETER FUNCTION FOR SO2
BAND: 420- 635, 1050-1440, 2430-2565 (1/CM)
LOG10 (CV (1/ATM-CM))
2.0
-4.0
-8.0
32.0
61.5
91.0
120.5
150.0
179.5
209.0
238.5
268.0
WAVENUMBER
X10 1

Table A1

C' VALUE FOR N2O

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
500	-8.0667	755	-6.9862	1350	-3.2635	2335	-2.6895
505	-7.2307	1100	-4.6703	1355	-4.1039	2340	-2.7551
510	-6.4149	1105	-3.6918	1360	-5.2761	2345	-2.8837
515	-5.4872	1110	-3.0656	1365	-6.1437	2350	-3.0884
520	-4.7083	1115	-2.5796	1370	-7.0079	2355	-3.3746
525	-4.0319	1120	-2.1876	2105	-6.5569	2360	-3.7078
530	-3.4752	1125	-1.8646	2110	-5.0880	2365	-4.0975
535	-3.0155	1130	-1.5919	2115	-4.4527	2370	-4.6272
540	-2.6046	1135	-1.3587	2120	-3.9302	2375	-5.2484
545	-2.2057	1140	-1.1684	2125	-3.4439	2380	-10.0000
550	-1.8137	1145	-1.0286	2130	-2.9701	2385	-10.0000
555	-1.4741	1150	-0.9470	2135	-2.5423	2390	-10.0000
560	-1.1914	1155	-0.9271	2140	-2.1616	2395	-7.3571
565	-0.9603	1160	-0.9442	2145	-1.8076	2400	-5.0287
570	-0.7923	1165	-0.9695	2150	-1.4763	2405	-4.3047
575	-0.6629	1170	-0.9753	2155	-1.1590	2410	-3.6431
580	-0.5849	1175	-0.9573	2160	-0.8445	2415	-3.1026
585	-0.5402	1180	-0.9550	2165	-0.5455	2420	-2.6122
590	-0.4975	1185	-1.0000	2170	-0.2506	2425	-2.1941
595	-0.5148	1190	-1.1070	2175	0.0234	2430	-1.8454
600	-0.5592	1195	-1.2791	2180	0.2775	2435	-1.5726
605	-0.6521	1200	-1.4976	2185	0.5113	2440	-1.3829
610	-0.8148	1205	-1.7281	2190	0.7154	2445	-1.2818
615	-1.0186	1210	-1.9277	2195	0.8929	2450	-1.2505
620	-1.2764	1215	-2.0227	2200	1.0359	2455	-1.2579
625	-1.5873	1220	-1.9577	2205	1.1306	2460	-1.2731
630	-1.9638	1225	-1.7625	2210	1.1697	2465	-1.2502
635	-2.3881	1230	-1.5020	2215	1.1807	2470	-1.2092
640	-2.8083	1235	-1.2186	2220	1.1803	2475	-1.2044
645	-3.2392	1240	-0.9270	2225	1.1974	2480	-1.2577
650	-3.6934	1245	-0.6326	2230	1.2466	2485	-1.3942
655	-4.0682	1250	-0.3429	2235	1.2629	2490	-1.6262
660	-4.1366	1255	-0.0768	2240	1.2068	2495	-1.9347
665	-3.9423	1260	0.1500	2245	1.0472	2500	-2.2830
670	-3.7143	1265	0.3215	2250	0.7695	2505	-2.5386
675	-3.4375	1270	0.4104	2255	0.4083	2510	-2.4801
680	-3.2602	1275	0.4385	2260	-0.0244	2515	-2.1671
685	-3.0976	1280	0.4288	2265	-0.5477	2520	-1.8061
690	-2.9815	1285	0.4185	2270	-1.2203	2525	-1.4726
695	-2.9153	1290	0.4570	2275	-2.1067	2530	-1.1797
700	-2.9596	1295	0.4972	2280	-2.9508	2535	-0.9377
705	-3.0281	1300	0.4987	2285	-3.2107	2540	-0.7542
710	-3.1264	1305	0.4216	2290	-3.1587	2545	-0.6392
715	-3.2650	1310	0.2360	2295	-2.9600	2550	-0.5899
720	-3.3906	1315	-0.0319	2300	-2.7641	2555	-0.5743
725	-3.5717	1320	-0.3714	2305	-2.6324	2560	-0.5669
730	-3.8312	1325	-0.7539	2310	-2.5671	2565	-0.5339
735	-4.1706	1330	-1.1534	2315	-2.5664	2570	-0.4745
740	-4.6077	1335	-1.5855	2320	-2.6088	2575	-0.4471
745	-5.1839	1340	-2.0610	2325	-2.6425	2580	-0.4779
750	-5.9224	1345	-2.6069	2330	-2.6606	2585	-0.5877

C' VALUE FOR N2O

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
2590	-0.7964	2605	-1.9593	2620	-3.8102		
2595	-1.0942	2610	-2.5140	2625	-4.5825		
2600	-1.4812	2615	-3.1350	2630	-5.5982		

Table A2

C' VALUE FOR CH4

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
1075	-8.8866	1330	-0.8781	1585	-3.5992	2430	-3.8712
1080	-8.2246	1335	-0.7559	1590	-3.4937	2435	-3.8692
1085	-7.7940	1340	-0.6628	1595	-3.3676	2440	-3.8777
1090	-7.1734	1345	-0.6128	1600	-3.2230	2445	-3.8965
1095	-6.7965	1350	-0.6119	1605	-3.1630	2450	-3.9092
1100	-6.5695	1355	-0.6575	1610	-3.0691	2455	-3.8788
1105	-6.1929	1360	-0.7620	1615	-3.0776	2460	-3.7661
1110	-5.9169	1365	-0.9217	1620	-3.0872	2465	-3.6900
1115	-5.7452	1370	-1.1264	1625	-3.0974	2470	-3.6239
1120	-5.4731	1375	-1.3660	1630	-3.1223	2475	-3.5597
1125	-5.3001	1380	-1.6352	1635	-3.1285	2480	-3.5193
1130	-5.1872	1385	-1.9264	1640	-3.1212	2485	-3.4906
1135	-4.9672	1390	-2.2266	1645	-3.1333	2490	-3.4415
1140	-4.8474	1395	-2.5123	1650	-3.1674	2495	-3.3730
1145	-4.6939	1400	-2.7472	1655	-3.1668	2500	-3.3579
1150	-4.5210	1405	-2.8820	1660	-3.2433	2505	-3.3427
1155	-4.3377	1410	-2.9129	1665	-3.2398	2510	-3.3208
1160	-4.1346	1415	-2.9145	1670	-3.3135	2515	-3.3048
1165	-3.9322	1420	-2.8854	1675	-3.3975	2520	-3.3136
1170	-3.7339	1425	-2.8508	1680	-3.4427	2525	-3.2904
1175	-3.5077	1430	-2.8512	1685	-3.6434	2530	-3.2545
1180	-3.2719	1435	-2.8202	1690	-3.7528	2535	-3.2241
1185	-3.0296	1440	-2.8023	1695	-3.9466	2540	-3.1453
1190	-2.8124	1445	-2.8004	1700	-4.1940	2545	-3.0187
1195	-2.6199	1450	-2.7800	1705	-4.3362	2550	-2.9427
1200	-2.4479	1455	-2.8175	1710	-4.5539	2555	-2.8630
1205	-2.2502	1460	-2.8413	1715	-4.7410	2560	-2.8146
1210	-2.0541	1465	-2.8943	1720	-4.9155	2565	-2.8604
1215	-1.8800	1470	-2.9876	1725	-5.1345	2570	-2.8922
1220	-1.7092	1475	-3.0688	1730	-5.3908	2575	-2.9650
1225	-1.5791	1480	-3.2424	1735	-5.5592	2580	-2.9959
1230	-1.4379	1485	-3.4064	1740	-5.8270	2585	-2.8920
1235	-1.2992	1490	-3.5759	1745	-6.0289	2590	-2.7989
1240	-1.1735	1495	-3.7630	1750	-6.2365	2595	-2.7028
1245	-1.0510	1500	-3.8925	1755	-6.6730	2600	-2.6506
1250	-0.9646	1505	-4.0774	1760	-7.0538	2605	-2.7285
1255	-0.8779	1510	-4.3243	1765	-7.6216	2610	-2.8420
1260	-0.8002	1515	-4.5964	1770	-8.5697	2615	-2.9304
1265	-0.7574	1520	-3.8654	1775	-9.8483	2620	-2.9622
1270	-0.7356	1525	-3.0974	2370	-6.3069	2625	-2.8726
1275	-0.7478	1530	-2.5967	2375	-5.5442	2630	-2.7566
1280	-0.7512	1535	-2.2482	2380	-5.1501	2635	-2.6745
1285	-0.6906	1540	-2.1016	2385	-4.8853	2640	-2.6337
1290	-0.5594	1545	-2.1488	2390	-4.6900	2645	-2.6533
1295	-0.4417	1550	-2.3261	2395	-4.5262	2650	-2.6800
1300	-0.4019	1555	-2.6448	2400	-4.3957	2655	-2.7098
1305	-0.5027	1560	-3.0446	2405	-4.2823	2660	-2.7479
1310	-0.7628	1565	-3.3958	2410	-4.2736	2665	-2.6859
1315	-0.9625	1570	-3.6510	2415	-4.2054	2670	-2.6216
1320	-1.0431	1575	-3.7049	2420	-4.1168	2675	-2.5701
1325	-1.0068	1580	-3.7240	2425	-3.9986	2680	-2.4683

C' VALUE FOR CH4

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
2685	-2.4426	2940	-1.1031	3195	-3.2413	4320	-1.6535
2690	-2.4463	2945	-1.0795	3200	-3.5058	4325	-1.8165
2695	-2.4194	2950	-1.0687	3205	-3.9508	4330	-1.8417
2700	-2.4578	2955	-1.0692	3210	-4.5133	4335	-1.7697
2705	-2.4894	2960	-1.0904	3215	-5.3536	4340	-1.6346
2710	-2.4639	2965	-1.1166	3220	-8.0815	4345	-1.5599
2715	-2.4825	2970	-1.1511	3225	-8.9081	4350	-1.5466
2720	-2.4998	2975	-1.1951	3230	-9.8155	4355	-1.5604
2725	-2.4381	2980	-1.2321	4105	-8.7367	4360	-1.6307
2730	-2.4123	2985	-1.2831	4110	-10.0000	4365	-1.6867
2735	-2.3654	2990	-1.2716	4115	-7.4757	4370	-1.7593
2740	-2.2698	2995	-1.1902	4120	-5.1602	4375	-1.8051
2745	-2.2387	3000	-0.9715	4125	-4.2454	4380	-1.8167
2750	-2.2364	3005	-0.6654	4130	-3.7640	4385	-1.8518
2755	-2.2029	3010	-0.4103	4135	-3.3256	4390	-1.8559
2760	-2.1780	3015	-0.3011	4140	-3.0103	4395	-1.8547
2765	-2.1433	3020	-0.5049	4145	-2.7726	4400	-1.8507
2770	-2.0355	3025	-0.8659	4150	-2.5510	4405	-1.8851
2775	-1.9458	3030	-1.1777	4155	-2.3849	4410	-1.8933
2780	-1.8723	3035	-1.3847	4160	-2.2318	4415	-1.9081
2785	-1.7936	3040	-1.4359	4165	-2.1080	4420	-1.9025
2790	-1.7639	3045	-1.3908	4170	-2.0086	4425	-1.9451
2795	-1.7782	3050	-1.2992	4175	-1.9290	4430	-1.9924
2800	-1.8022	3055	-1.1923	4180	-1.8902	4435	-2.0321
2805	-1.8115	3060	-1.0951	4185	-1.8750	4440	-2.0816
2810	-1.7818	3065	-1.0213	4190	-1.8700	4445	-2.1026
2815	-1.6986	3070	-0.9578	4195	-1.8476	4450	-2.1137
2820	-1.6169	3075	-0.9299	4200	-1.7390	4455	-2.1351
2825	-1.5975	3080	-0.9207	4205	-1.5724	4460	-2.1629
2830	-1.6545	3085	-0.9292	4210	-1.4284	4465	-2.1876
2835	-1.7742	3090	-0.9725	4215	-1.3425	4470	-2.2340
2840	-1.8937	3095	-1.0126	4220	-1.3791	4475	-2.2960
2845	-1.9544	3100	-1.0750	4225	-1.5132	4480	-2.3747
2850	-1.8942	3105	-1.1149	4230	-1.6508	4485	-2.4970
2855	-1.7761	3110	-1.1636	4235	-1.7283	4490	-2.6244
2860	-1.6392	3115	-1.2059	4240	-1.6684	4495	-2.7641
2865	-1.5236	3120	-1.2638	4245	-1.5432	4500	-2.8912
2870	-1.4551	3125	-1.3327	4250	-1.4447	4505	-3.0329
2875	-1.4221	3130	-1.4079	4255	-1.3773	4510	-3.1944
2880	-1.4245	3135	-1.4983	4260	-1.3490	4515	-3.3877
2885	-1.4174	3140	-1.5711	4265	-1.3642	4520	-3.4566
2890	-1.4177	3145	-1.6872	4270	-1.4016	4525	-3.1662
2895	-1.3776	3150	-1.7870	4275	-1.4713	4530	-2.7253
2900	-1.3349	3155	-1.9266	4280	-1.5836	4535	-2.3992
2905	-1.2909	3160	-2.0774	4285	-1.6984	4540	-2.2214
2910	-1.2470	3165	-2.2119	4290	-1.8085	4545	-2.2022
2915	-1.2162	3170	-2.3875	4295	-1.8486	4550	-2.3978
2920	-1.1850	3175	-2.5155	4300	-1.7464	4555	-2.7449
2925	-1.1677	3180	-2.6822	4305	-1.6338	4560	-3.2639
2930	-1.1449	3185	-2.8372	4310	-1.5555	4565	-3.9311
2935	-1.1229	3190	-3.0032	4315	-1.5552	4570	-4.1470

C' VALUE FOR CH_4

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
4575	-3.9351	4615	-3.4140	4655	-4.3518	4695	-10.0000
4580	-3.7471	4620	-3.4908	4660	-4.6486	4700	-10.0000
4585	-3.6245	4625	-3.5164	4665	-4.8778	4705	-10.0000
4590	-3.4791	4630	-3.5944	4670	-5.2542	4710	-10.0000
4595	-3.4710	4635	-3.7403	4675	-5.7834	4715	-10.0000
4600	-3.4210	4640	-3.8192	4680	-6.3451	4720	-7.7337
4605	-3.4125	4645	-4.0177	4685	-7.7212	4725	-7.9729
4610	-3.4475	4650	-4.1833	4690	-10.0000	4730	-7.7973

Table A3

C' VALUE FOR CO

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
1955	-8.2642	2120	-0.4268	4055	-8.6139	4220	-2.7531
1960	-7.5767	2125	-0.4657	4060	-7.9747	4225	-2.7023
1965	-6.9972	2130	-0.5571	4065	-7.5250	4230	-2.6635
1970	-6.5408	2135	-0.6573	4070	-7.1931	4235	-2.6440
1975	-6.1219	2140	-0.7404	4075	-6.8596	4240	-2.6550
1980	-5.6734	2145	-0.7523	4080	-6.5741	4245	-2.7225
1985	-5.2658	2150	-0.6601	4085	-6.2922	4250	-2.8161
1990	-4.8686	2155	-0.5360	4090	-6.0098	4255	-2.9015
1995	-4.4918	2160	-0.4211	4095	-5.7669	4260	-2.9241
2000	-4.1423	2165	-0.3367	4100	-5.5345	4265	-2.8228
2005	-3.8133	2170	-0.3167	4105	-5.3229	4270	-2.6726
2010	-3.4998	2175	-0.3320	4110	-5.1461	4275	-2.5320
2015	-3.2104	2180	-0.3753	4115	-4.9882	4280	-2.4291
2020	-2.9443	2185	-0.4489	4120	-4.8493	4285	-2.3772
2025	-2.7139	2190	-0.5438	4125	-4.7239	4290	-2.3732
2030	-2.5084	2195	-0.6653	4130	-4.6064	4295	-2.3995
2035	-2.3109	2200	-0.8052	4135	-4.5009	4300	-2.4574
2040	-2.1245	2205	-0.9690	4140	-4.4071	4305	-2.5486
2045	-1.9387	2210	-1.1506	4145	-4.3322	4310	-2.6664
2050	-1.7608	2215	-1.3522	4150	-4.2661	4315	-2.8209
2055	-1.6054	2220	-1.5791	4155	-4.1926	4320	-3.0129
2060	-1.4733	2225	-1.8248	4160	-4.0956	4325	-3.2516
2065	-1.3594	2230	-2.1073	4165	-3.9611	4330	-3.5482
2070	-1.2540	2235	-2.4246	4170	-3.7984	4335	-3.9165
2075	-1.1480	2240	-2.7877	4175	-3.6314	4340	-4.3714
2080	-1.0341	2245	-3.2152	4180	-3.4757	4345	-4.9326
2085	-0.9216	2250	-3.7069	4185	-3.3406	4350	-5.6394
2090	-0.8189	2255	-4.2832	4190	-3.2237	4355	-6.5163
2095	-0.7235	2260	-4.9518	4195	-3.1219	4360	-7.6063
2100	-0.6362	2265	-5.7251	4200	-3.0325	4365	-9.3575
2105	-0.5549	2270	-6.5319	4205	-2.9494		
2110	-0.4856	2275	-7.4879	4210	-2.8765		
2115	-0.4401	2280	-9.0885	4215	-2.8117		

Table A4

C' VALUE FOR O2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
7760	-9.8136	7895	-6.9936	12935	-9.7871	13070	-5.6969
7765	-9.7772	7900	-7.0519	12940	-9.6557	13075	-5.5923
7770	-9.5680	7905	-7.0597	12945	-9.6106	13080	-5.5076
7775	-9.4595	7910	-7.0680	12950	-9.5142	13085	-5.4002
7780	-9.3502	7915	-7.1242	12955	-9.4763	13090	-5.3413
7785	-9.1411	7920	-7.2088	12960	-9.4163	13095	-5.2826
7790	-9.0476	7925	-7.3265	12965	-9.2348	13100	-5.2458
7795	-8.8628	7930	-7.4673	12970	-9.1088	13105	-5.2877
7800	-8.7051	7935	-7.6326	12975	-8.7946	13110	-5.3743
7805	-8.5838	7940	-7.8110	12980	-8.5876	13115	-5.4654
7810	-8.4282	7945	-8.0096	12985	-8.3128	13120	-5.5262
7815	-8.3271	7950	-8.2104	12990	-8.0945	13125	-5.4429
7820	-8.1958	7955	-8.4036	12995	-7.9127	13130	-5.2430
7825	-8.0938	7960	-8.5853	13000	-7.7229	13135	-5.0284
7830	-7.9652	7965	-8.7252	13005	-7.5860	13140	-4.8464
7835	-7.8371	7970	-8.8511	13010	-7.4215	13145	-4.7534
7840	-7.7476	7975	-8.9427	13015	-7.2726	13150	-4.7825
7845	-7.6431	7980	-9.0375	13020	-7.1179	13155	-4.9462
7850	-7.5736	7985	-9.1228	13025	-6.9516	13160	-5.2290
7855	-7.5149	7990	-9.2246	13030	-6.8075	13165	-5.6440
7860	-7.4194	7995	-9.3291	13035	-6.6413	13170	-6.1889
7865	-7.2688	8000	-9.4436	13040	-6.5043	13175	-6.8427
7870	-7.0722	8005	-9.5716	13045	-6.3519	13180	-7.7731
7875	-6.8815	8010	-9.6951	13050	-6.2112	13185	-9.1688
7880	-6.7627	8015	-9.8408	13055	-6.0839	13190	-9.6893
7885	-6.8055	8020	-9.9759	13060	-5.9337		
7890	-6.9114	12930	-9.9226	13065	-5.8321		

Table A5

C' VALUE FOR CO2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
425	-8.6068	680	0.0066	935	-4.4213	1190	-9.3754
430	-8.4323	685	-0.1269	940	-4.3198	1195	-8.7756
435	-8.9708	690	-0.2994	945	-4.2786	1200	-8.0904
440	-8.3978	695	-0.4934	950	-4.2843	1205	-7.4827
445	-9.0449	700	-0.7101	955	-4.3099	1210	-6.9585
450	-8.9544	705	-0.9087	960	-4.3210	1215	-6.5095
455	-8.6127	710	-1.1004	965	-4.2769	1220	-6.1194
460	-8.4076	715	-1.2694	970	-4.2229	1225	-5.7824
465	-8.2710	720	-1.4064	975	-4.2179	1230	-5.4910
470	-8.0391	725	-1.5622	980	-4.2950	1235	-5.2532
475	-7.9485	730	-1.6810	985	-4.4789	1240	-5.0840
480	-7.9638	735	-1.7841	990	-4.7550	1245	-4.9920
485	-7.7849	740	-1.8973	995	-5.0902	1250	-4.9577
490	-7.6278	745	-2.0274	1000	-5.4329	1255	-4.9638
495	-7.1418	750	-2.2079	1005	-5.6689	1260	-4.9741
500	-6.7823	755	-2.4264	1010	-5.6608	1265	-4.9555
505	-6.3826	760	-2.6763	1015	-5.4582	1270	-4.9466
510	-6.0323	765	-2.9312	1020	-5.1969	1275	-4.9774
515	-5.7501	770	-3.1896	1025	-4.9419	1280	-5.0719
520	-5.5249	775	-3.4262	1030	-4.7106	1285	-5.2558
525	-5.3304	780	-3.5979	1035	-4.5094	1290	-5.5213
530	-5.0105	785	-3.7051	1040	-4.3409	1295	-5.8633
535	-4.7703	790	-3.7372	1045	-4.2211	1300	-6.2877
540	-4.5714	795	-3.7983	1050	-4.1563	1305	-6.7878
545	-4.3919	800	-3.9154	1055	-4.1259	1310	-7.2602
550	-4.2974	805	-4.0520	1060	-4.1108	1315	-7.2940
555	-4.1370	810	-4.2567	1065	-4.0803	1320	-6.8524
560	-3.8761	815	-4.4661	1070	-4.0211	1325	-6.3372
565	-3.5936	820	-4.6670	1075	-3.9824	1330	-5.8854
570	-3.2852	825	-4.9226	1080	-4.0053	1335	-5.5065
575	-3.0016	830	-5.2203	1085	-4.1221	1340	-5.2011
580	-2.7303	835	-5.5597	1090	-4.3504	1345	-4.9776
585	-2.4868	840	-5.9075	1095	-4.6741	1350	-4.8471
590	-2.2741	845	-6.2130	1100	-5.0826	1355	-4.7885
595	-2.0936	850	-6.4719	1105	-5.5857	1360	-4.7783
600	-1.9424	855	-5.8310	1110	-6.2301	1365	-4.7815
605	-1.8092	860	-5.8948	1115	-7.0827	1370	-4.7538
610	-1.6843	865	-5.9503	1120	-8.1344	1375	-4.7228
615	-1.5372	870	-6.0217	1125	-8.8601	1380	-4.7259
620	-1.3803	875	-6.0392	1130	-9.0457	1385	-4.7860
625	-1.2043	880	-5.9855	1135	-9.1231	1390	-4.9231
630	-0.9930	885	-5.8620	1140	-9.0728	1395	-5.1270
635	-0.7724	890	-5.6934	1145	-9.1413	1400	-5.3831
640	-0.5509	895	-5.5083	1150	-9.1221	1405	-5.6849
645	-0.3465	900	-5.3473	1155	-9.1892	1410	-6.0351
650	-0.1785	905	-5.2028	1160	-9.2752	1415	-6.4437
655	-0.0470	910	-5.0799	1165	-9.2237	1420	-6.9160
660	0.0449	915	-4.9629	1170	-9.3604	1425	-7.4815
665	0.1114	920	-4.8379	1175	-9.3058	1430	-8.1437
670	0.1367	925	-4.7032	1180	-9.5455	1435	-8.9449
675	0.0910	930	-4.5584	1185	-9.5567	1440	-9.8564

C' VALUE FOR CO2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
1445	-9.7726	2055	-3.2100	2310	0.4386	2565	-5.9818
1450	-9.7872	2060	-3.1041	2315	0.6260	2570	-6.0065
1455	-9.6974	2065	-3.0411	2320	0.8081	2575	-5.9747
1460	-9.7232	2070	-3.0471	2325	0.9681	2580	-5.8741
1820	-8.5288	2075	-3.1077	2330	1.0859	2585	-5.7230
1825	-8.1134	2080	-3.2305	2335	1.1522	2590	-5.5620
1830	-7.6555	2085	-3.4274	2340	1.1861	2595	-5.4389
1835	-7.1673	2090	-3.6115	2345	1.2039	2600	-5.3788
1840	-6.7226	2095	-3.7542	2350	1.2255	2605	-5.3679
1845	-6.3423	2100	-3.8666	2355	1.2587	2610	-5.3827
1850	-6.0410	2105	-3.9338	2360	1.2473	2615	-5.3837
1855	-5.8154	2110	-4.0079	2365	1.1457	2620	-5.3460
1860	-5.6519	2115	-4.0962	2370	0.9139	2625	-5.3186
1865	-5.5186	2120	-4.2142	2375	0.5250	2630	-5.3394
1870	-5.3859	2125	-4.1433	2380	0.0177	2635	-5.4320
1875	-5.2279	2130	-4.2870	2385	-0.5796	2640	-5.6095
1880	-5.0238	2135	-4.4796	2390	-1.3944	2645	-5.8446
1885	-4.7865	2140	-4.6618	2395	-2.3841	2650	-6.0992
1890	-4.5343	2145	-4.8204	2400	-2.7244	2655	-6.3399
1895	-4.2846	2150	-4.9499	2405	-2.9264	2660	-6.5499
1900	-4.0560	2155	-4.9862	2410	-3.0699	2665	-6.7434
1905	-3.8717	2160	-5.0171	2415	-3.2120	2670	-6.9359
1910	-3.7624	2165	-5.0282	2420	-3.3353	2675	-7.1219
1915	-3.7231	2170	-5.0580	2425	-3.4510	2680	-7.2818
1920	-3.7335	2175	-5.0398	2430	-3.5566	2685	-7.3984
1925	-3.8312	2180	-4.9465	2435	-3.6518	2690	-7.4881
1930	-3.9854	2185	-4.7816	2440	-3.7460	2695	-7.5452
1935	-4.1930	2190	-4.5538	2445	-3.8500	2700	-7.5994
1940	-4.4895	2195	-4.2975	2450	-3.9680	2705	-7.6445
1945	-4.7394	2200	-4.0286	2455	-4.0981	2710	-7.6734
1950	-4.8892	2205	-3.7528	2460	-4.2259	2715	-7.6422
1955	-4.9499	2210	-3.4715	2465	-4.3369	2720	-7.5057
1960	-4.9392	2215	-3.1899	2470	-4.4329	2725	-7.2650
1965	-4.9787	2220	-2.9041	2475	-4.5305	2730	-6.9975
1970	-5.1129	2225	-2.6127	2480	-4.6264	2735	-6.7749
1975	-5.3330	2230	-2.3212	2485	-4.7438	2740	-6.6398
1980	-5.6093	2235	-2.0435	2490	-4.8842	2745	-6.5875
1985	-5.8962	2240	-1.7894	2495	-5.0248	2750	-6.5912
1990	-6.0581	2245	-1.5531	2500	-5.1448	2755	-6.6192
1995	-6.0274	2250	-1.3382	2505	-5.2371	2760	-6.6155
2000	-5.8356	2255	-1.1515	2510	-5.2781	2765	-6.5866
2005	-5.5989	2260	-0.9990	2515	-5.3299	2770	-6.5851
2010	-5.3738	2265	-0.8833	2520	-5.4120	2775	-6.6382
2015	-5.1661	2270	-0.8006	2525	-5.5352	2780	-6.7736
2020	-4.9472	2275	-0.7227	2530	-5.3347	2785	-7.0009
2025	-4.7020	2280	-0.6288	2535	-5.4523	2790	-7.2896
2030	-4.4354	2285	-0.4977	2540	-5.5633	2795	-7.6327
2035	-4.1439	2290	-0.3249	2545	-5.6646	2800	-7.9767
2040	-3.8561	2295	-0.1349	2550	-5.7593	2805	-8.2633
2045	-3.5944	2300	0.0576	2555	-5.8461	2810	-8.4744
2050	-3.3694	2305	0.2487	2560	-5.9229	2815	-8.5455

C' VALUE FOR CO_2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
2820	-8.5813	3310	-5.3068	3565	-1.5992	3820	-5.0636
2825	-8.6025	3315	-5.2546	3570	-1.4873	3825	-5.0354
2830	-8.6459	3320	-5.2991	3575	-1.3646	3830	-5.0546
3070	-9.8006	3325	-5.3819	3580	-1.2260	3835	-5.1454
3075	-9.5049	3330	-5.4615	3585	-1.0721	3840	-5.3274
3080	-9.1947	3335	-5.4117	3590	-0.9281	3845	-5.5863
3085	-8.7254	3340	-5.2107	3595	-0.8379	3850	-5.8889
3090	-8.4410	3345	-5.0103	3600	-0.8123	3855	-6.1770
3095	-8.1781	3350	-4.8232	3605	-0.8261	3860	-6.3555
3100	-8.0182	3355	-4.7071	3610	-0.8483	3865	-6.4096
3105	-7.9381	3360	-4.6850	3615	-0.8305	3870	-6.4371
3110	-7.8793	3365	-4.7385	3620	-0.7792	3875	-6.5112
3115	-7.7636	3370	-4.8797	3625	-0.7626	3880	-6.6680
3120	-7.5549	3375	-5.1024	3630	-0.8228	3885	-6.9183
3125	-7.2962	3380	-5.4015	3635	-0.9908	3890	-7.2418
3130	-7.0244	3385	-5.7758	3640	-1.2503	3895	-7.5827
3135	-6.7556	3390	-6.2225	3645	-1.5347	3900	-7.8704
3140	-6.4888	3395	-6.6681	3650	-1.7934	3905	-8.0551
3145	-6.2443	3400	-6.9127	3655	-1.9837	3910	-8.1705
3150	-6.0422	3405	-6.8919	3660	-2.0715	3915	-8.2500
3155	-5.9088	3410	-6.6972	3665	-2.0375	3920	-8.3554
3160	-5.8590	3415	-6.5012	3670	-1.8975	3925	-8.3961
3165	-5.8890	3420	-6.3123	3675	-1.6906	3930	-8.4354
3170	-5.9850	3425	-6.1091	3680	-1.4497	3935	-8.3920
3175	-6.0949	3430	-5.8641	3685	-1.2048	3940	-8.2785
3180	-6.1164	3435	-5.5889	3690	-0.9831	3945	-8.0499
3185	-6.0207	3440	-5.3057	3695	-0.8125	3950	-7.7437
3190	-5.8592	3445	-5.0340	3700	-0.7157	3955	-7.4130
3195	-5.7110	3450	-4.7826	3705	-0.6707	3960	-7.1153
3200	-5.6329	3455	-4.5476	3710	-0.6532	3965	-6.8861
3205	-5.6369	3460	-4.3277	3715	-0.6297	3970	-6.7422
3210	-5.7274	3465	-4.1224	3720	-0.5706	3975	-6.6786
3215	-5.9069	3470	-3.9333	3725	-0.5263	3980	-6.6774
3220	-6.1720	3475	-3.7675	3730	-0.5489	3985	-6.7053
3225	-6.5203	3480	-3.6324	3735	-0.6857	3990	-6.7090
3230	-6.9586	3485	-3.5163	3740	-0.9793	3995	-6.6794
3235	-7.4776	3490	-3.4043	3745	-1.3962	4000	-6.6055
3240	-8.0607	3495	-3.2744	3750	-1.8673	4005	-6.4827
3245	-8.5514	3500	-3.1180	3755	-2.3655	4010	-6.3454
3250	-8.7011	3505	-2.9557	3760	-3.5436	4015	-6.2401
3255	-9.4232	3510	-2.8254	3765	-4.0424	4020	-6.1992
3260	-7.9274	3515	-2.7359	3770	-4.4084	4025	-6.2676
3265	-7.6159	3520	-2.6721	3775	-4.6849	4030	-6.4833
3270	-7.3836	3525	-2.6084	3780	-4.8663	4035	-6.8490
3275	-7.1969	3530	-2.5105	3785	-4.9516	4040	-7.4310
3280	-7.0523	3535	-2.3772	3790	-4.9790	4045	-8.4606
3285	-6.7685	3540	-2.2317	3795	-4.9923	4050	-9.7364
3290	-6.4022	3545	-2.0866	3800	-5.0207	4055	-9.8771
3295	-6.0354	3550	-1.9521	3805	-5.0596	4060	-9.8840
3300	-5.7125	3555	-1.8292	3810	-5.0958	4065	-9.9559
3305	-5.4659	3560	-1.7110	3815	-5.1018	4070	-10.0000

C' VALUE FOR CO2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
4075	-10.0000	4755	-4.7213	5010	-3.3966	5265	-7.0561
4080	-10.0000	4760	-4.5868	5015	-3.8525	5270	-6.7966
4085	-10.0000	4765	-4.4594	5020	-4.2541	5275	-6.4771
4090	-10.0000	4770	-4.3387	5025	-4.5682	5280	-6.1996
4095	-9.9764	4775	-4.2219	5030	-4.7376	5285	-5.9593
4100	-10.0000	4780	-4.1002	5035	-4.7524	5290	-5.7560
4105	-9.9822	4785	-3.9812	5040	-4.6733	5295	-5.5370
4535	-9.6003	4790	-3.8876	5045	-4.5170	5300	-5.2836
4540	-9.0910	4795	-3.8207	5050	-4.3123	5305	-5.0966
4545	-8.5793	4800	-3.7673	5055	-4.0891	5310	-4.9583
4550	-8.2059	4805	-3.7120	5060	-3.8565	5315	-4.9126
4555	-7.9099	4810	-3.6223	5065	-3.6219	5320	-5.0022
4560	-7.7157	4815	-3.4912	5070	-3.3909	5325	-5.1370
4565	-7.6145	4820	-3.3444	5075	-3.1785	5330	-5.3465
4570	-7.5964	4825	-3.1983	5080	-3.0100	5335	-5.6279
4575	-7.5942	4830	-3.0732	5085	-2.9105	5340	-5.9364
4580	-7.5256	4835	-3.0262	5090	-2.8588	5345	-6.3695
4585	-7.3190	4840	-3.0078	5095	-2.8286	5350	-6.9602
4590	-6.9986	4845	-3.0123	5100	-2.7912	5355	-7.6823
4595	-6.6884	4850	-3.0213	5105	-2.7207	5360	-8.2701
4600	-6.4102	4855	-2.9957	5110	-2.6729	5365	-8.6427
4605	-6.1769	4860	-2.9261	5115	-2.6858	5370	-9.0728
4610	-5.9882	4865	-2.8770	5120	-2.7745	5375	-9.5366
4615	-5.8421	4870	-2.8887	5125	-2.9414	5920	-8.9954
4620	-5.7499	4875	-2.9853	5130	-3.1445	5925	-8.5140
4625	-5.7201	4880	-3.1609	5135	-3.3617	5930	-8.2066
4630	-5.7189	4885	-3.3643	5140	-3.5954	5935	-7.9742
4635	-5.7108	4890	-3.5468	5145	-3.8508	5940	-7.8579
4640	-5.6669	4895	-3.6759	5150	-4.1739	5945	-7.8073
4645	-5.5955	4900	-3.7488	5155	-4.5122	5950	-7.7894
4650	-5.5686	4905	-3.7704	5160	-4.8985	5955	-7.7466
4655	-5.6287	4910	-3.7535	5165	-5.3426	5960	-7.7009
4660	-5.8000	4915	-3.7113	5170	-5.8737	5965	-7.6393
4665	-6.0855	4920	-3.6368	5175	-6.4734	5970	-7.5889
4670	-6.4398	4925	-3.5277	5180	-7.0715	5975	-7.5697
4675	-6.7793	4930	-3.3812	5185	-7.5042	5980	-7.5200
4680	-6.9427	4935	-3.2020	5190	-7.6034	5985	-7.3908
4685	-6.9205	4940	-3.0043	5195	-7.5143	5990	-7.1796
4690	-6.8363	4945	-2.8020	5200	-7.4358	5995	-6.9610
4695	-6.7059	4950	-2.6122	5205	-7.4089	6000	-6.7869
4700	-6.5272	4955	-2.4524	5210	-7.3969	6005	-6.6972
4705	-6.2903	4960	-2.3405	5215	-7.3813	6010	-6.6735
4710	-6.0085	4965	-2.2838	5220	-7.3018	6015	-6.6775
4715	-5.7224	4970	-2.2521	5225	-7.1858	6020	-6.6495
4720	-5.4722	4975	-2.2319	5230	-7.0633	6025	-6.5292
4725	-5.2772	4980	-2.1960	5235	-6.9962	6030	-6.3435
4730	-5.1501	4985	-2.1562	5240	-6.9905	6035	-6.1371
4735	-5.0768	4990	-2.1732	5245	-7.0319	6040	-5.9268
4740	-5.0219	4995	-2.2913	5250	-7.1331	6045	-5.7254
4745	-4.9579	5000	-2.5476	5255	-7.2054	6050	-5.5433
4750	-4.9555	5005	-2.9382	5260	-7.1856	6055	-5.4023

C' VALUE FOR CO2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
6060	-5.3292	6315	-4.8634	6570	-7.5010	6825	-10.0000
6065	-5.3090	6320	-4.6378	6575	-8.1628	6830	-10.0000
6070	-5.3171	6325	-4.4559	6580	-8.9951	6835	-9.4090
6075	-5.3193	6330	-4.3360	6585	-9.8931	6840	-8.8272
6080	-5.2705	6335	-4.2752	6590	-10.0000	6845	-8.3057
6085	-5.2085	6340	-4.2461	6595	-10.0000	6850	-7.8885
6090	-5.1835	6345	-4.2257	6600	-10.0000	6855	-7.5044
6095	-5.2186	6350	-4.1768	6605	-10.0000	6860	-7.1560
6100	-5.3367	6355	-4.1068	6610	-10.0000	6865	-6.8292
6105	-5.5305	6360	-4.0743	6615	-10.0000	6870	-6.5250
6110	-5.7725	6365	-4.1193	6620	-10.0000	6875	-6.2461
6115	-6.0228	6370	-4.2732	6625	-10.0000	6880	-5.9904
6120	-6.2150	6375	-4.5464	6630	-9.4967	6885	-5.7533
6125	-6.2857	6380	-4.9256	6635	-8.9198	6890	-5.5295
6130	-6.2634	6385	-5.4090	6640	-8.5081	6895	-5.3135
6135	-6.2250	6390	-6.0184	6645	-8.1255	6900	-5.1058
6140	-6.2234	6395	-6.7985	6650	-7.8286	6905	-4.9152
6145	-6.2616	6400	-7.7078	6655	-7.5478	6910	-4.7463
6150	-6.2931	6405	-8.3457	6660	-7.1487	6915	-4.6054
6155	-6.2508	6410	-8.5160	6665	-6.7853	6920	-4.4937
6160	-6.0971	6415	-8.6106	6670	-6.5537	6925	-4.3928
6165	-5.8679	6420	-8.8175	6675	-6.3931	6930	-4.2838
6170	-5.6195	6425	-9.1922	6680	-6.4107	6935	-4.1626
6175	-5.3906	6430	-9.6775	6685	-6.5087	6940	-4.0387
6180	-5.1944	6435	-9.7423	6690	-6.6607	6945	-3.9295
6185	-5.0216	6440	-9.1980	6695	-6.9026	6950	-3.8612
6190	-4.8566	6445	-8.4120	6700	-7.2104	6955	-3.8501
6195	-4.6919	6450	-7.7499	6705	-7.4445	6960	-3.8647
6200	-4.5255	6455	-7.1685	6710	-7.6303	6965	-3.8625
6205	-4.3785	6460	-6.6817	6715	-7.6346	6970	-3.8099
6210	-4.2879	6465	-6.2701	6720	-7.4521	6975	-3.7351
6215	-4.2583	6470	-5.9301	6725	-7.2211	6980	-3.7179
6220	-4.2636	6475	-5.6567	6730	-7.0043	6985	-3.6549
6225	-4.2768	6480	-5.4521	6735	-6.7903	6990	-4.2312
6230	-4.2484	6485	-5.3289	6740	-6.5666	6995	-4.7632
6235	-4.1853	6490	-5.2776	6745	-6.3499	7000	-5.4270
6240	-4.1586	6495	-5.2630	6750	-6.1534	7005	-6.4200
6245	-4.2079	6500	-5.2547	6755	-5.9988	7010	-8.1414
6250	-4.3651	6505	-5.2083	6760	-5.9033	7015	-9.0451
6255	-4.6407	6510	-5.1296	6765	-5.8760	7020	-9.5326
6260	-5.0141	6515	-5.0823	6770	-5.8693	7025	-9.8301
6265	-5.4719	6520	-5.0914	6775	-5.8277	7395	-9.9472
6270	-6.0015	6525	-5.1806	6780	-5.7282	7400	-9.8274
6275	-6.5173	6530	-5.3503	6785	-5.6262	7405	-8.9797
6280	-6.7829	6535	-5.5603	6790	-5.5865	7410	-8.4298
6285	-6.6805	6540	-5.7877	6795	-5.6665	7415	-7.8906
6290	-6.4180	6545	-5.9936	6800	-5.9229	7420	-7.4477
6295	-6.0793	6550	-6.1720	6805	-6.3399	7425	-7.0750
6300	-5.7404	6555	-6.3801	6810	-7.0180	7430	-6.7698
6305	-5.4204	6560	-6.6371	6815	-8.4230	7435	-6.5338
6310	-5.1265	6565	-6.9964	6820	-10.0000	7440	-6.3739

C' VALUE FOR CO_2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
7445	-6.2980	7630	-7.2957	7815	-10.0000	8175	-5.3426
7450	-6.2739	7635	-8.2799	7820	-9.7837	8180	-5.3061
7455	-6.2726	7640	-9.9457	8000	-8.0071	8185	-5.2648
7460	-6.2555	7645	-10.0000	8005	-8.3143	8190	-5.1864
7465	-6.1989	7650	-10.0000	8010	-8.9433	8195	-5.0876
7470	-6.1529	7655	-10.0000	8015	-9.8283	8200	-5.0226
7475	-6.1654	7660	-10.0000	8020	-10.0000	8205	-5.0397
7480	-6.2584	7665	-10.0000	8025	-10.0000	8210	-5.1905
7485	-6.4610	7670	-10.0000	8030	-10.0000	8215	-5.4858
7490	-6.7805	7675	-10.0000	8035	-9.5350	8220	-5.9101
7495	-7.2235	7680	-9.2766	8040	-8.9686	8225	-6.4851
7500	-7.8191	7685	-8.6201	8045	-8.5329	8230	-6.7862
7505	-8.5850	7690	-8.0764	8050	-8.1920	8235	-6.5368
7510	-9.6084	7695	-7.6374	8055	-7.9237	8240	-6.2765
7515	-10.0000	7700	-7.2752	8060	-7.6797	8245	-6.0398
7520	-10.0000	7705	-6.9802	8065	-7.5039	8250	-5.8260
7525	-9.9199	7710	-6.7578	8070	-7.3667	8255	-5.6397
7530	-9.1093	7715	-6.6163	8075	-7.2856	8260	-5.4799
7535	-8.4490	7720	-6.5546	8080	-7.1969	8265	-5.3438
7540	-7.9158	7725	-6.5392	8085	-7.0745	8270	-5.2274
7545	-7.4364	7730	-6.5397	8090	-6.9330	8275	-5.1411
7550	-7.0430	7735	-6.5132	8095	-6.7926	8280	-5.0917
7555	-6.6958	7740	-6.4531	8100	-6.6818	8285	-5.0473
7560	-6.4131	7745	-6.4161	8105	-6.6144	8290	-4.9820
7565	-6.1855	7750	-6.4482	8110	-6.5643	8295	-4.9114
7570	-6.0158	7755	-6.5683	8115	-6.5183	8300	-4.8634
7575	-5.9123	7760	-6.8086	8120	-6.4910	8305	-4.8844
7580	-5.8700	7765	-7.1762	8125	-6.4481	8310	-5.0363
7585	-5.8530	7770	-7.6772	8130	-6.3567	8315	-5.3351
7590	-5.8340	7775	-8.3574	8135	-6.2177	8320	-5.7802
7595	-5.7866	7780	-9.2188	8140	-6.0566	8325	-6.5387
7600	-5.7224	7785	-10.0000	8145	-5.9096	8330	-8.3735
7605	-5.7048	7790	-10.0000	8150	-5.7975	8335	-9.9977
7610	-5.7653	7795	-10.0000	8155	-5.7093	8340	-10.0000
7615	-5.9281	7800	-10.0000	8160	-5.6165	8345	-9.8473
7620	-6.2234	7805	-10.0000	8165	-5.5127		
7625	-6.6646	7810	-9.9508	8170	-5.4124		

Table A6

C' VALUE FOR NO

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
1700	-5.1830	1775	-3.0368	1850	-0.5488	1925	-0.7062
1705	-5.0434	1780	-2.7282	1855	-0.5673	1930	-0.8751
1710	-5.4919	1785	-2.4448	1860	-0.6076	1935	-1.0852
1715	-5.1001	1790	-2.1791	1865	-0.6791	1940	-1.3406
1720	-6.4802	1795	-1.9315	1870	-0.7553	1945	-1.6473
1725	-6.0647	1800	-1.7046	1875	-0.7811	1950	-2.0068
1730	-5.7193	1805	-1.4984	1880	-0.7711	1955	-2.4335
1735	-5.3955	1810	-1.3133	1885	-0.6840	1960	-2.9068
1740	-5.1475	1815	-1.1486	1890	-0.5704	1965	-3.4595
1745	-4.8233	1820	-1.0036	1895	-0.4791	1970	-4.0370
1750	-4.5194	1825	-0.8776	1900	-0.4138	1975	-4.6795
1755	-4.3184	1830	-0.7699	1905	-0.3950	1980	-4.7664
1760	-3.9664	1835	-0.6811	1910	-0.4189	1985	-4.7903
1765	-3.7045	1840	-0.6124	1915	-0.4794	1990	-4.6311
1770	-3.3398	1845	-0.5663	1920	-0.5751	1995	-4.4528

Table A7

C' VALUE FOR NO2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
1540	-2.9612	1605	1.2926	1670	-2.4451	2900	-0.0934
1545	-2.1733	1610	1.3006	2840	-2.8320	2905	-0.0723
1550	-1.5514	1615	1.3128	2845	-2.3736	2910	-0.0267
1555	-1.0260	1620	1.3449	2850	-1.9565	2915	0.0016
1560	-0.5817	1625	1.3656	2855	-1.5769	2920	-0.0394
1565	-0.2030	1630	1.3245	2860	-1.2400	2925	-0.1700
1570	0.1231	1635	1.1868	2865	-0.9384	2930	-0.4141
1575	0.4098	1640	0.9310	2870	-0.6781	2935	-0.7861
1580	0.6653	1645	0.5907	2875	-0.4630	2940	-1.2951
1585	0.8895	1650	0.2056	2880	-0.2944	2945	-2.0379
1590	1.0716	1655	-0.2337	2885	-0.1783	2950	-3.0984
1595	1.2025	1660	-0.7633	2890	-0.1213		
1600	1.2697	1665	-1.4541	2895	-0.1033		

Table A8

C' VALUE FOR NH3

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
660	-4.9341	915	-0.5100	1170	-1.6841	1460	-2.1212
665	-4.7768	920	-0.1627	1175	-1.7984	1465	-2.0140
670	-4.5938	925	0.0595	1180	-1.9437	1470	-1.8868
675	-4.3749	930	0.1488	1185	-2.0432	1475	-1.8353
680	-4.1982	935	0.0281	1190	-2.1450	1480	-1.7307
685	-4.0293	940	-0.2419	1195	-2.2407	1485	-1.6113
690	-3.8234	945	-0.5056	1200	-2.4288	1490	-1.5590
695	-3.6327	950	-0.4987	1205	-2.5620	1495	-1.4623
700	-3.4693	955	-0.2867	1210	-2.7198	1500	-1.3716
705	-3.3029	960	-0.0587	1215	-2.9606	1505	-1.3386
710	-3.1214	965	0.0428	1220	-3.1045	1510	-1.2717
715	-2.9817	970	-0.1298	1225	-3.2475	1515	-1.2039
720	-2.8317	975	-0.4164	1230	-3.4040	1520	-1.1798
725	-2.6983	980	-0.7749	1235	-3.6805	1525	-1.1452
730	-2.5246	985	-1.1858	1240	-3.8494	1530	-1.1172
735	-2.3539	990	-1.1686	1245	-4.0514	1535	-1.1408
740	-2.2043	995	-1.0070	1250	-4.3797	1540	-1.1639
745	-2.0501	1000	-0.9132	1255	-4.5783	1545	-1.1725
750	-1.9518	1005	-0.8298	1260	-4.7647	1550	-1.2132
755	-1.8494	1010	-0.7863	1300	-7.3952	1555	-1.2481
760	-1.7400	1015	-0.7886	1305	-[illegible].1910	1560	-1.2675
765	-1.6151	1020	-0.7423	1310	-7.4919	1565	-1.3185
770	-1.4915	1025	-0.6954	1315	-7.2079	1570	-1.3827
775	-1.3762	1030	-0.6174	1320	-7.6170	1575	-1.4162
780	-1.2546	1035	-0.5505	1325	-7.2198	1580	-1.4494
785	-1.2019	1040	-0.5353	1330	-6.8949	1585	-1.4850
790	-1.1593	1045	-0.5225	1335	-6.5680	1590	-1.4669
795	-1.1205	1050	-0.5341	1340	-6.3074	1595	-1.4293
800	-1.0624	1055	-0.5582	1345	-6.0441	1600	-1.3651
805	-0.9933	1060	-0.5597	1350	-5.7979	1605	-1.1944
810	-0.9223	1065	-0.5469	1355	-5.5944	1610	-0.9926
815	-0.8408	1070	-0.5302	1360	-5.3634	1615	-0.7724
820	-0.8162	1075	-0.5105	1365	-5.1414	1620	-0.5642
825	-0.8055	1080	-0.5307	1370	-4.8809	1625	-0.4187
830	-0.8144	1085	-0.5574	1375	-4.6796	1630	-0.3624
835	-0.8371	1090	-0.6223	1380	-4.5039	1635	-0.3733
840	-0.8369	1095	-0.6887	1385	-4.3317	1640	-0.4224
845	-0.8209	1100	-0.7404	1390	-4.1864	1645	-0.4976
850	-0.7950	1105	-0.7807	1395	-4.0550	1650	-0.5992
855	-0.7933	1110	-0.8110	1400	-3.8773	1655	-0.7177
860	-0.8461	1115	-0.8389	1405	-3.6570	1660	-0.8393
865	-0.9037	1120	-0.8775	1410	-3.4706	1665	-0.9737
870	-0.9816	1125	-0.9553	1415	-3.3075	1670	-1.1044
875	-1.0600	1130	-1.0419	1420	-3.1389	1675	-1.1958
880	-1.0776	1135	-1.1318	1425	-2.9973	1680	-1.2569
885	-1.0928	1140	-1.1937	1430	-2.8696	1685	-1.2831
890	-1.0888	1145	-1.2768	1435	-2.7134	1690	-1.2384
895	-1.1118	1150	-1.3430	1440	-2.5529	1695	-1.1918
900	-1.1490	1155	-1.4061	1445	-2.4479	1700	-1.1441
905	-1.1097	1160	-1.4710	1450	-2.3261	1705	-1.0739
910	-0.8999	1165	-1.5791	1455	-2.1880	1710	-1.0268

C' VALUE FOR NH3

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
1715	-1.0058	1765	-1.0909	1815	-1.6031	1865	-2.2126
1720	-1.0062	1770	-1.1256	1820	-1.6977	1870	-2.1714
1725	-1.0087	1775	-1.1630	1825	-1.8202	1875	-2.1803
1730	-1.0064	1780	-1.2036	1830	-1.8948	1880	-2.2731
1735	-0.9734	1785	-1.2444	1835	-1.9623	1885	-2.4550
1740	-0.9503	1790	-1.2782	1840	-2.0170	1890	-2.6636
1745	-0.9755	1795	-1.3410	1845	-2.0618	1895	-2.8875
1750	-1.0121	1800	-1.4087	1850	-2.1687	1900	-3.1030
1755	-1.0538	1805	-1.4636	1855	-2.2386		
1760	-1.0781	1810	-1.5330	1860	-2.2434		

Table A9

C' VALUE FOR SO2

WAVE #	C'	WAVE #	C'	WAVE #	C'	WAVE #	C'
420	-5.2563	610	-2.1065	1210	-0.7019	1400	-1.0612
425	-4.4248	615	-2.5705	1215	-0.8299	1405	-1.7715
430	-3.7369	620	-3.1238	1220	-0.9729	1410	-2.6089
435	-3.0917	625	-3.7691	1225	-1.1305	1415	-3.0225
440	-2.5200	630	-4.5793	1230	-1.3036	1420	-3.3542
445	-2.0303	635	-5.7012	1235	-1.4924	1425	-3.7339
450	-1.6307	1050	-2.4522	1240	-1.7000	1430	-4.1986
455	-1.3056	1055	-2.1783	1245	-1.9306	1435	-4.7852
460	-1.0373	1060	-1.9317	1250	-2.1906	1440	-5.6390
465	-0.8189	1065	-1.7073	1255	-2.4959	2430	-6.1933
470	-0.6395	1070	-1.5004	1260	-2.8613	2435	-5.3530
475	-0.4880	1075	-1.3136	1265	-3.3176	2440	-4.8602
480	-0.3574	1080	-1.1444	1270	-3.9236	2445	-4.1286
485	-0.2369	1085	-0.9901	1275	-4.6847	2450	-2.9922
490	-0.1237	1090	-0.8505	1280	-5.2561	2455	-2.3525
495	-0.0261	1095	-0.7238	1285	-4.7082	2460	-1.8905
500	0.0250	1100	-0.6083	1290	-4.1110	2465	-1.5178
505	0.0186	1105	-0.5025	1295	-3.6582	2470	-1.2295
510	-0.0194	1110	-0.4016	1300	-3.1963	2475	-1.0082
515	-0.0659	1115	-0.3047	1305	-2.7063	2480	-0.8484
520	-0.0638	1120	-0.2112	1310	-1.9643	2485	-0.7634
525	-0.0065	1125	-0.1263	1315	-1.3089	2490	-0.7340
530	0.0468	1130	-0.0656	1320	-0.6856	2495	-0.7203
535	0.0682	1135	-0.0414	1325	-0.0412	2500	-0.7167
540	0.0355	1140	-0.0509	1330	0.3678	2505	-0.7097
545	-0.0431	1145	-0.0731	1335	0.6712	2510	-0.7297
550	-0.1334	1150	-0.0802	1340	0.9031	2515	-0.8391
555	-0.2175	1155	-0.0483	1345	1.0577	2520	-1.0472
560	-0.2954	1160	0.0032	1350	1.1145	2525	-1.3607
565	-0.3738	1165	0.0339	1355	1.1272	2530	-1.7720
570	-0.4588	1170	0.0249	1360	1.1300	2535	-2.2957
575	-0.5571	1175	-0.0296	1365	1.1237	2540	-3.0566
580	-0.6729	1180	-0.1170	1370	1.1459	2545	-4.1073
585	-0.8131	1185	-0.2141	1375	1.1047	2550	-4.5337
590	-0.9805	1190	-0.3069	1380	0.9617	2555	-4.9481
595	-1.1831	1195	-0.3968	1385	0.7107	2560	-5.4542
600	-1.4334	1200	-0.4881	1390	0.3254	2565	-6.2445
605	-1.7354	1205	-0.5881	1395	-0.2322		

APPENDIX B

Sample Comparison Between High-Resolution and Degraded Line-By - Line Calculations and Measured Transmittance Spectra for CO_2, CH_4, NO_2, N_2O and SO_2.

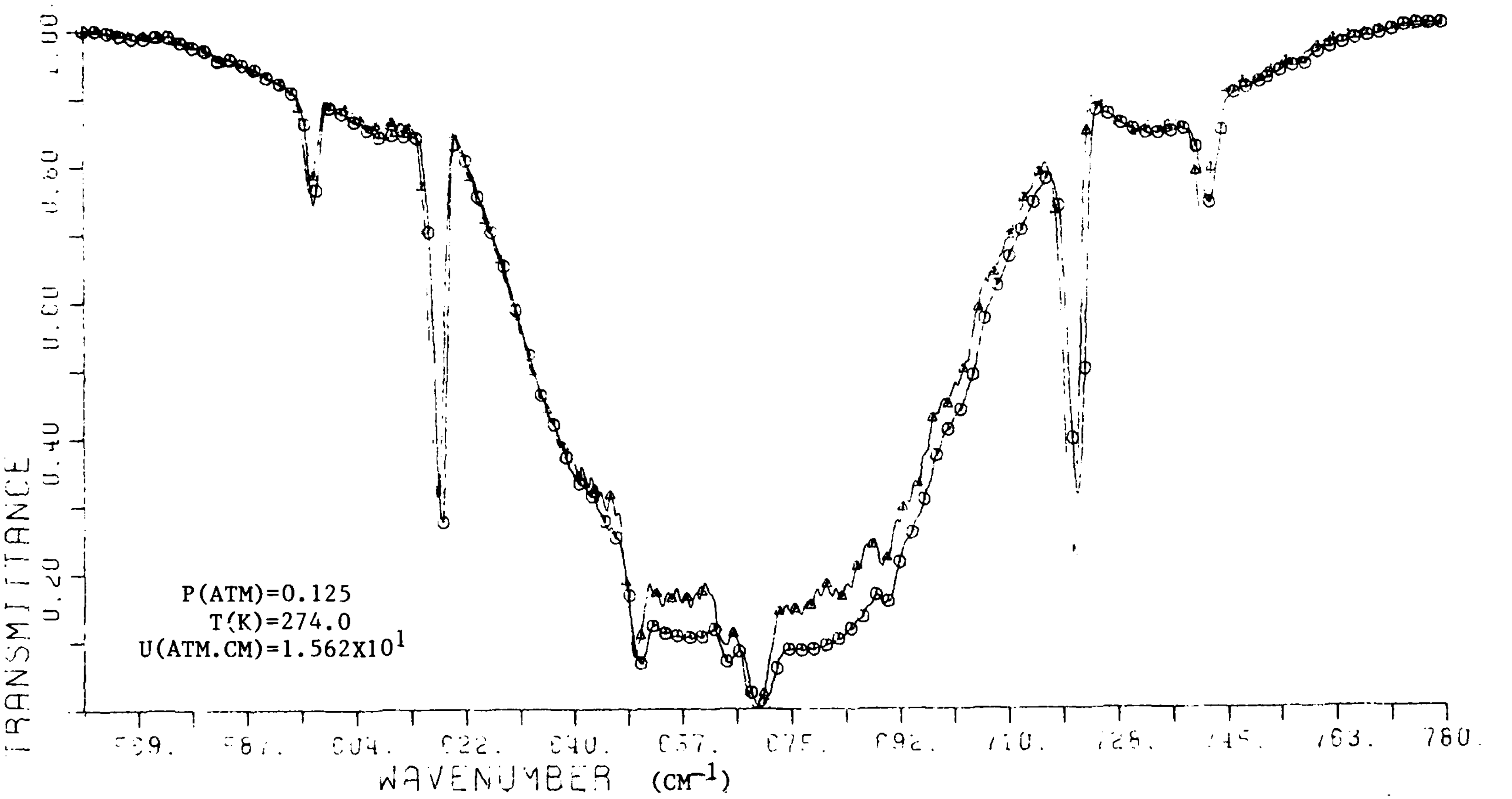


Figure B1(a). Comparison between high-resolution CO_2 line-by-line (Δ) and measured (O) transmittance spectra for Burch sample ZF04, file 108.

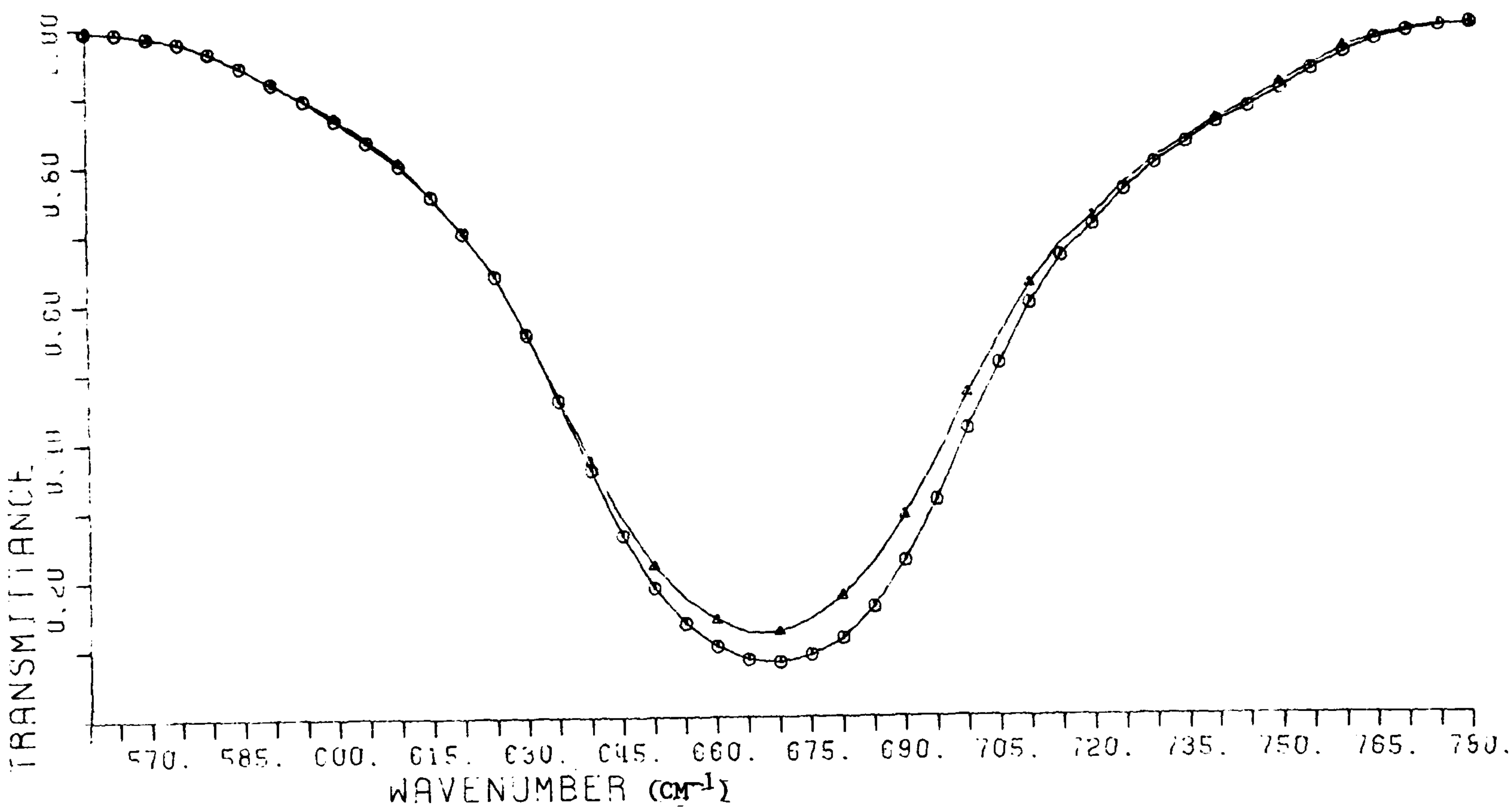


Figure B1(b). Transmittance spectra of Fig.B1(a) degraded to 20 cm^{-1} resolution.

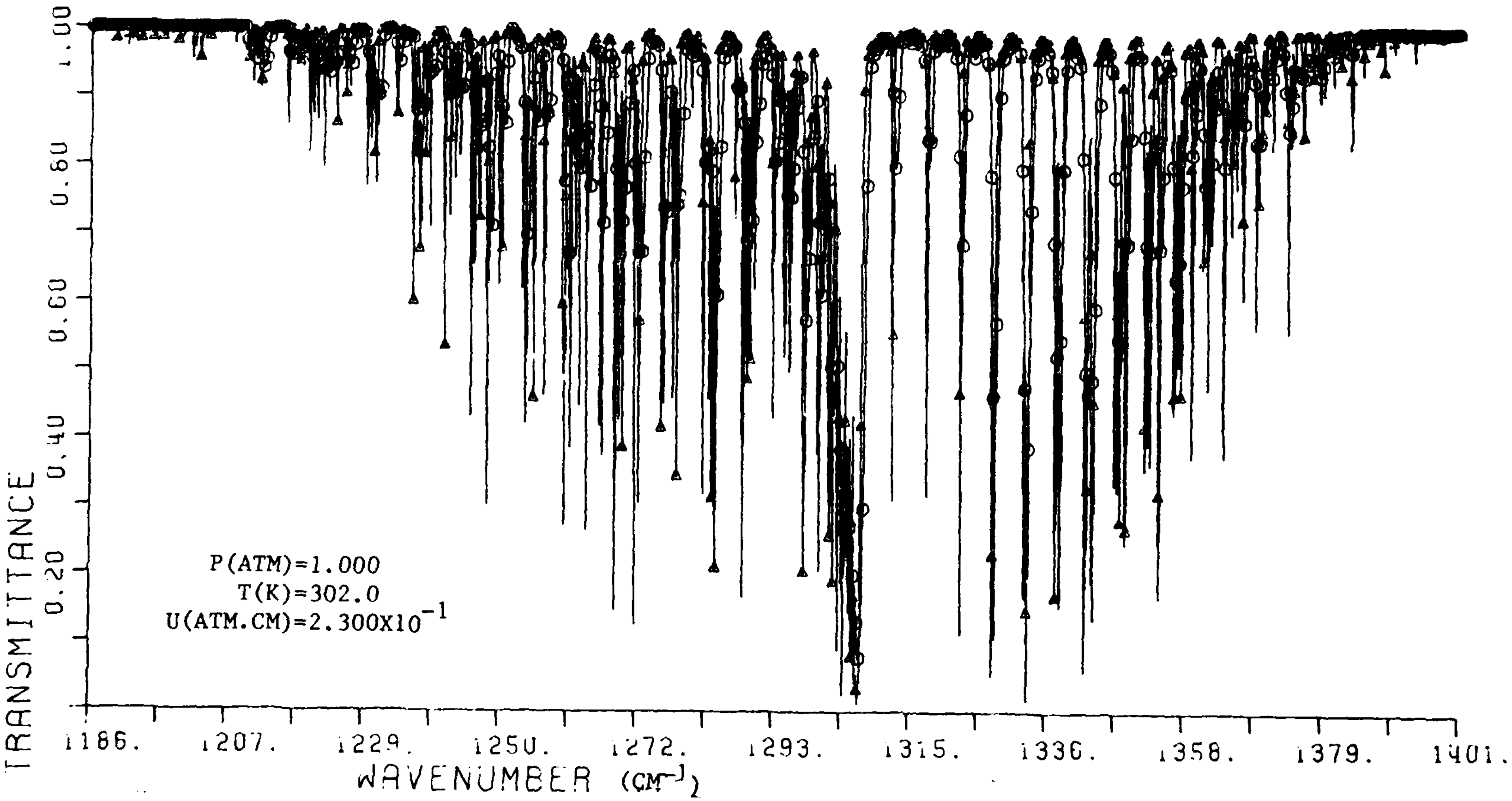


Figure B2(a). Comparison between high-resolution CH_4 line-by-line (Δ) and measured transmittance spectra for Burch sample 510CH, file 100.

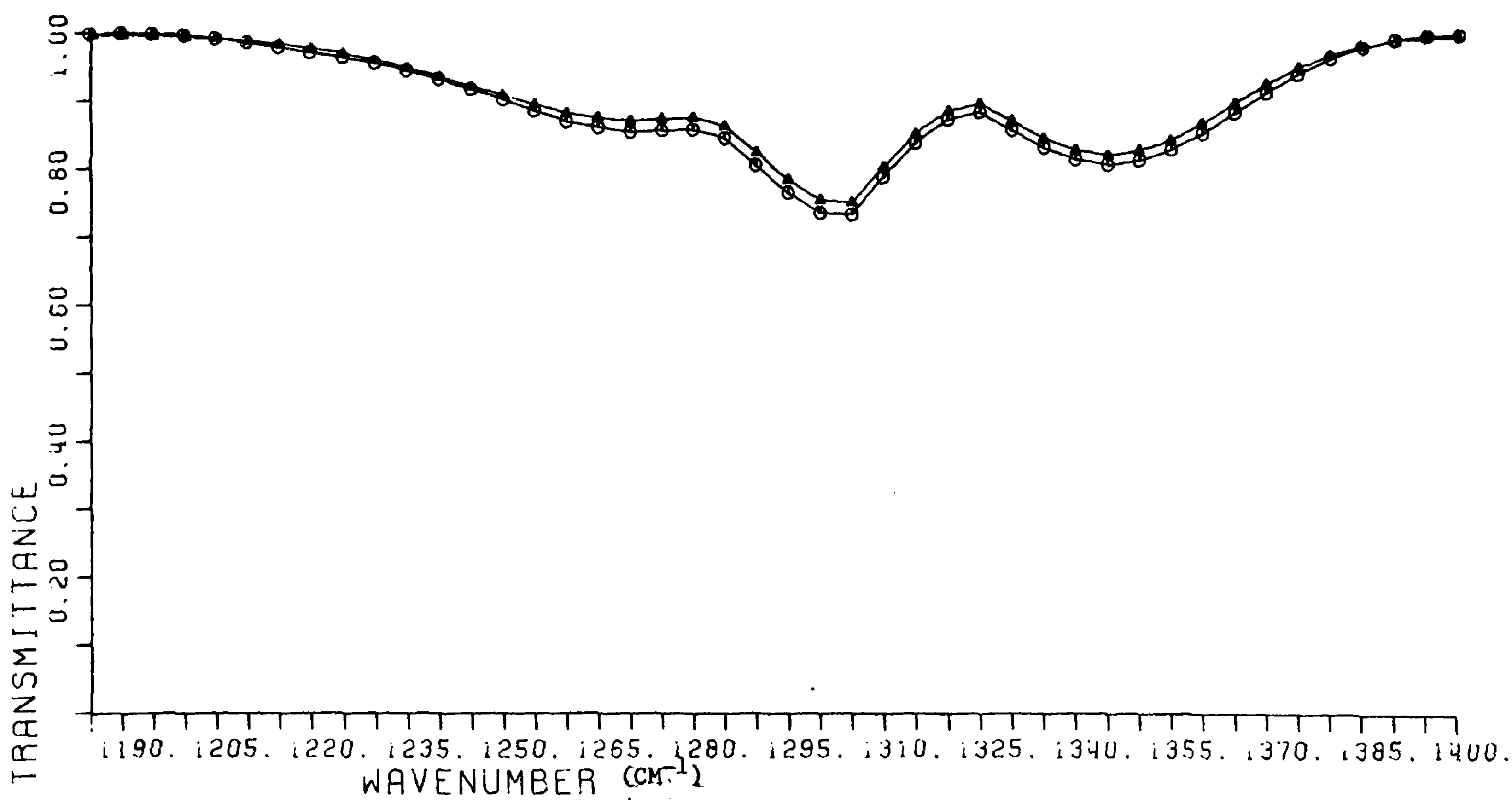


Figure B2(b). Transmittance spectra of Fig.B2(a) degraded to 20 cm^{-1} resolution.

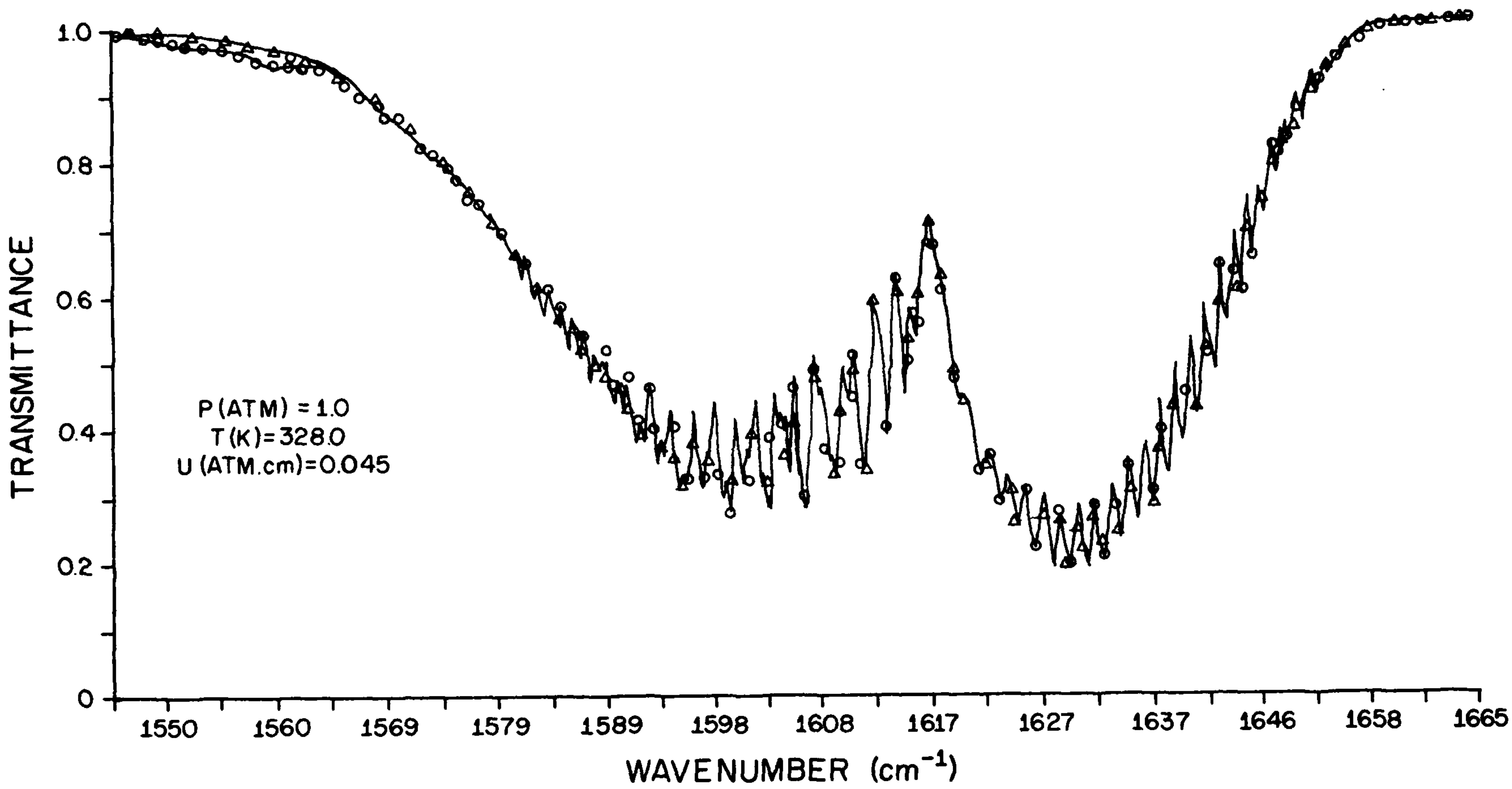


Figure B3(a). Comparison between high resolution NO_2 line-by-line (Δ) and measured (O) transmittance spectra for Burch sample 310ND, file 95.

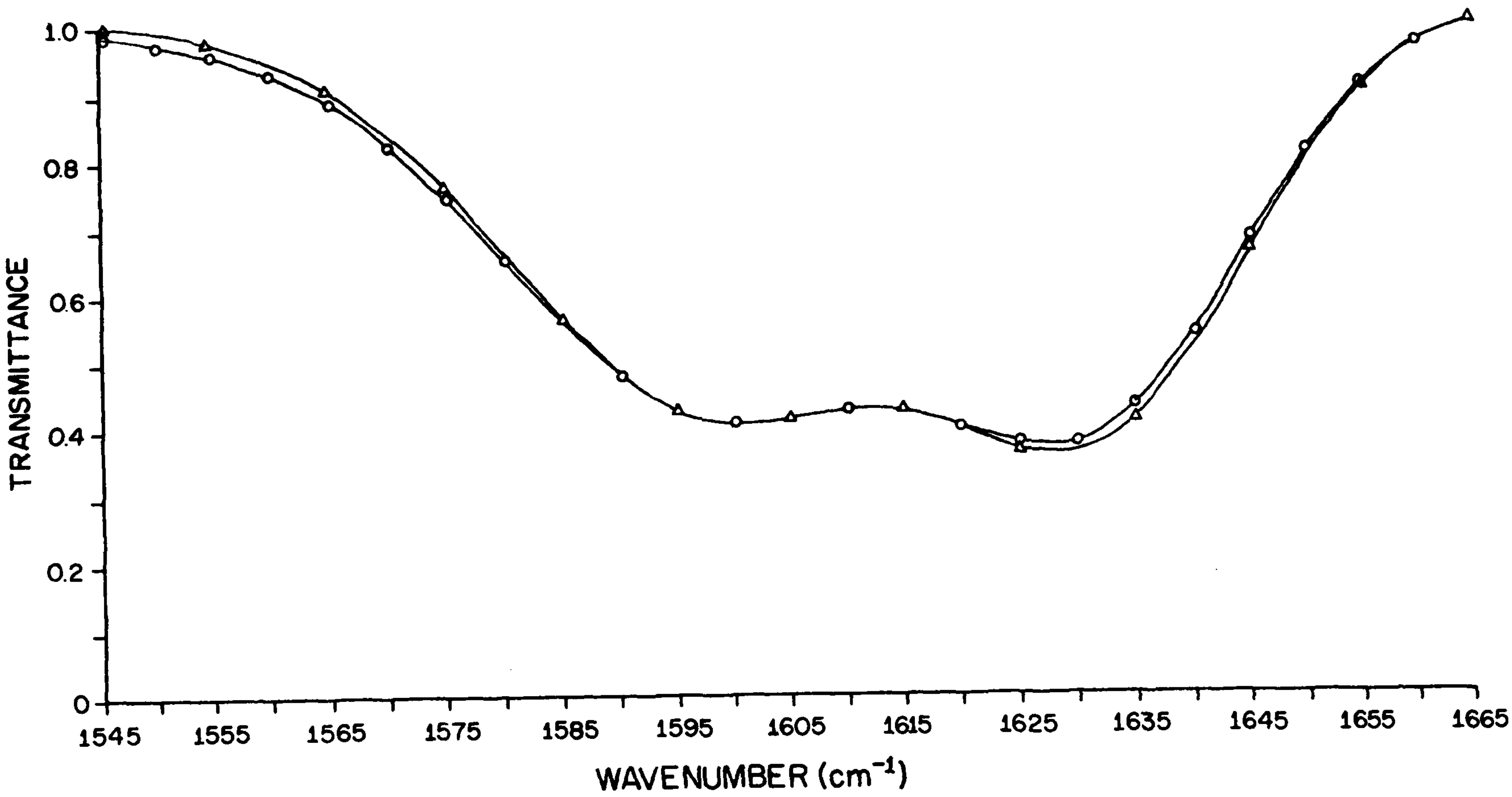


Figure B3(b) . Transmittance spectra of Fig. B3(a) degraded to 20 cm^{-1} resolution

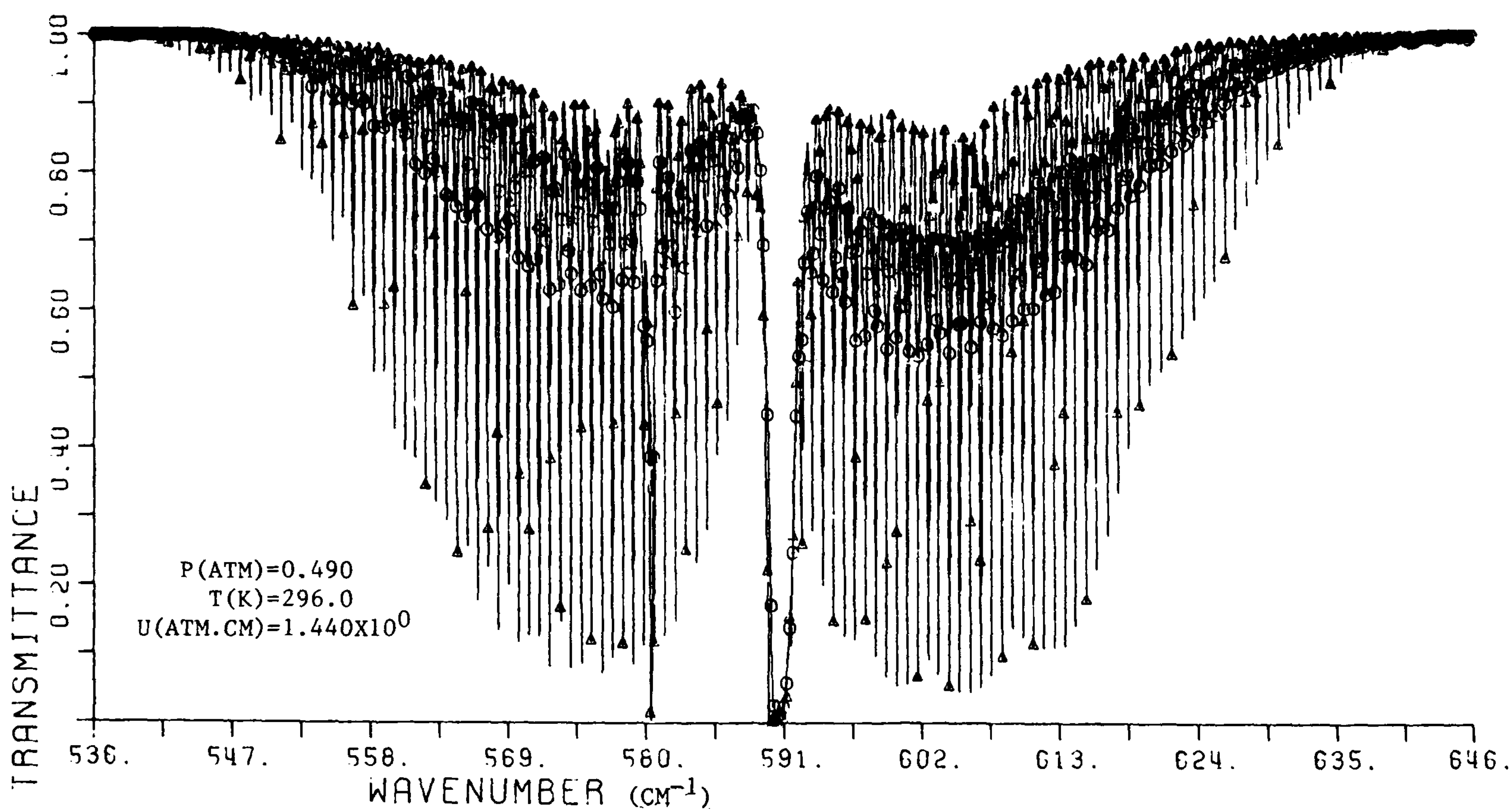


Figure B4(a). Comparison between high-resolution N_2O line-by-line (Δ) and measured (O) transmittance spectra for Burch sample 17373, file 83.

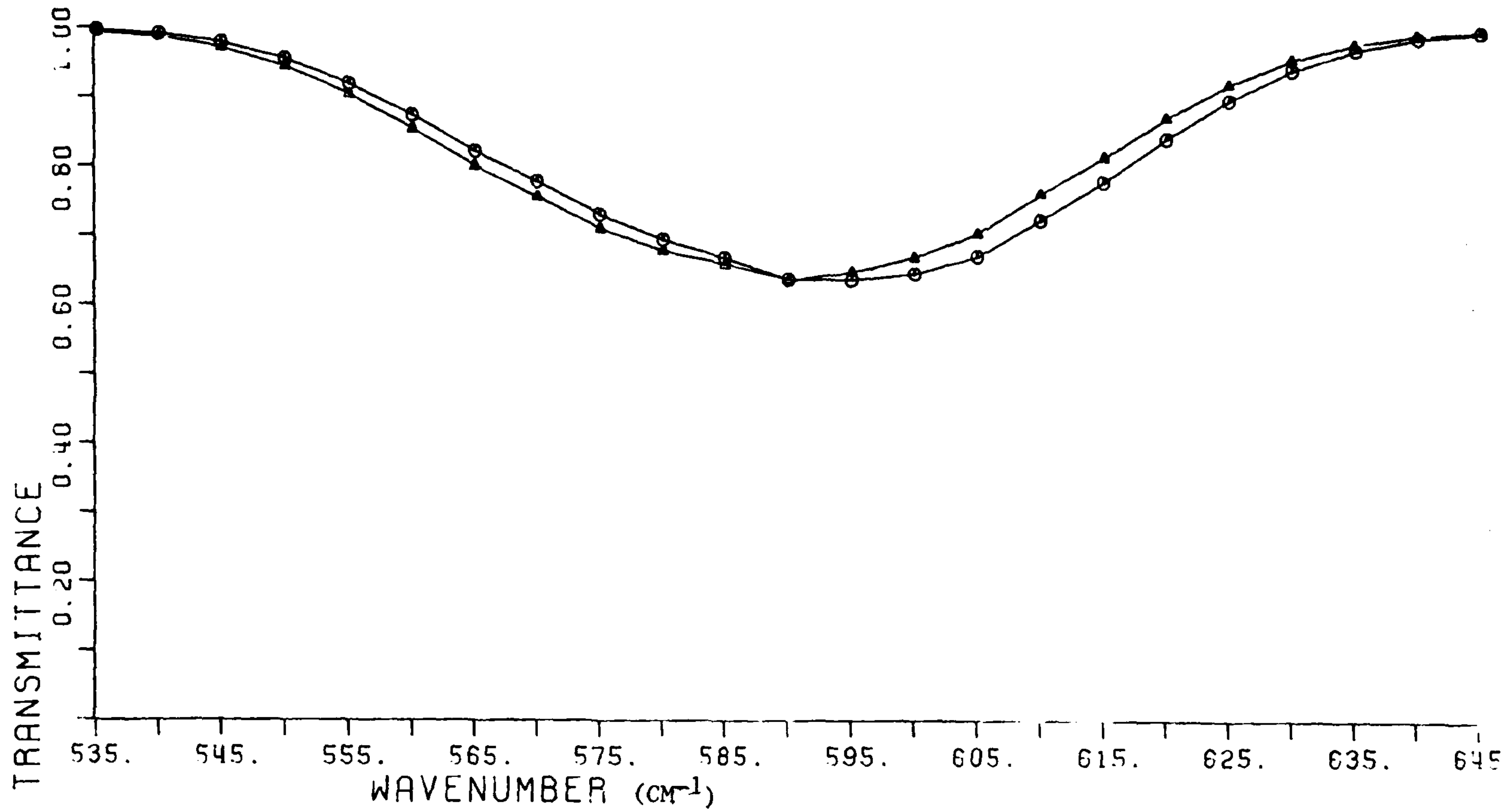


Figure B4(b). Transmittance spectra of Fig.B4(a) degraded to 20 cm^{-1} resolution.

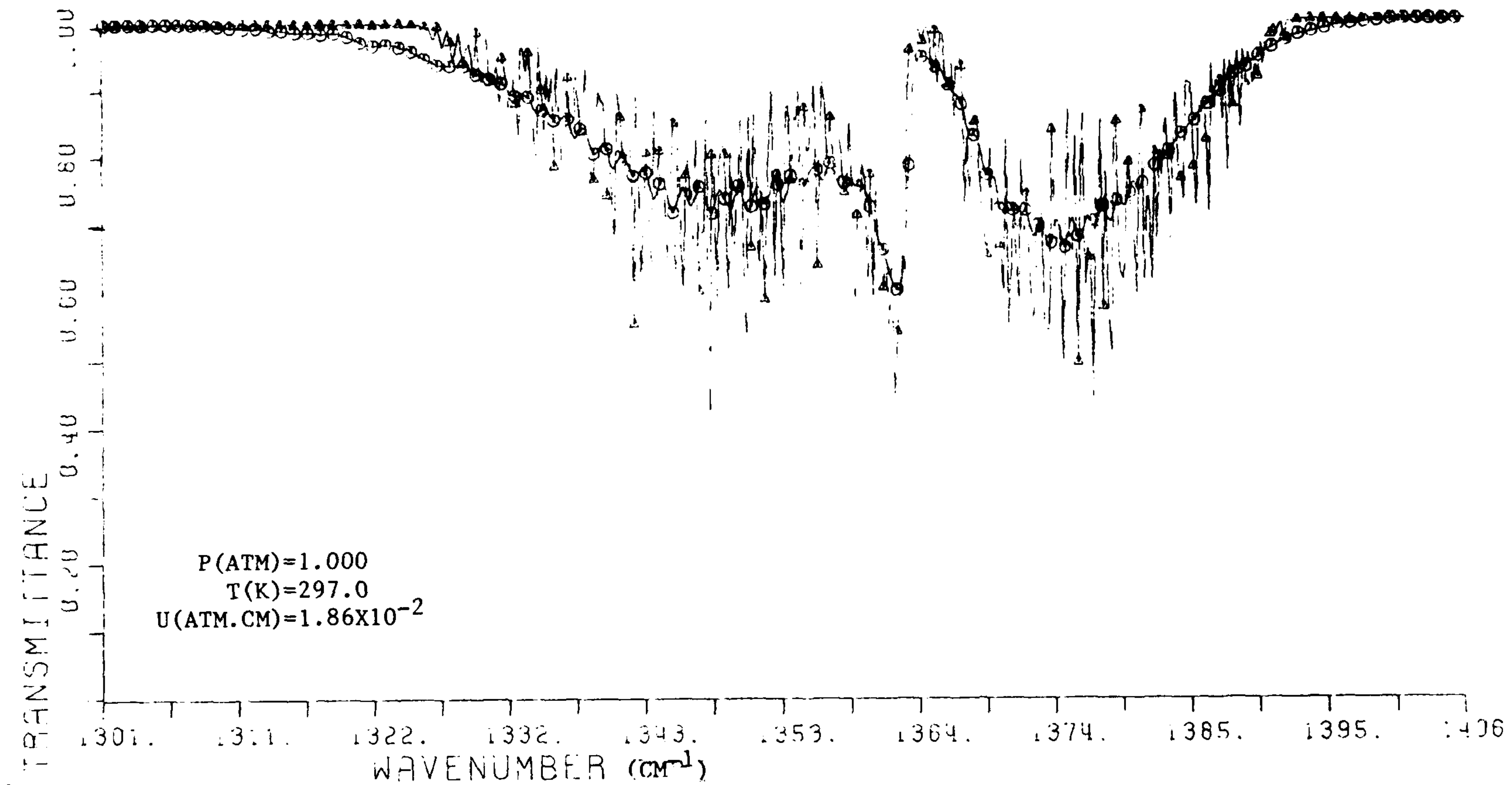


Figure B5(a). Comparison between high-resolution SO_2 line-by-line (Δ) and measured (O) transmittance spectra for Burch sample 28, file 9.

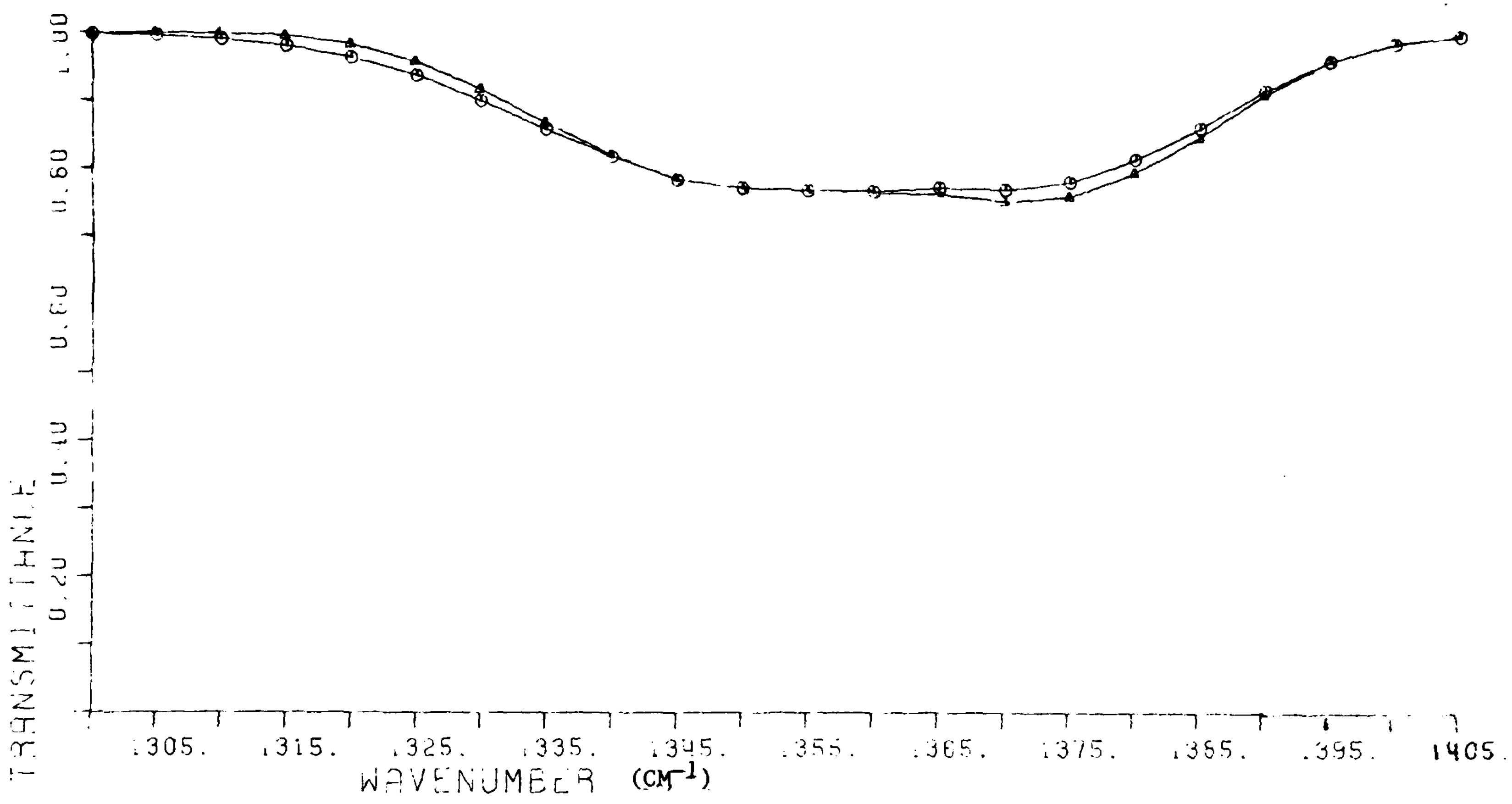


Figure B5(b). Transmittance spectra of Fig.B5(a) degraded to 20 cm^{-1} resoluiton.

APPENDIX C

Sample Comparisons Between Degraded Line-By-Line or Measured Transmittance Spectra, and Band Model Calculations for CO_2, CH_4, NO_2, N_2O and SO_2.

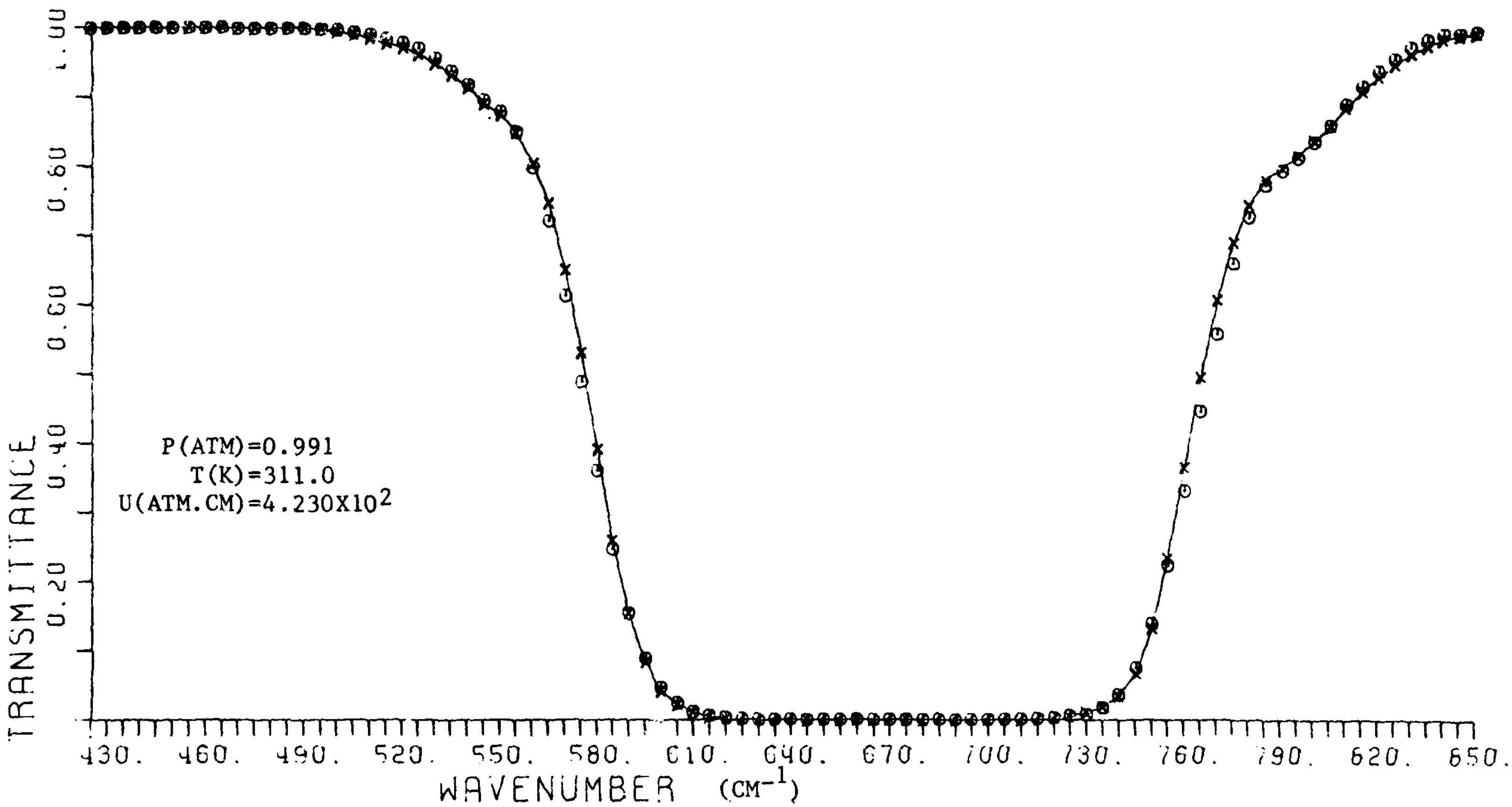


Figure C1. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (0) and proposed band model calculations (X).

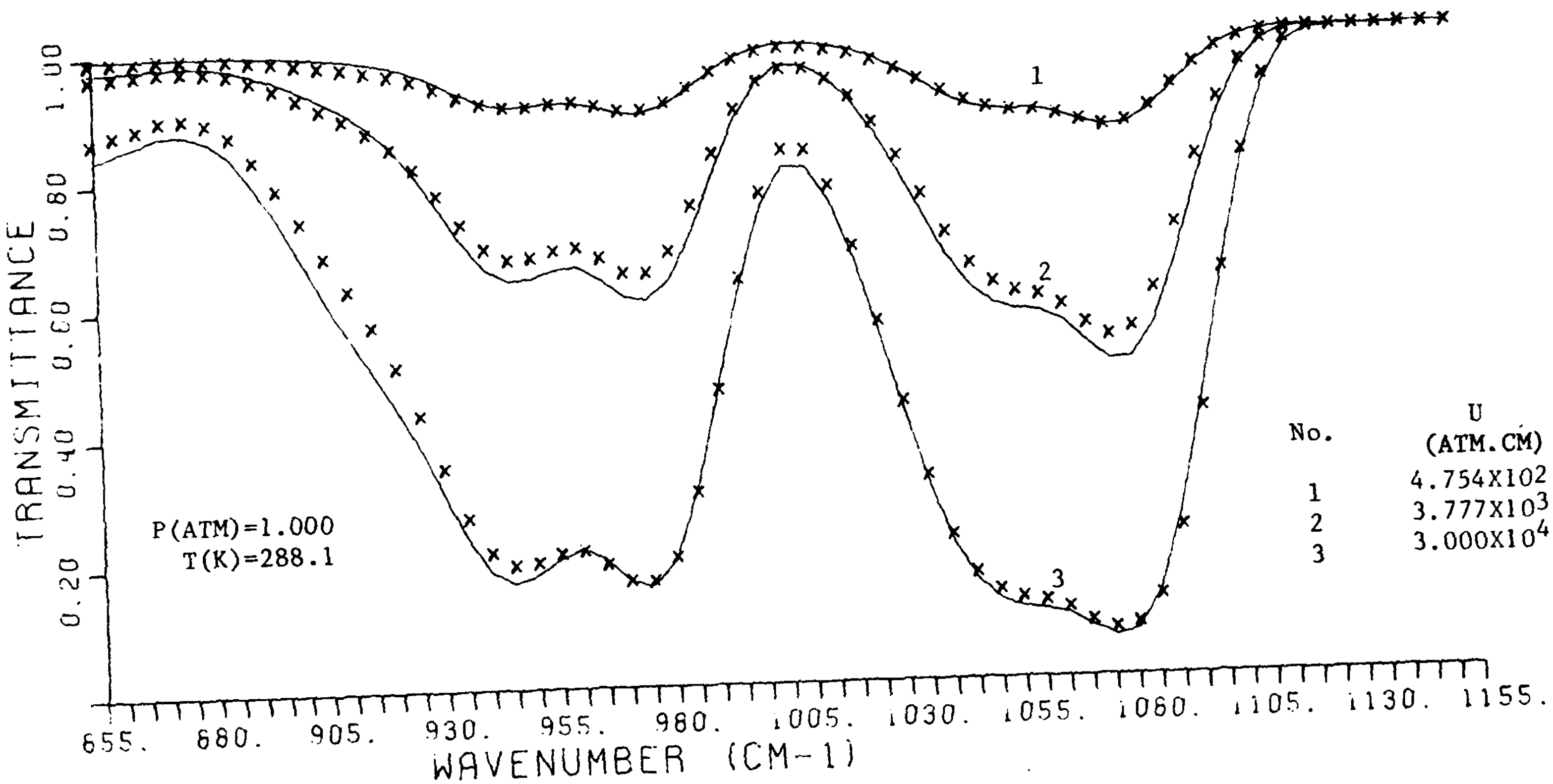


Figure C2. Comparison between 20 cm^{-1} degraded CO_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

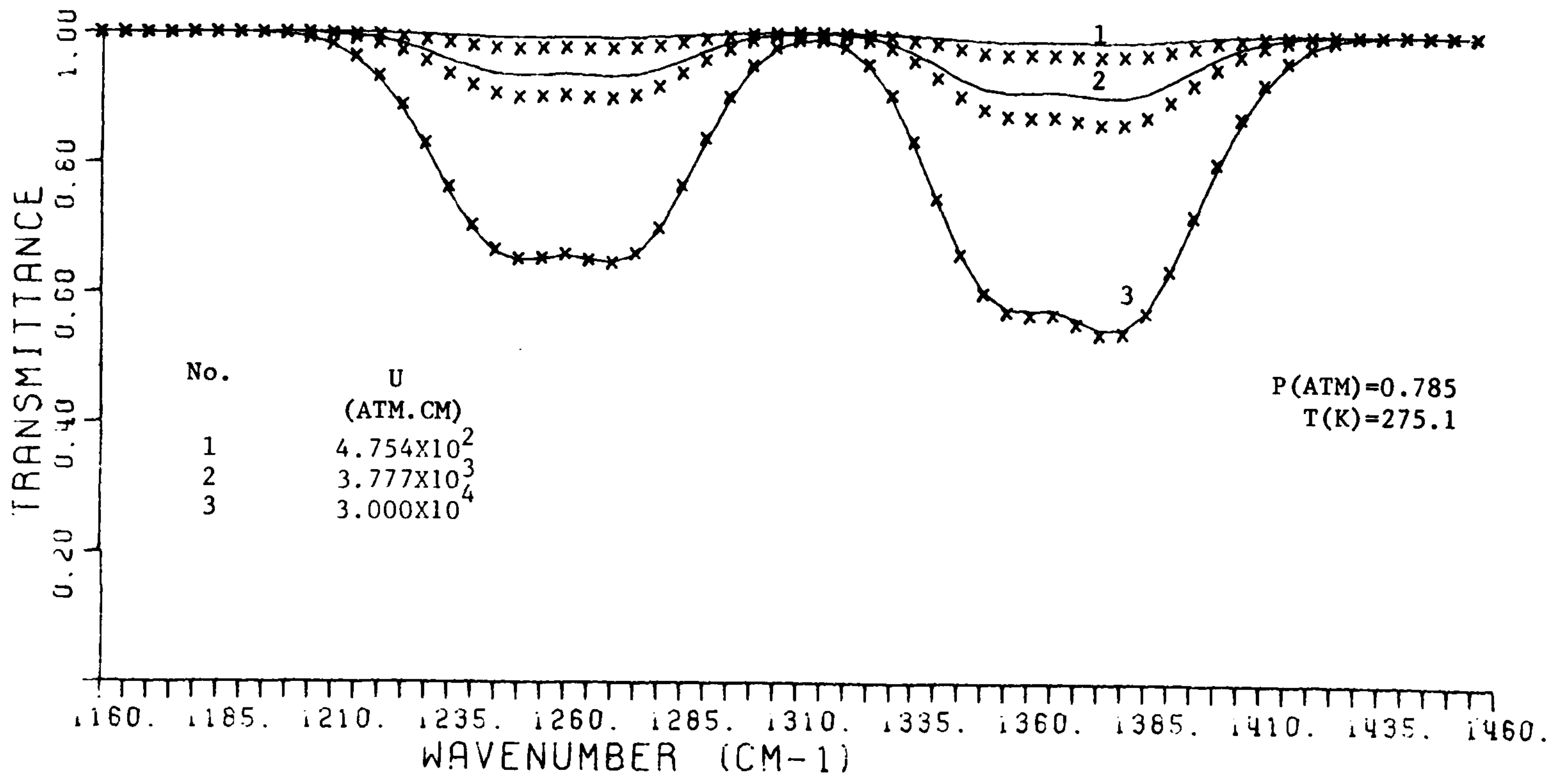


Figure C3. Comparison between 20 cm^{-1} degraded CO_2 line-by-line transmittance spectra (—) and proposed band model (X).

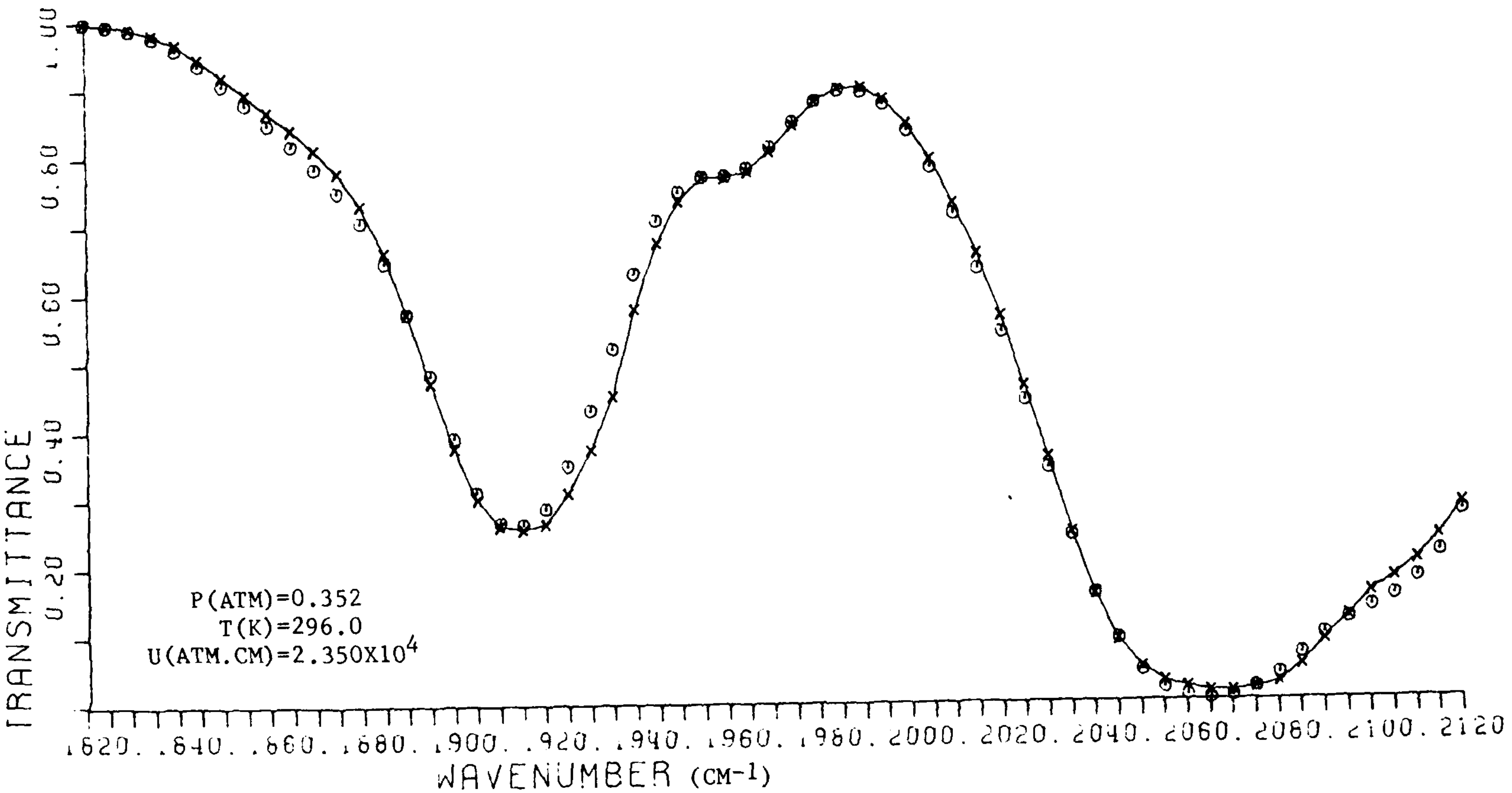


Figure C4. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (O) and proposed band model calculations (X).

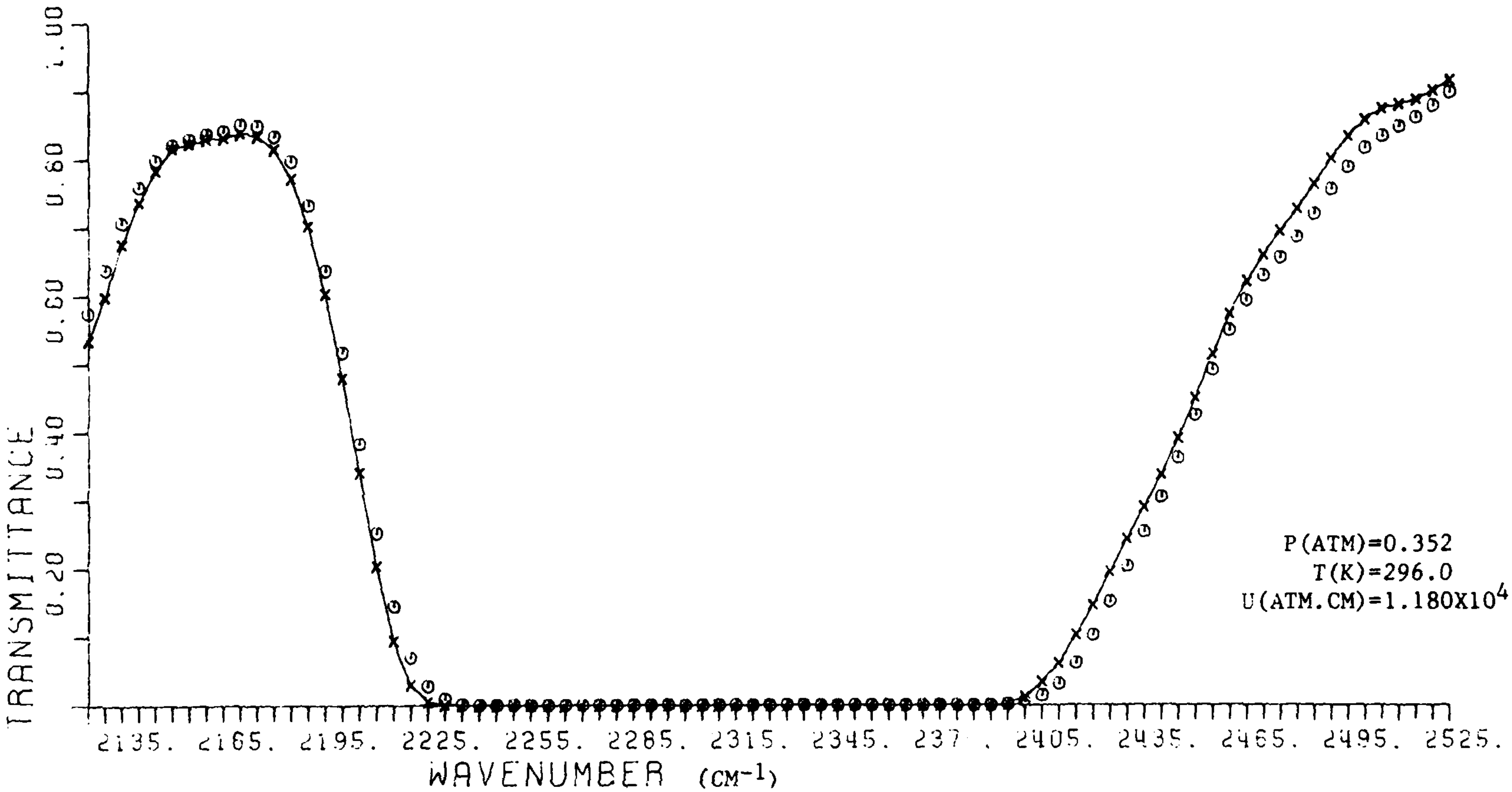


Figure C5. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (O) and proposed band model calculations (X).

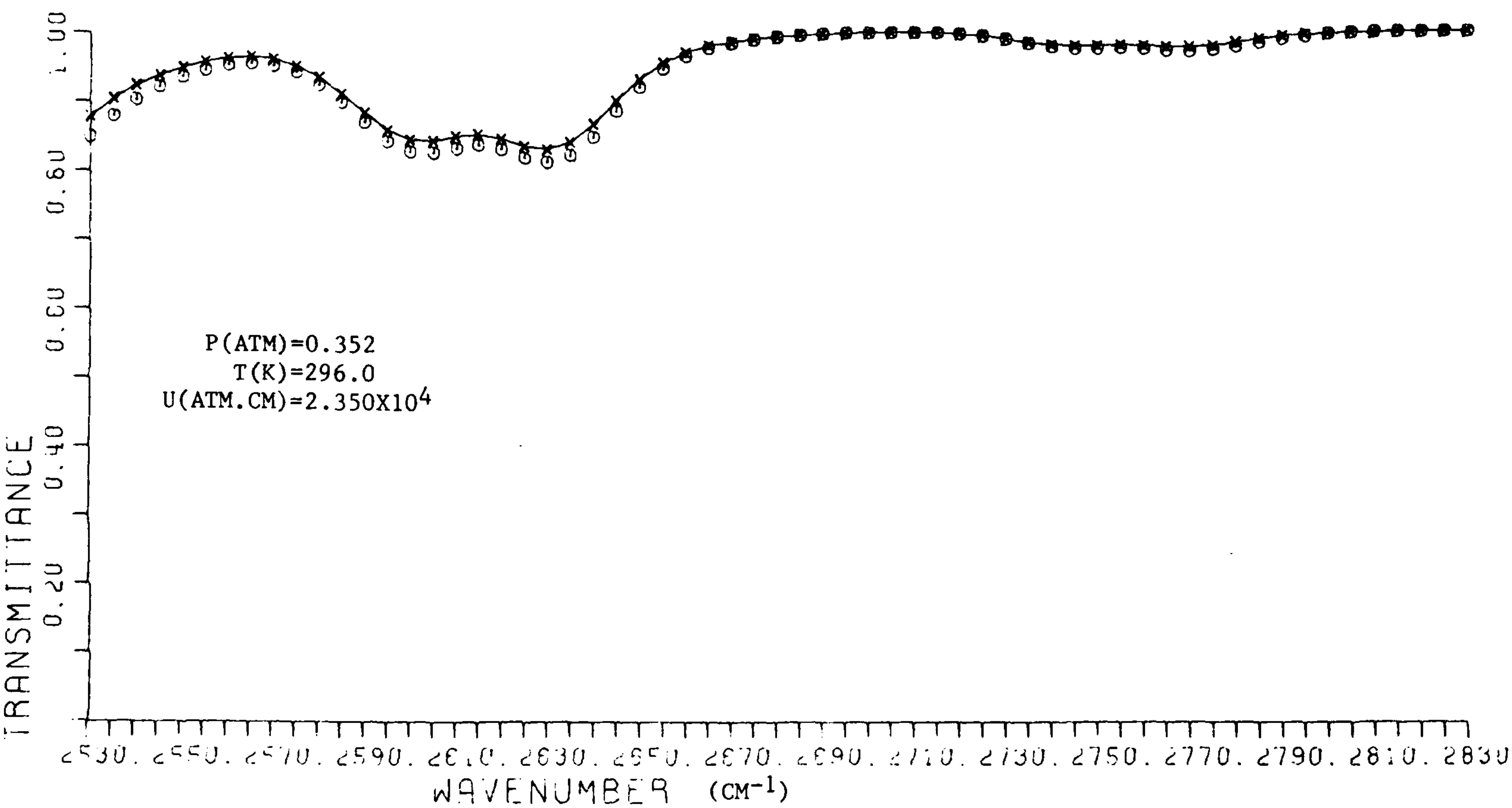


Figure C6. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (0) and proposed band model calculations (X).

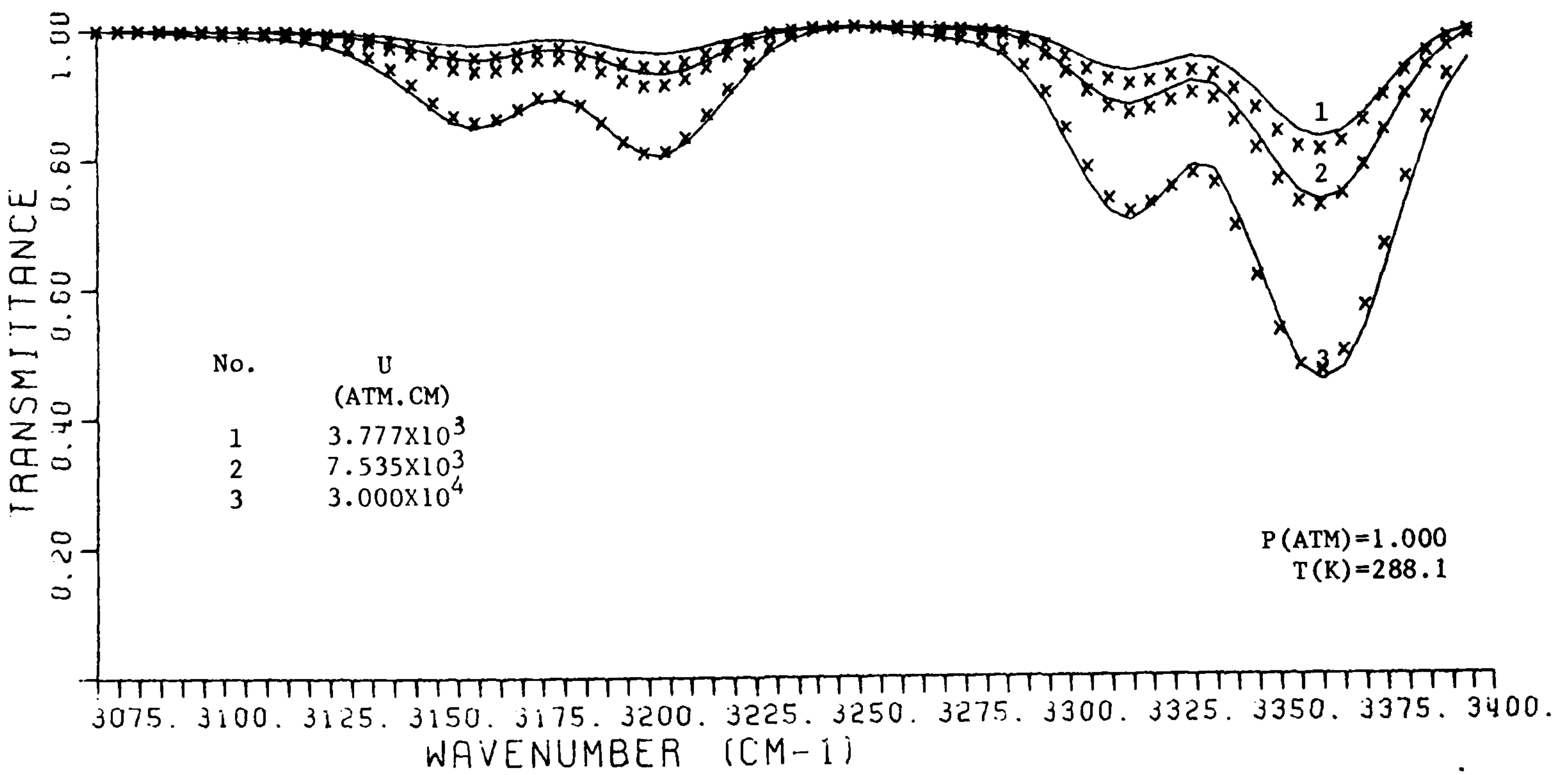


Figure C7. Comparison between 20 cm^{-1} degraded CO_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

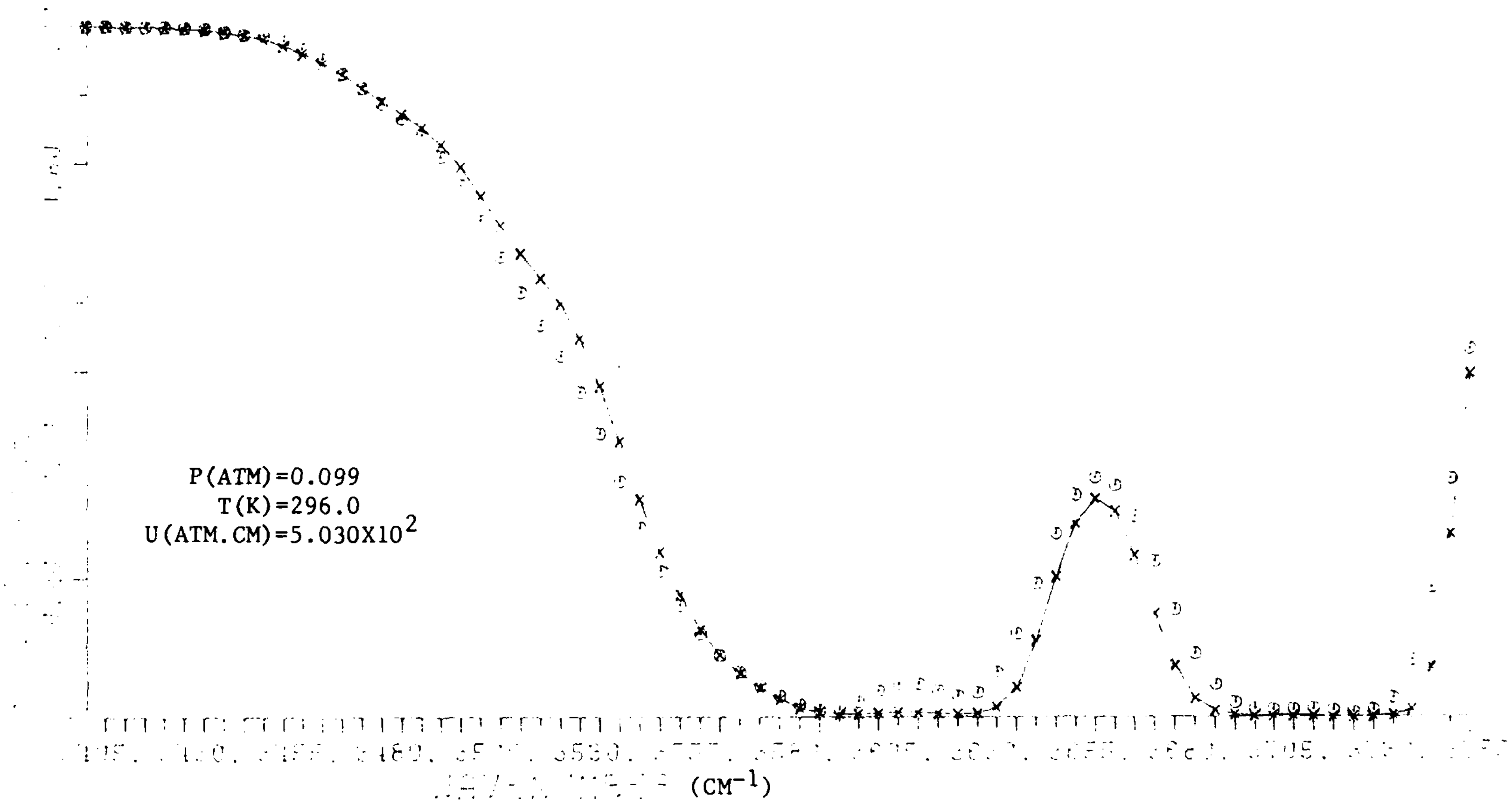


Figure C8. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (0) and proposed band model calculations (X).

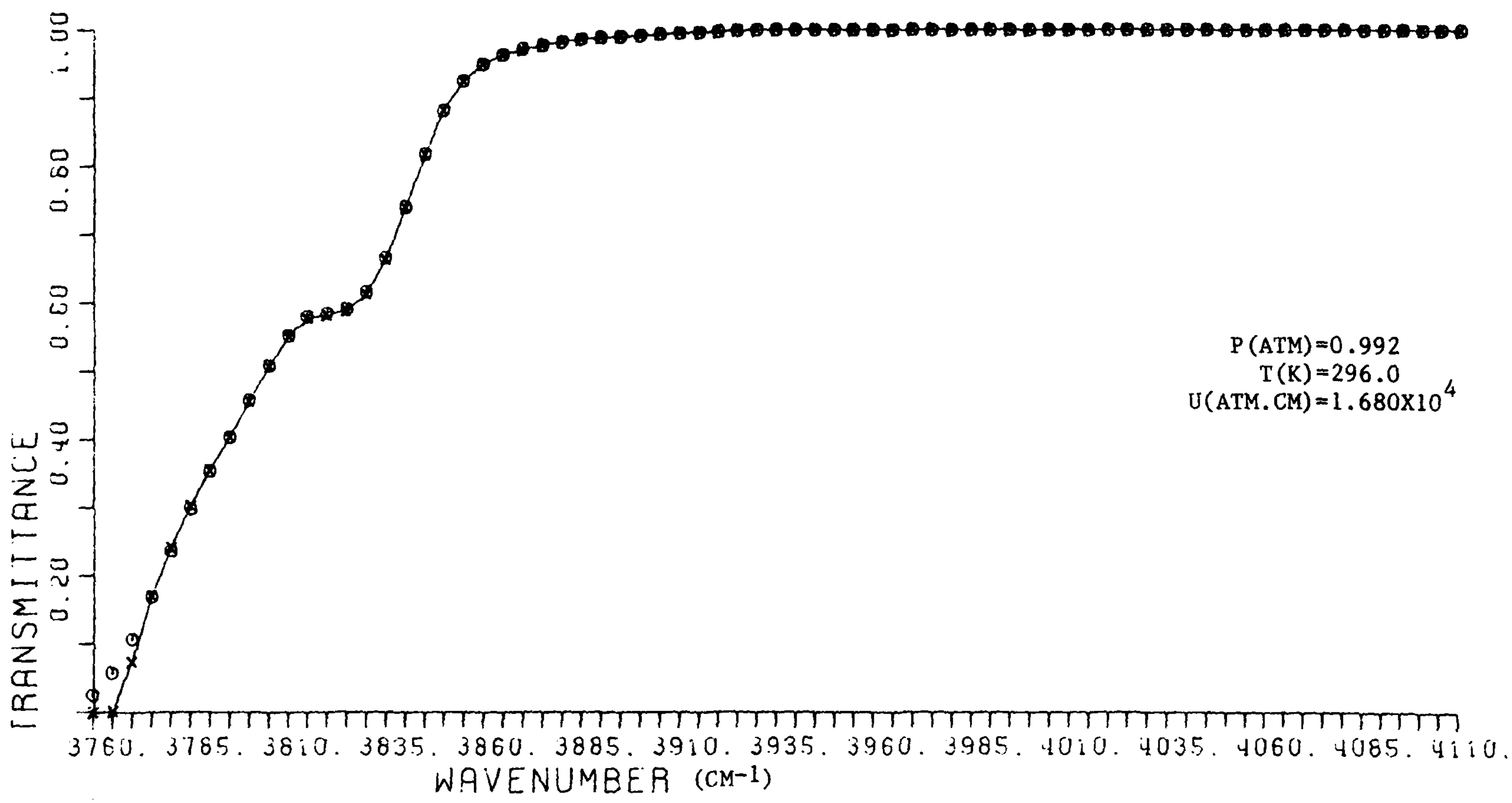


Figure C9. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (0) and proposed band model calculations (X).

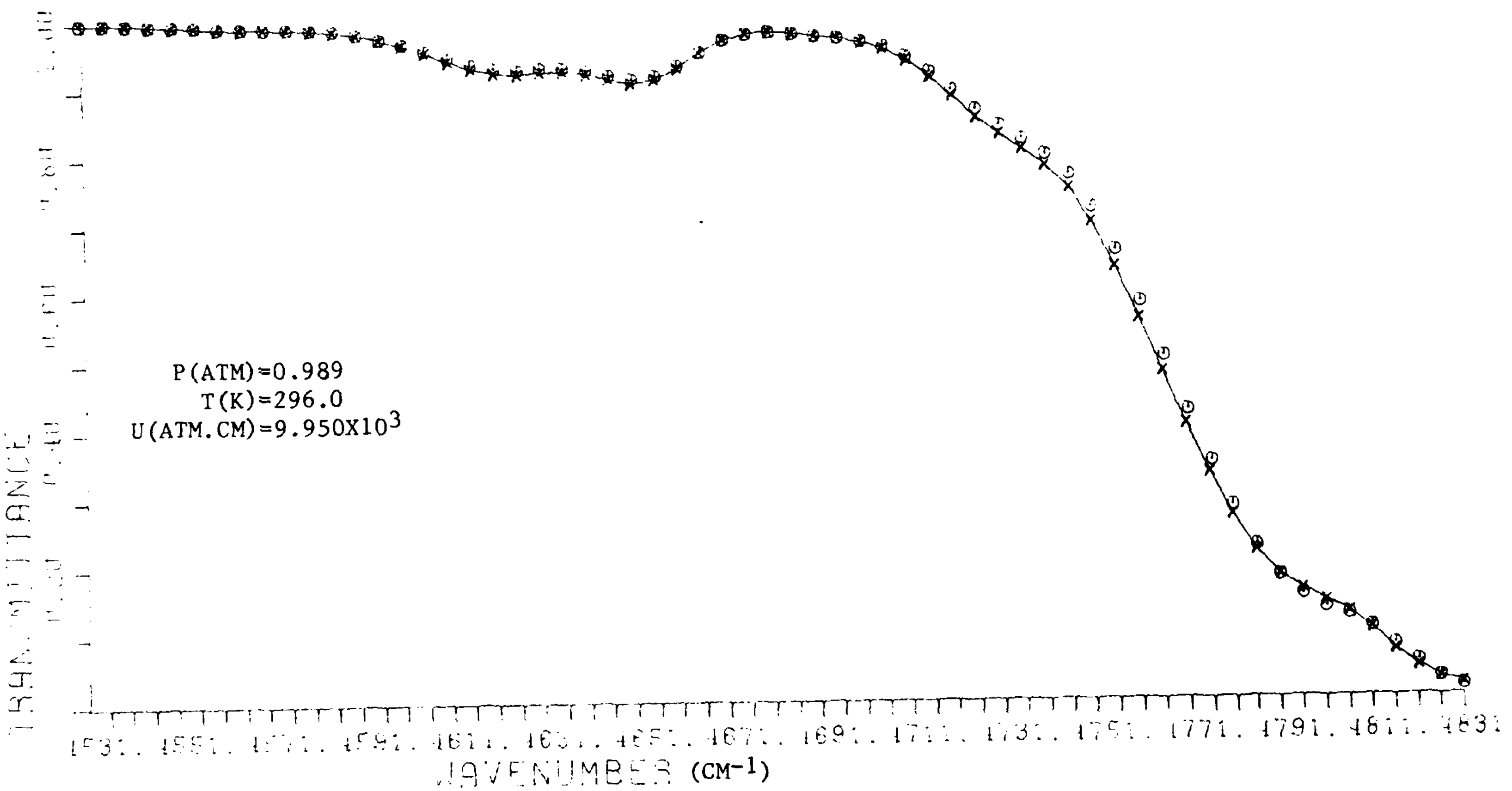


Figure C10. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (0) and proposed band model calculations (X).

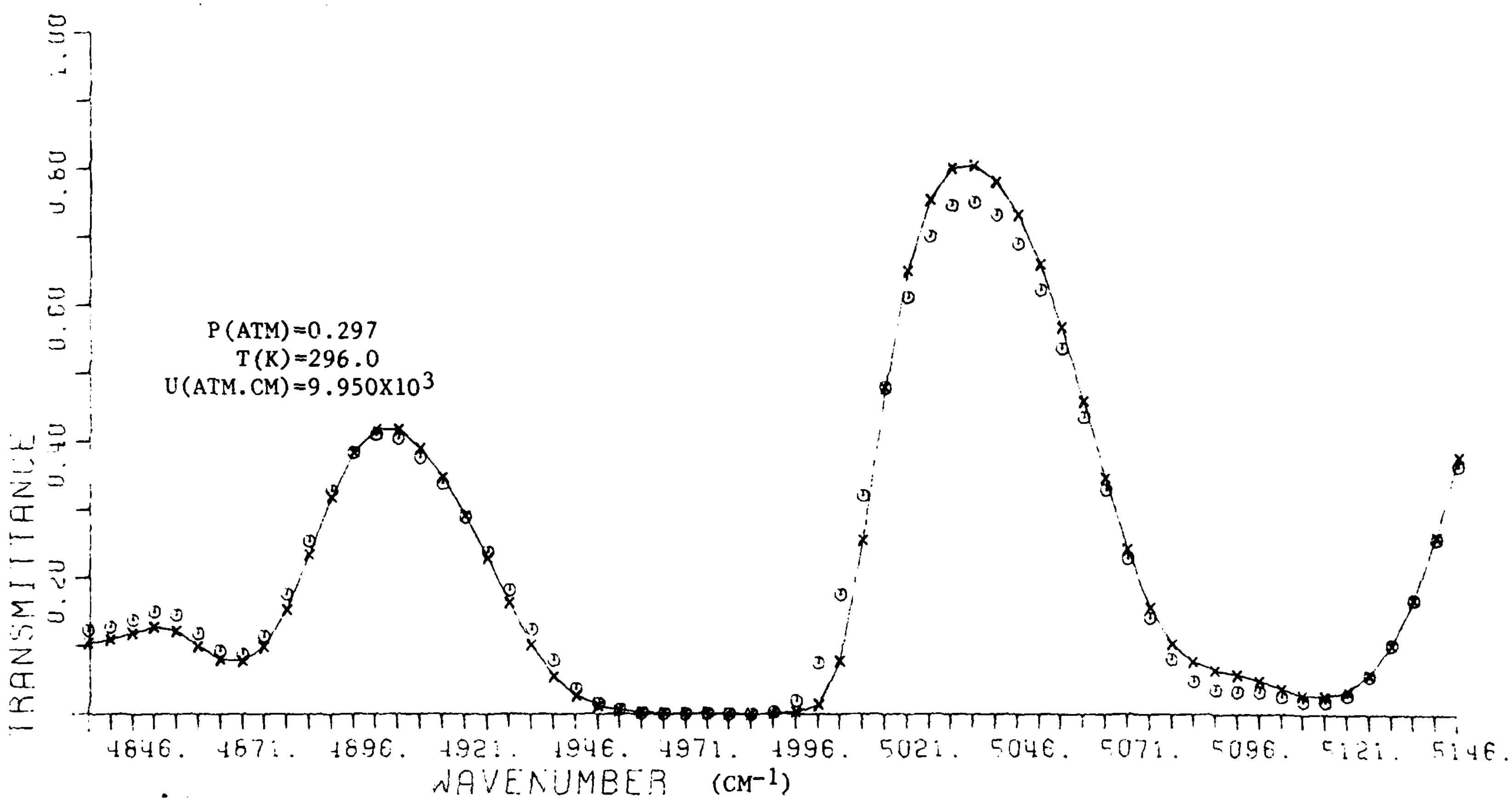


Figure C11. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (O) and proposed band model calculations (X).

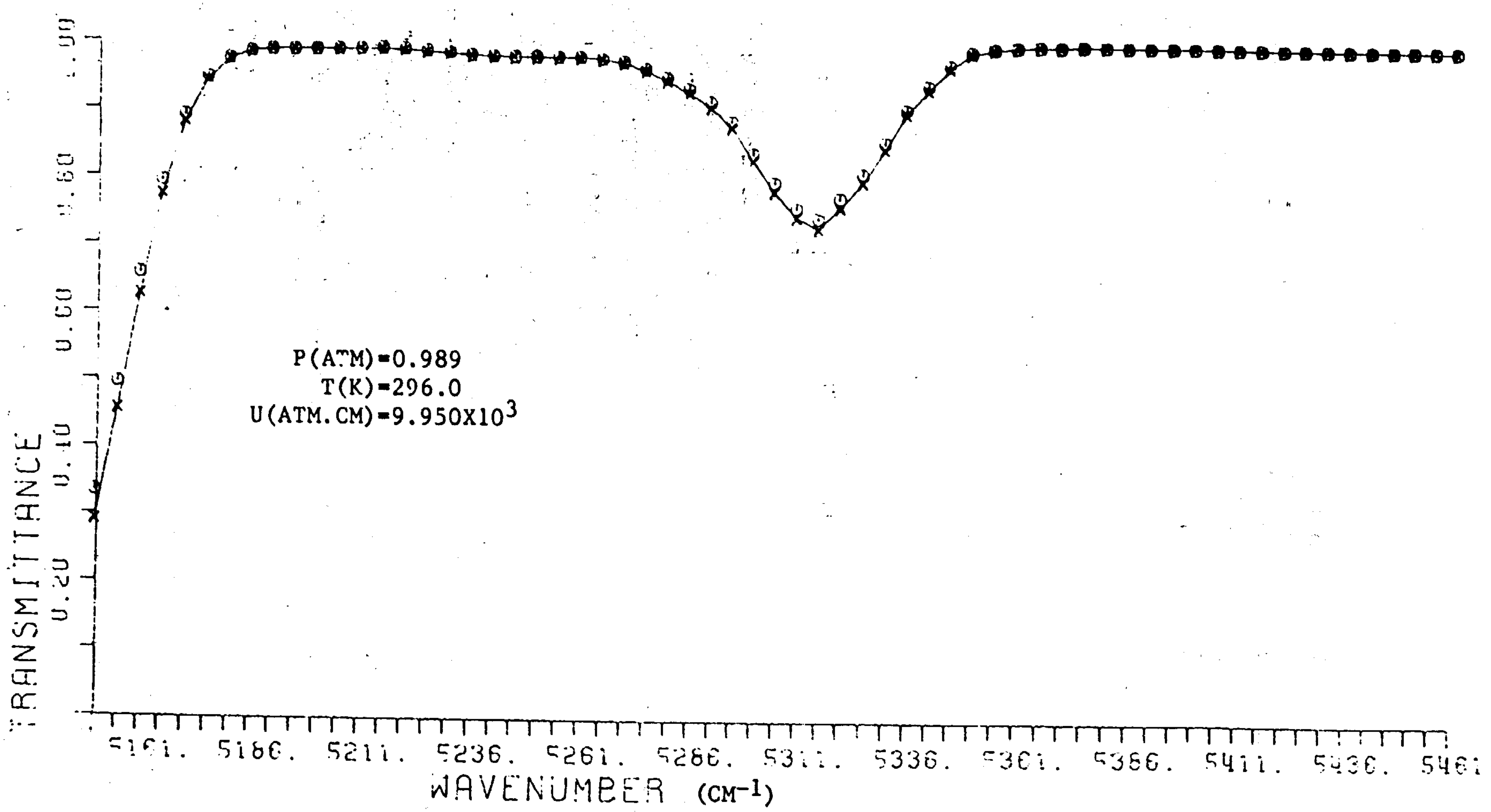


Figure C12. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (O) and proposed band model calculations (X).

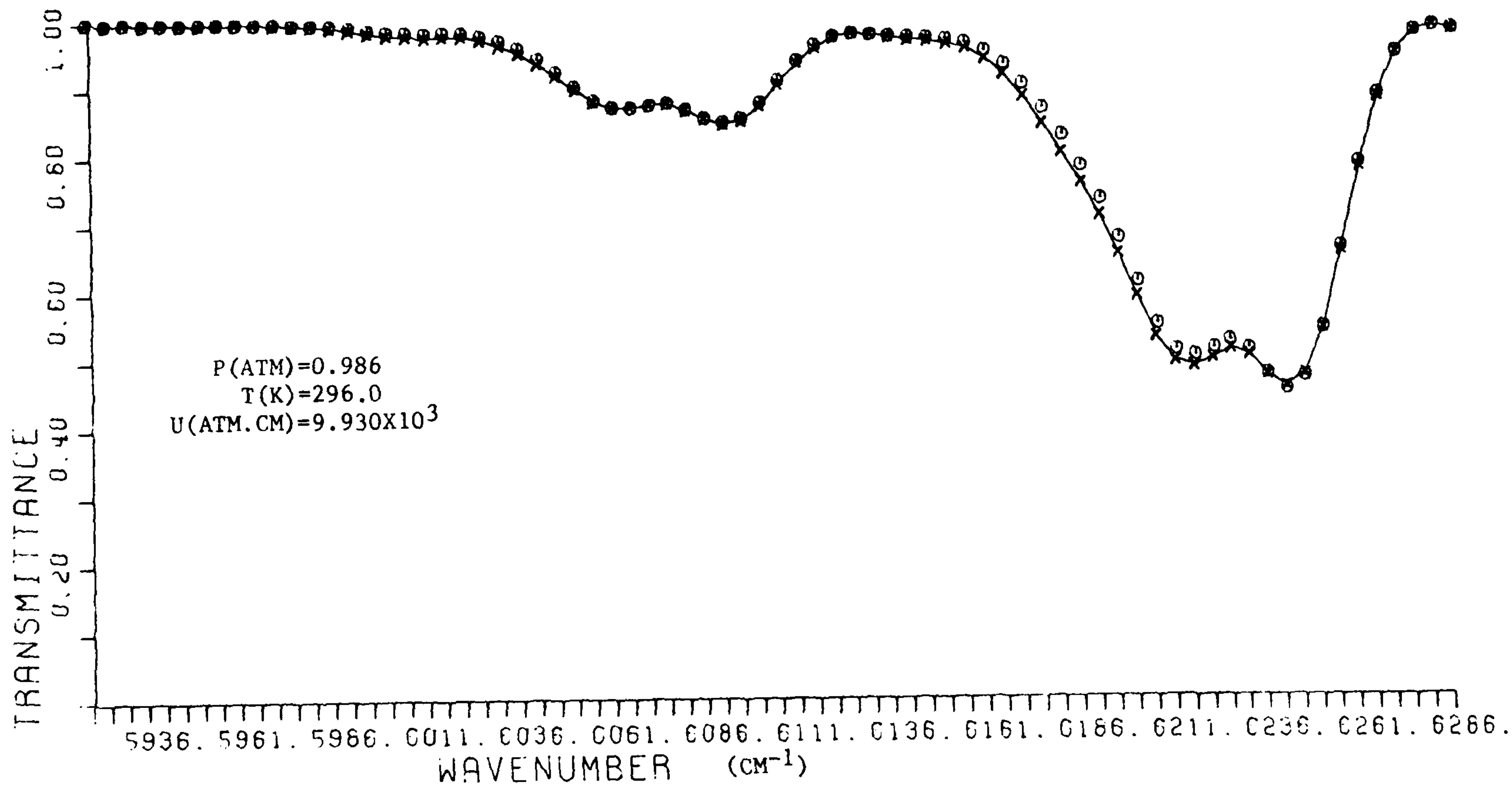


Figure C13. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (0) and proposed band model calculations (X).

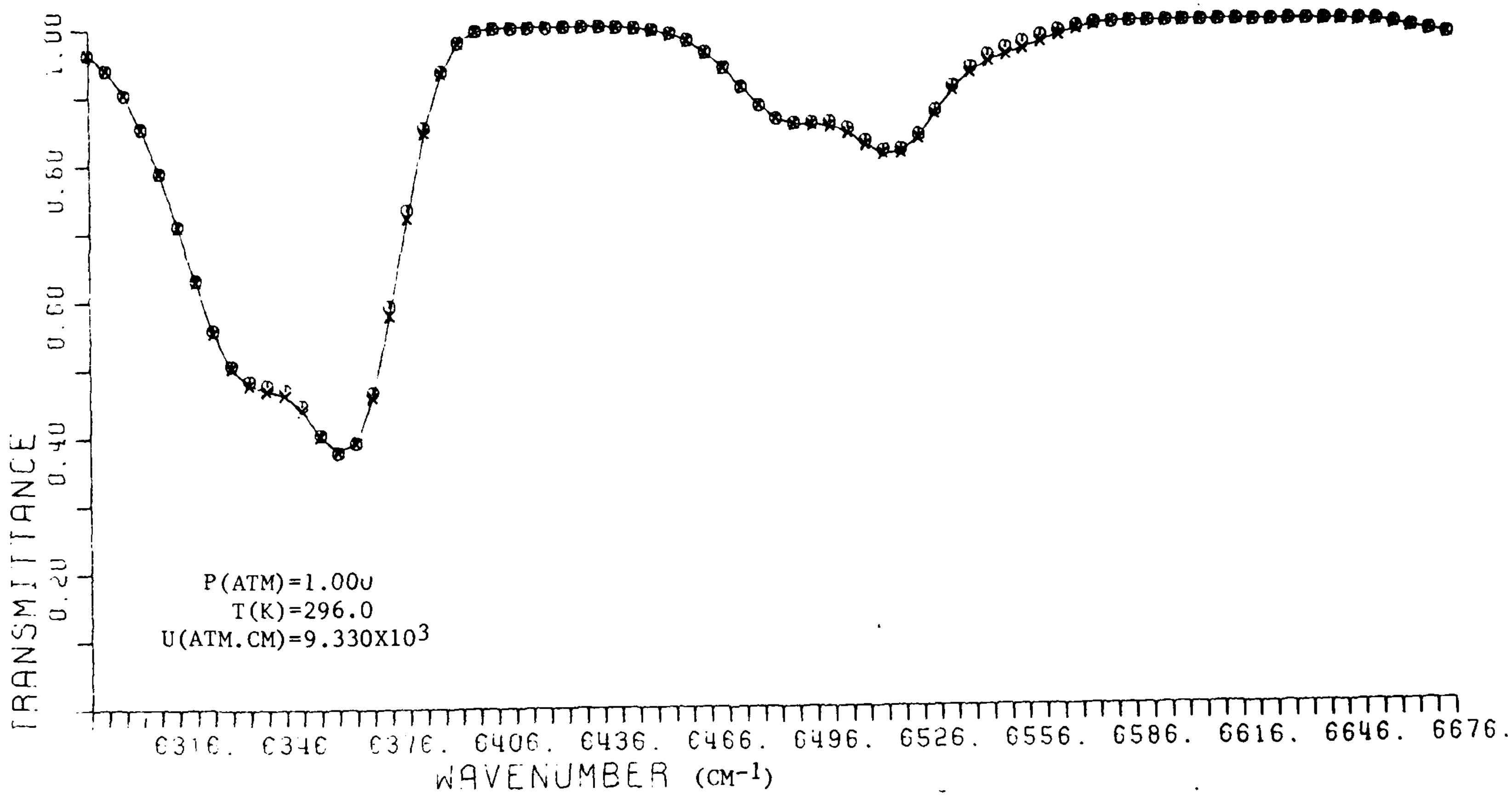


Figure C14. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (0) and proposed band model calculations (X).

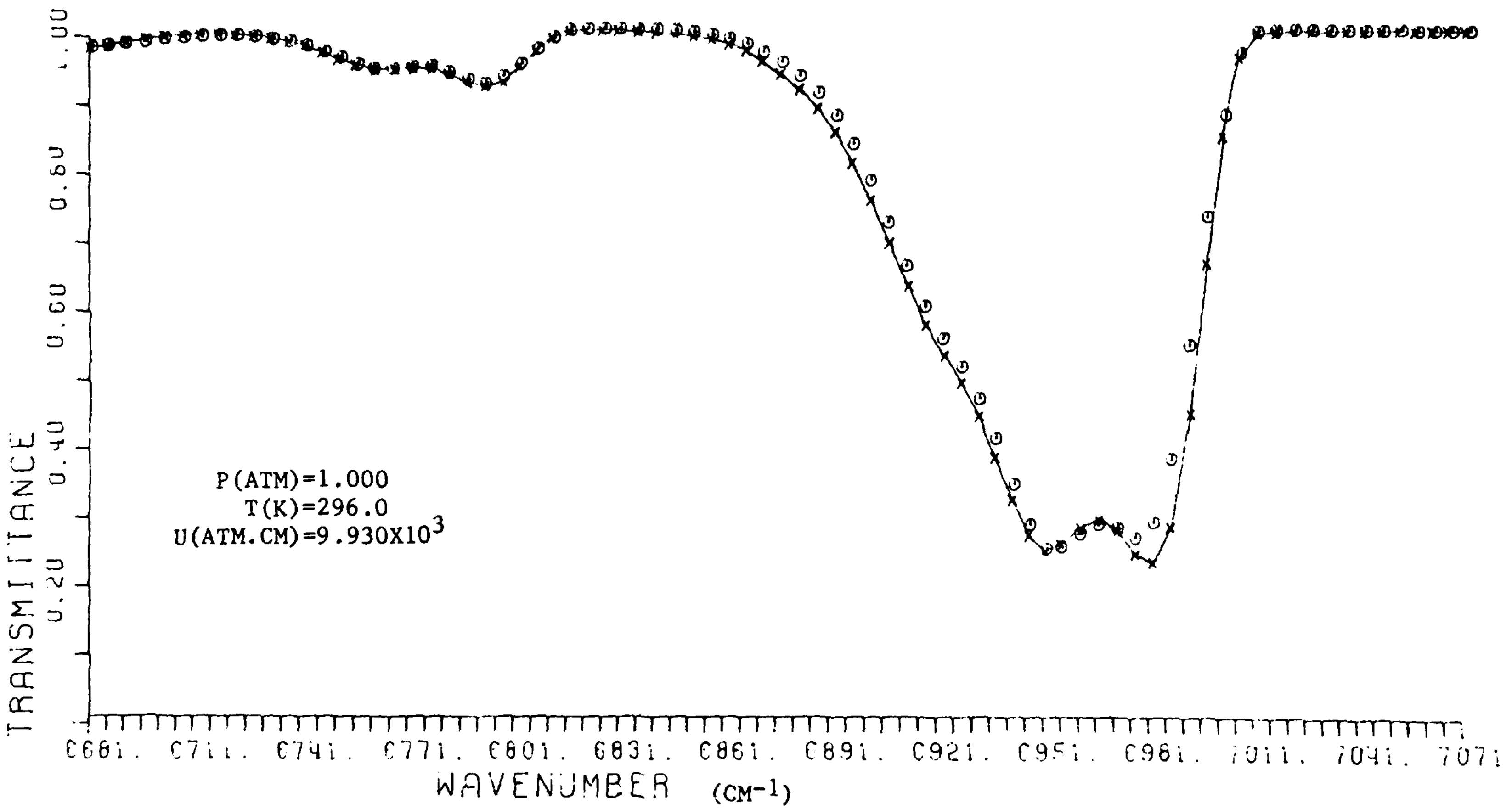


Figure C15. Comparison between 20 cm^{-1} degraded CO_2 measured transmittance spectra (0) and proposed band model calculations (X).

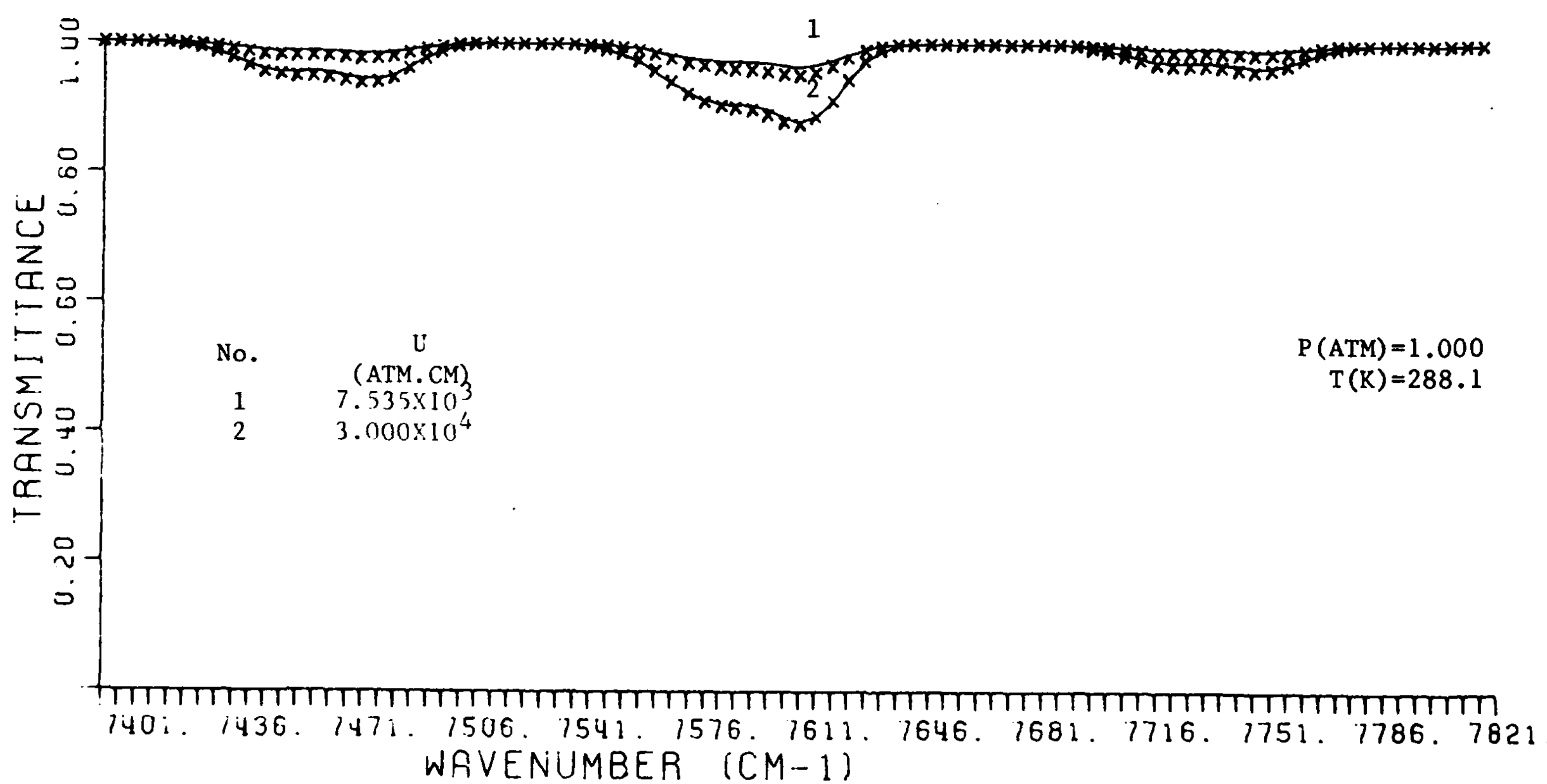


Figure C16. Comparisom between 20 cm^{-1} degraded CO_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

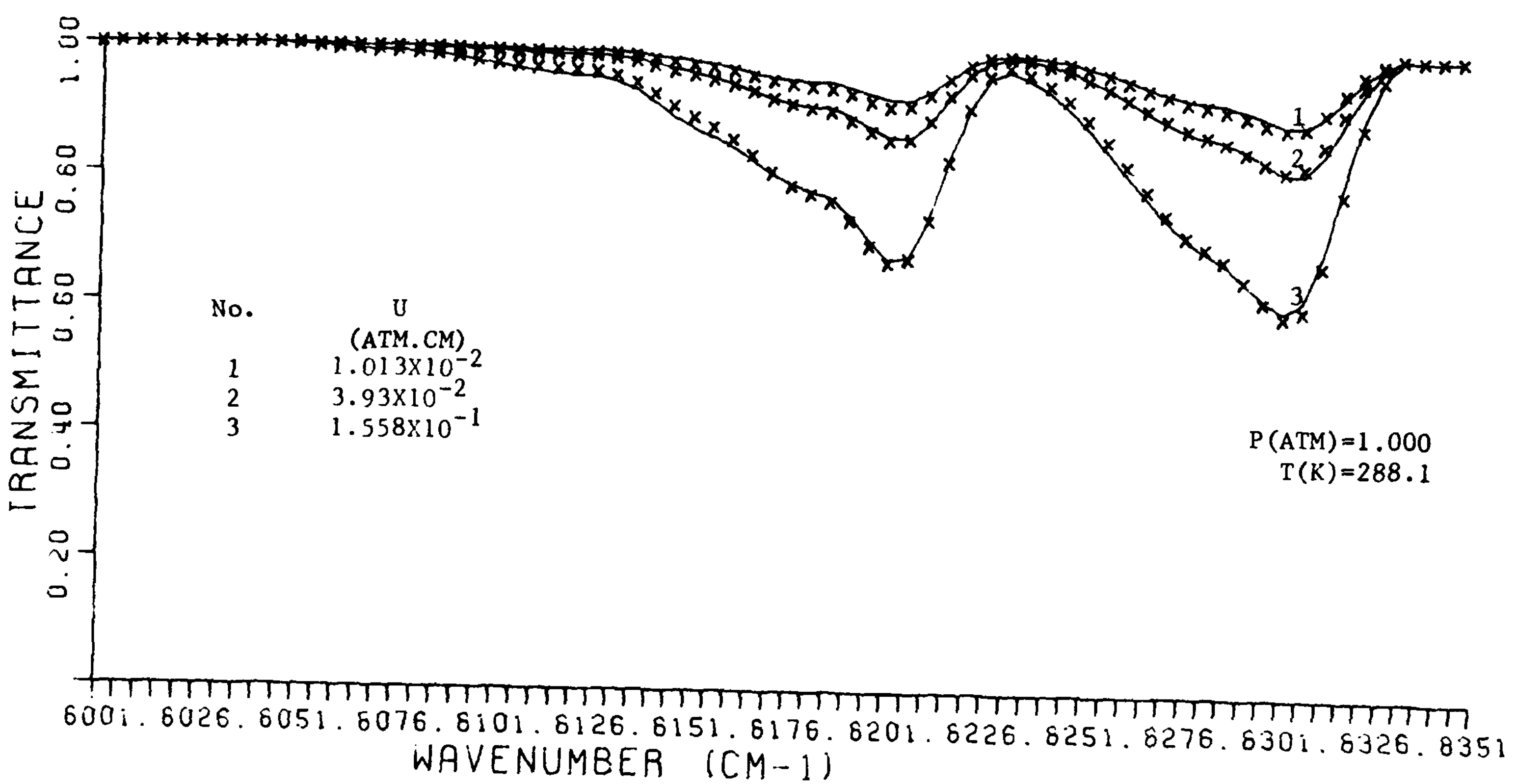


Figure C17. Comparison between 20 cm^{-1} degraded CO_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

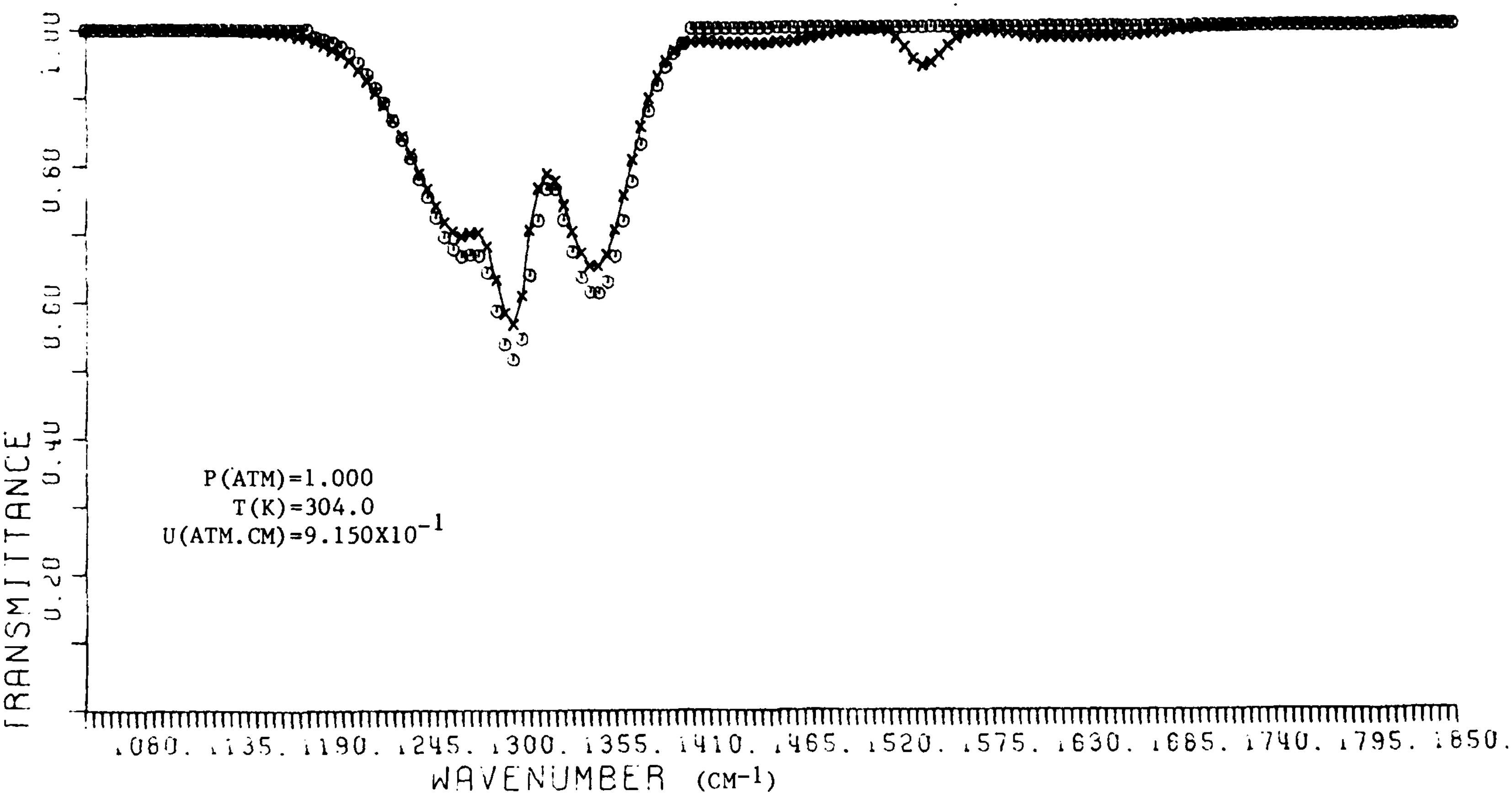


Figure C18. Comparison between 20 cm^{-1} degraded CH_4 measured transmittance spectra (O) and proposed band model calculations (X).

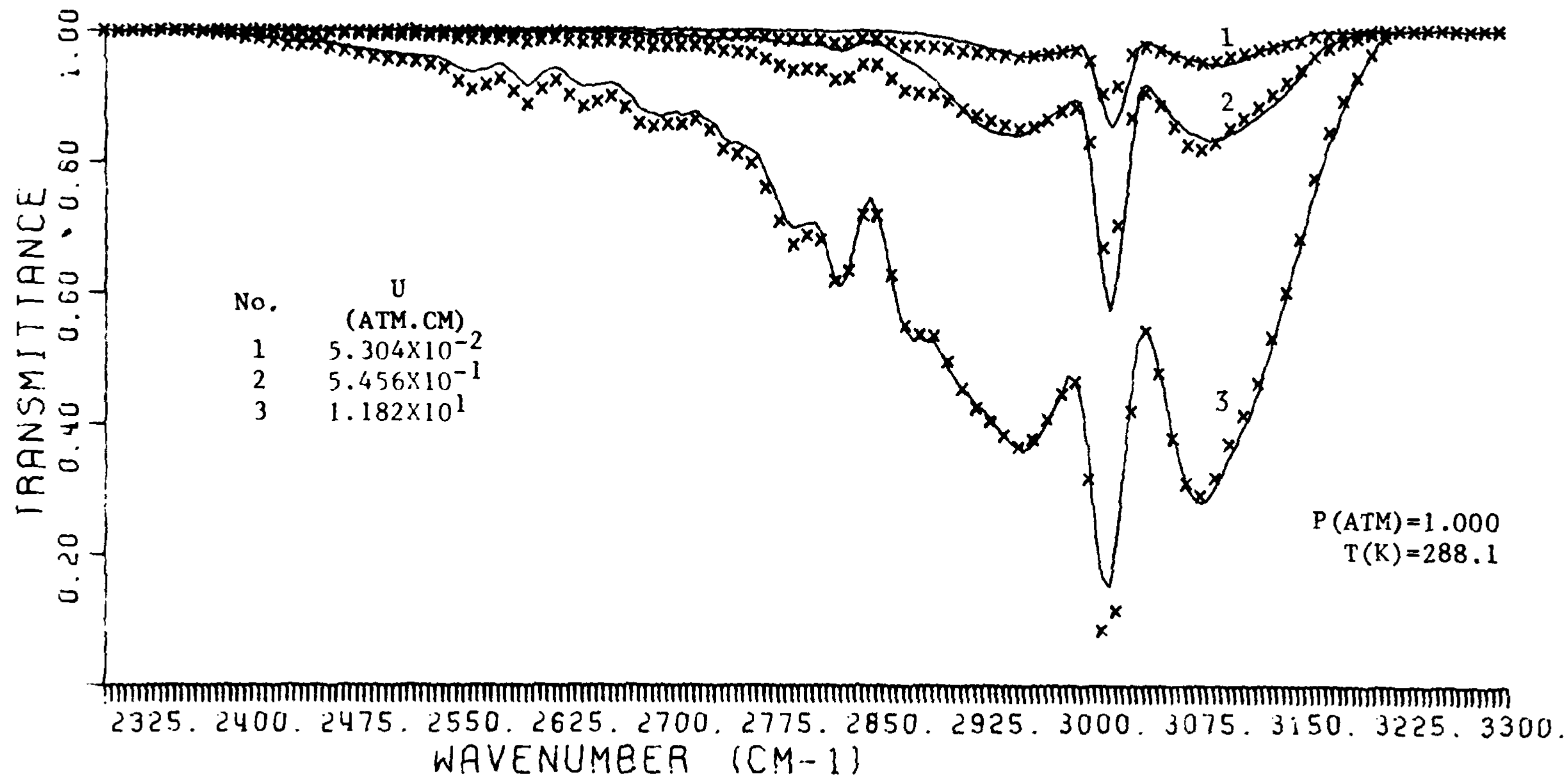


Figure C19. Comparison between 20 cm^{-1} degraded CH_4 line-by-line transmittance spectra (—) and proposed band model calculations (X).

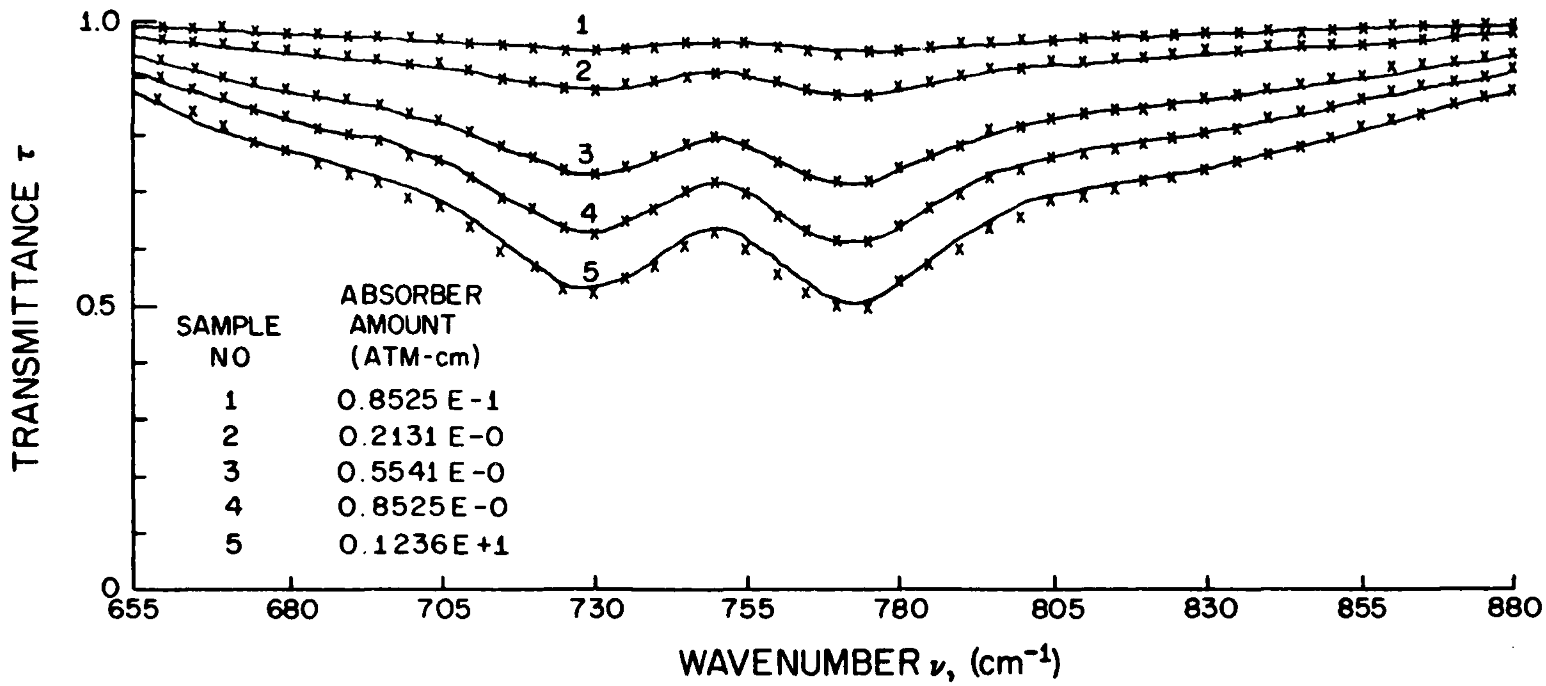


Figure C20. Comparison between 20 cm^{-1} degraded NO_2 line-by-line transmittance spectra (-) and proposed band model calculations (X).

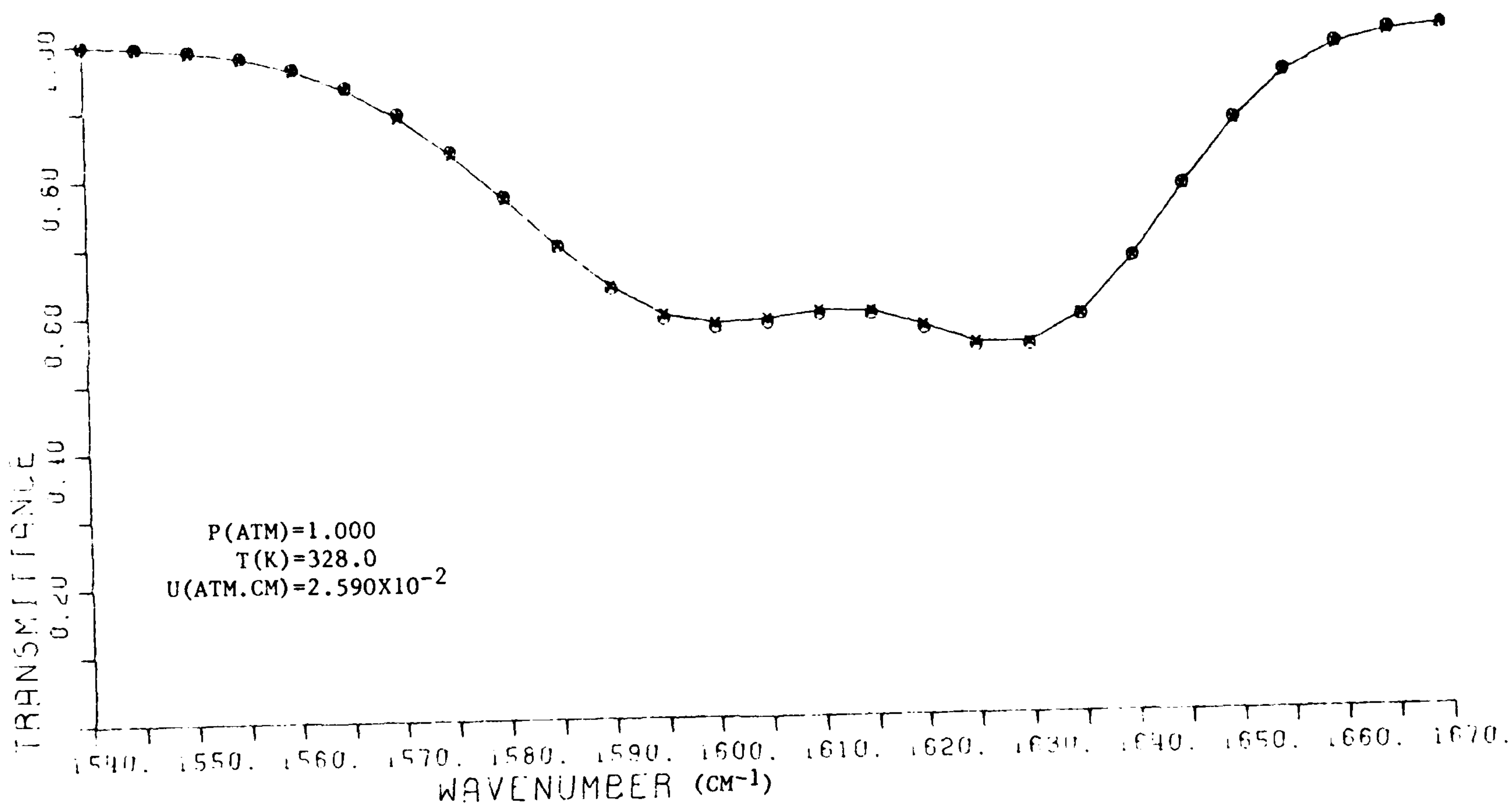


Figure C21. Comparison between 20 cm^{-1} degraded NO_2 measured transmittance spectra (O) and proposed band model calculations (X).

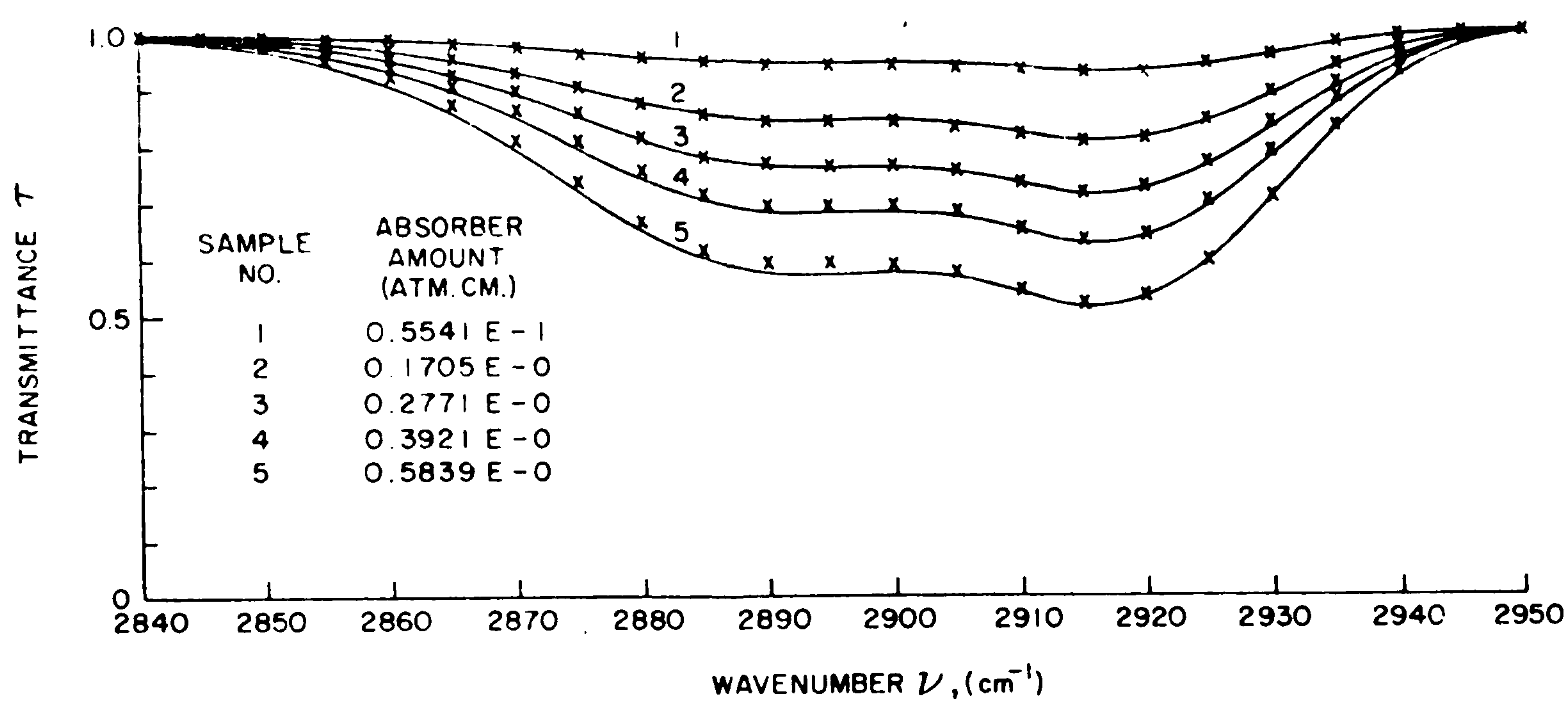


Figure C22. Comparison between $20 cm^{-1}$ degraded NO_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

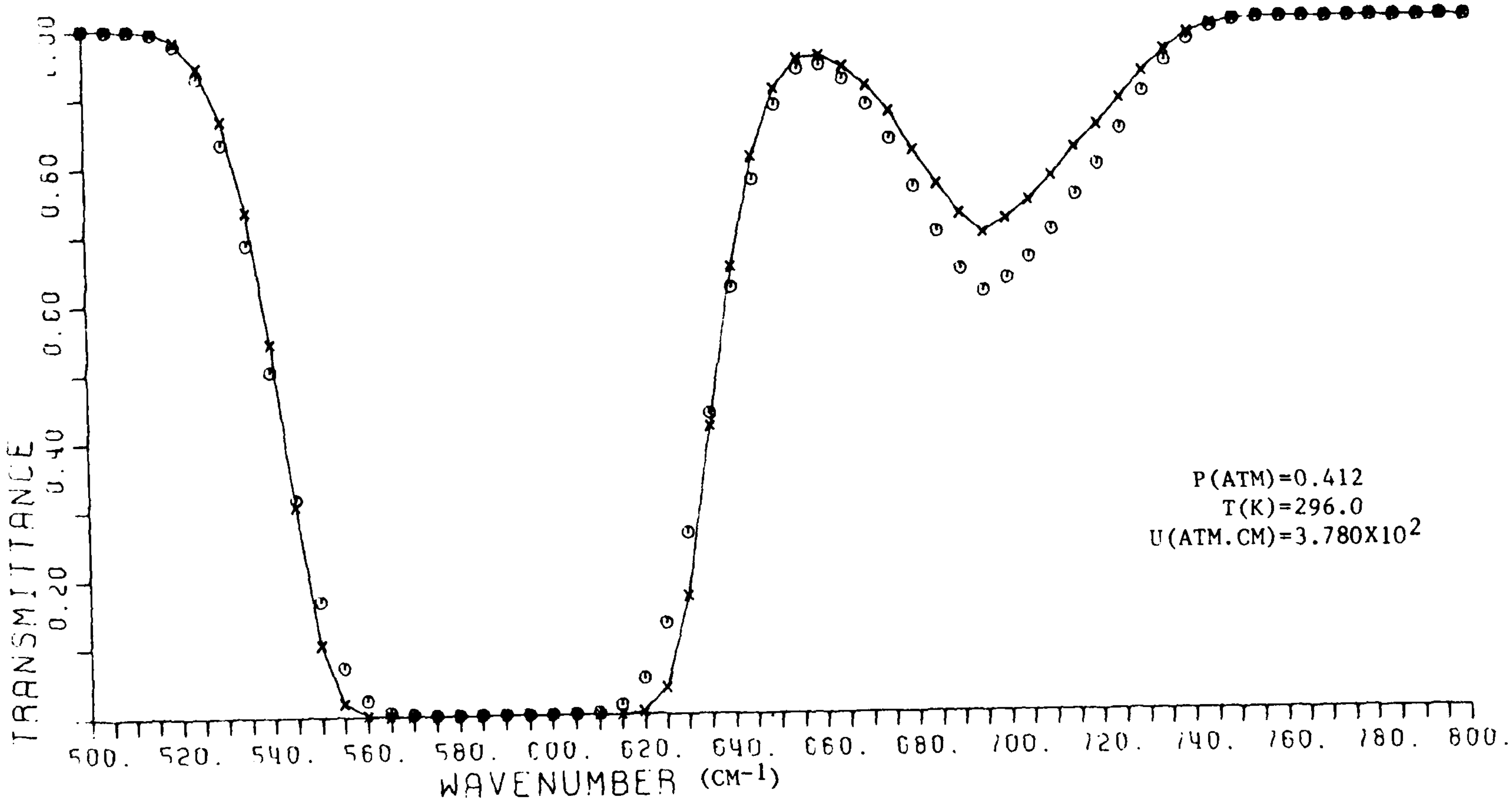


Figure C23. Comparison between 20 cm^{-1} degraded N_2O measured transmittance spectra (O) and proposed band model calculations (X).

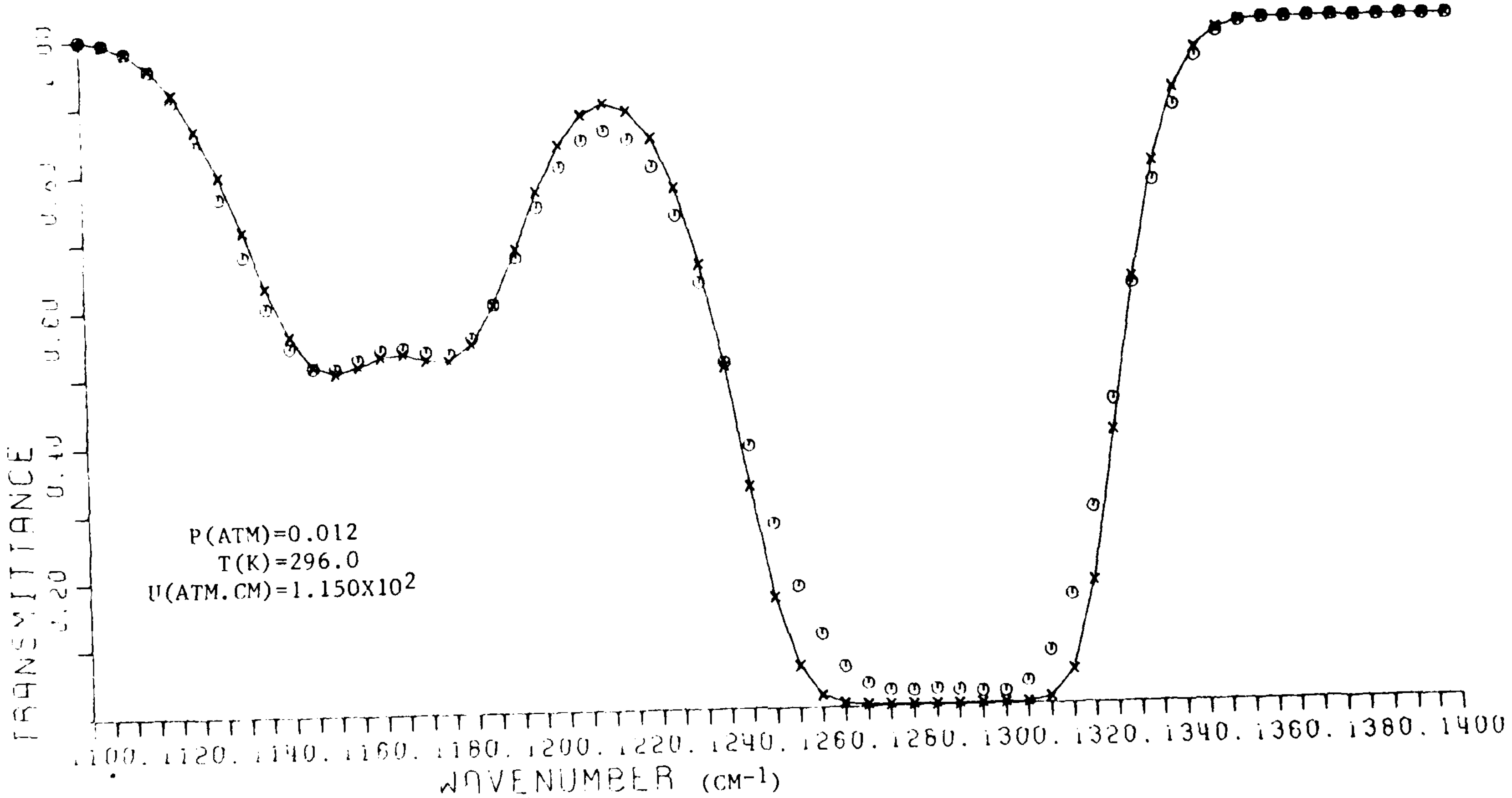


Figure C24. Comparison between 20 cm^{-1} degraded N_2O measured transmittance spectra (O) and proposed band model calculations (X).

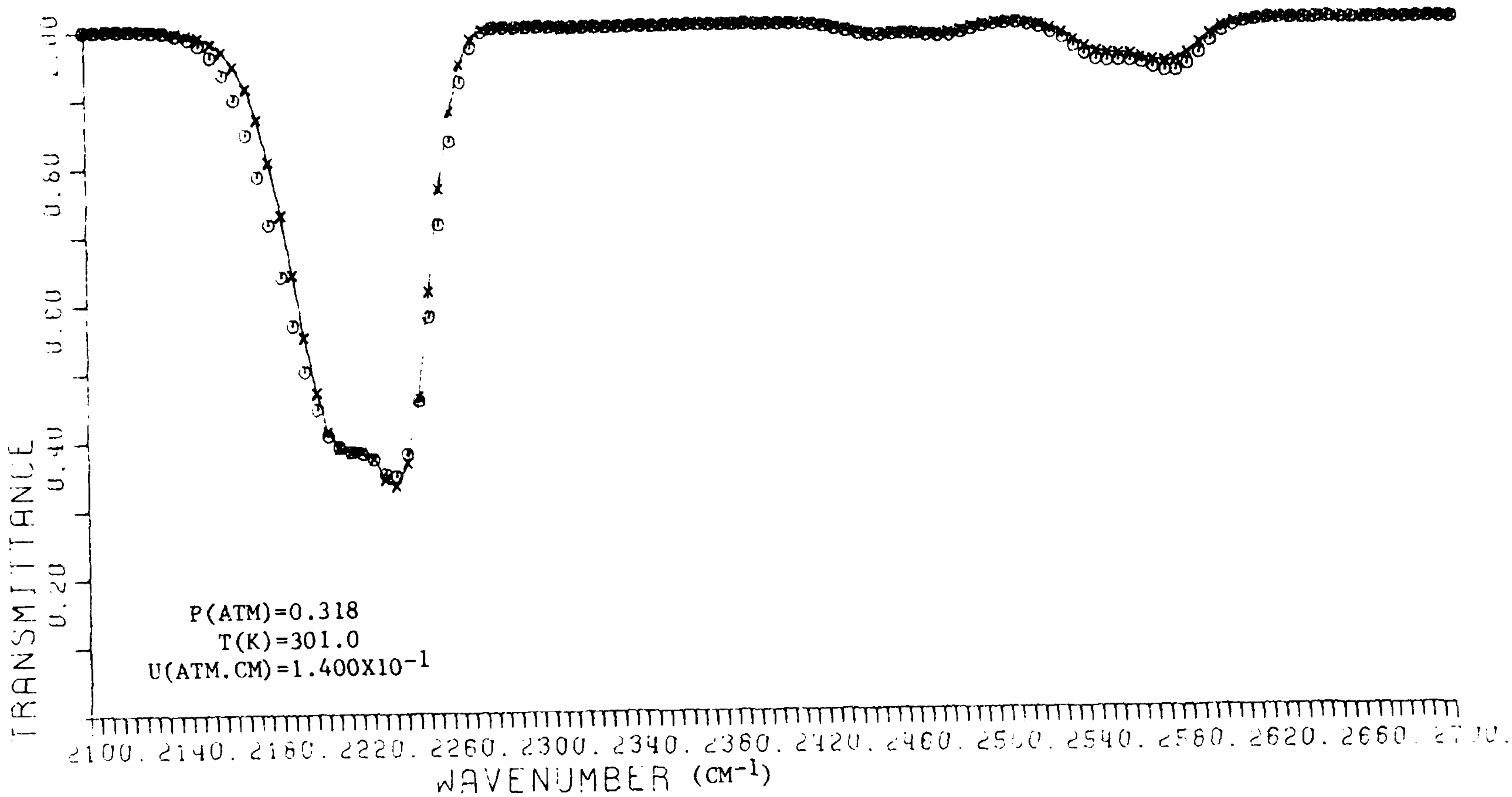


Figure C25. Comparison between 20 cm^{-1} degraded N_2O measured transmittance spectra (O) and proposed band model calculations (X).

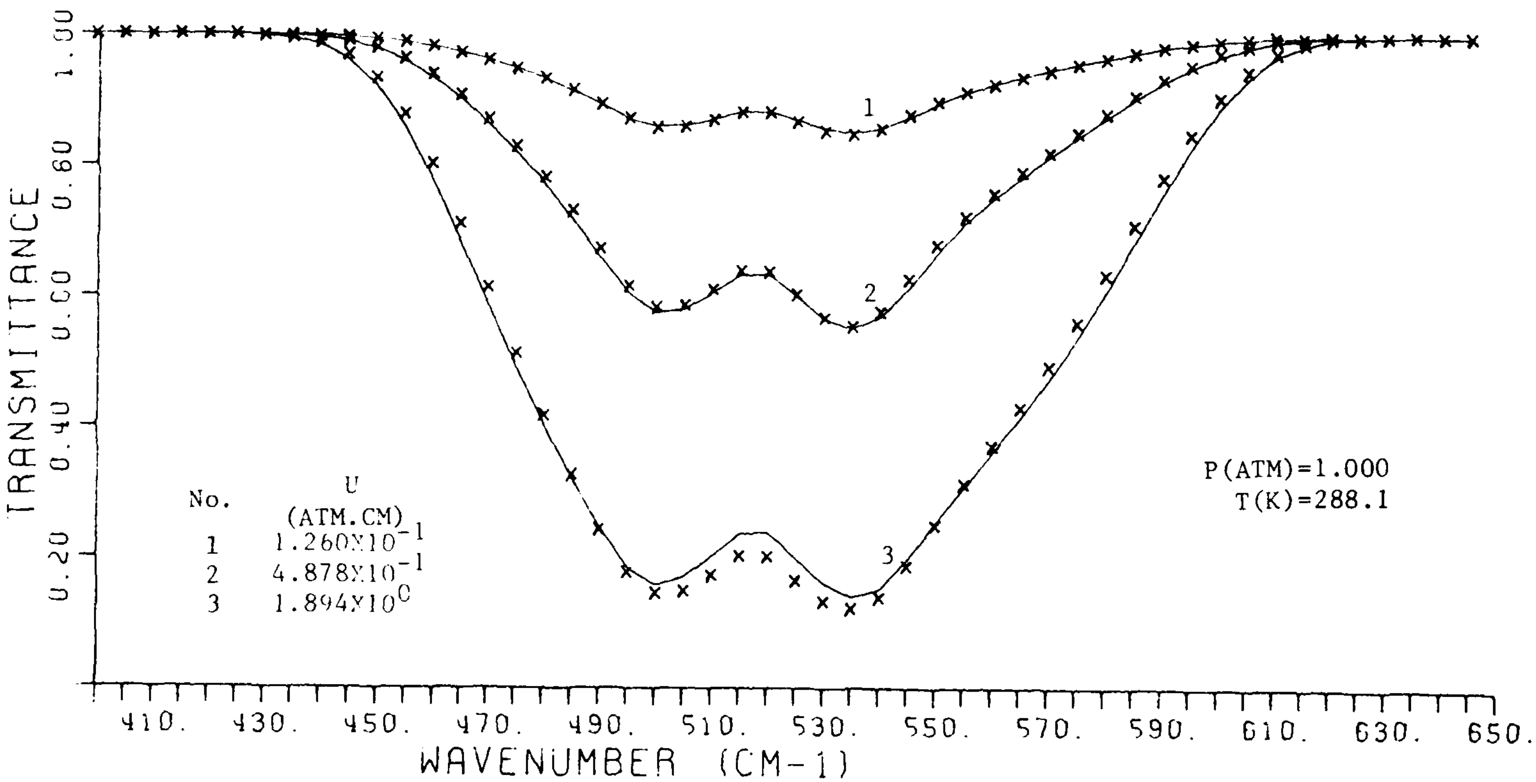


Figure C26. Comparison between 20 cm^{-1} degraded SO_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

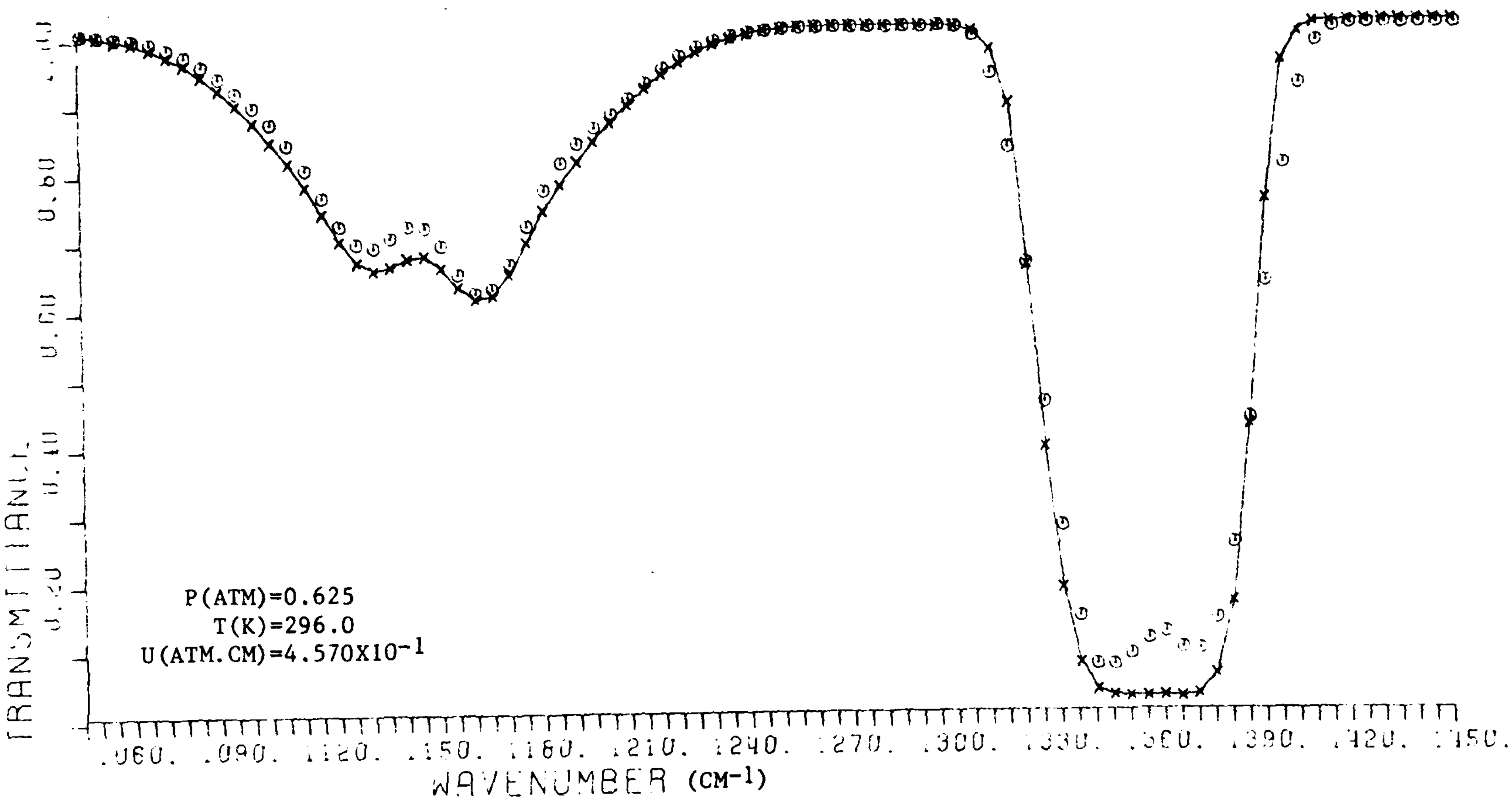


Figure C27. Comparison between 20 cm^{-1} degraded SO_2 measured transmittance spectra (O) and proposed band model calculations (X).

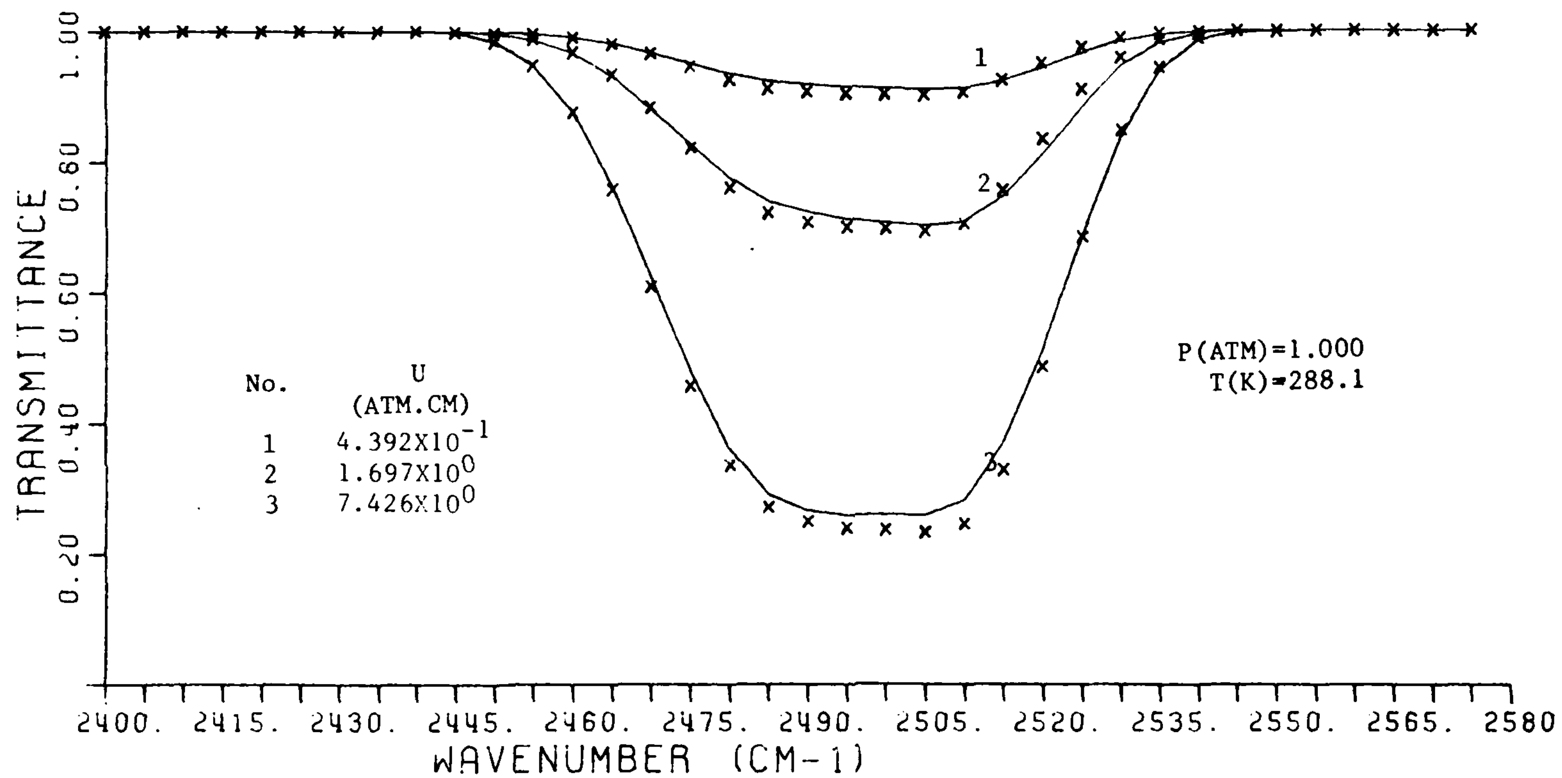


Figure C28. Comparison between 20 cm^{-1} degraded SO_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

APPENDIX D

Sample Comparison Between Medium or High-Resolution Line-By-Line Calculations and Measured Transmittance Spectra CO, NH_3, NO and O_2.

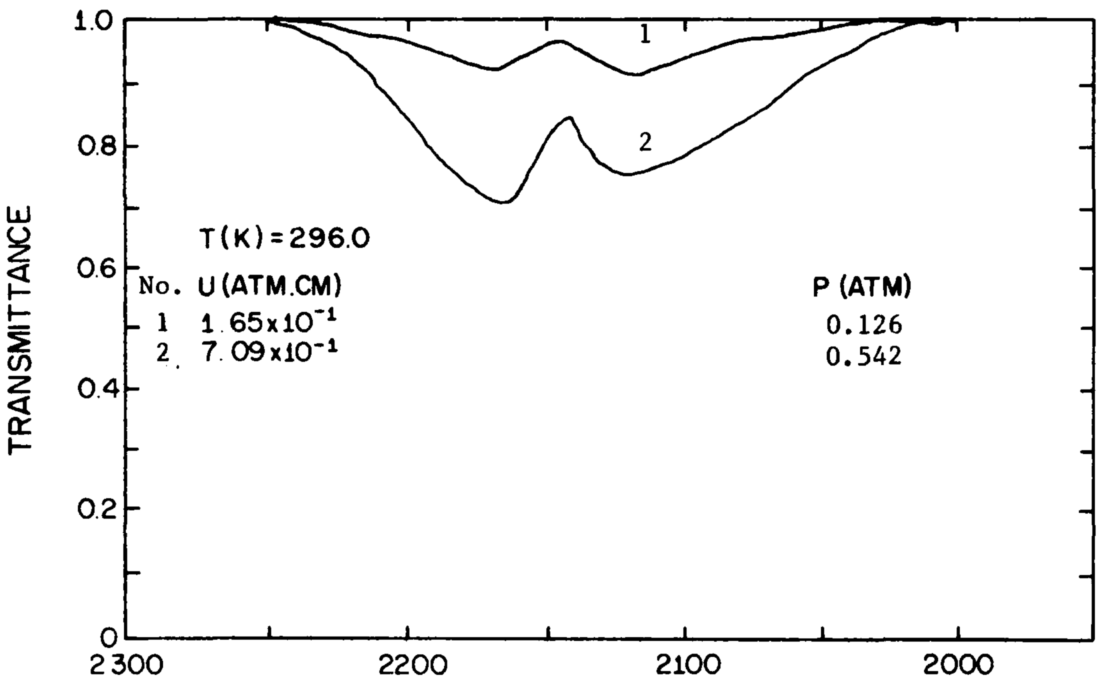


Figure D1(a). Medium resolution CO measured transmittance spectra.

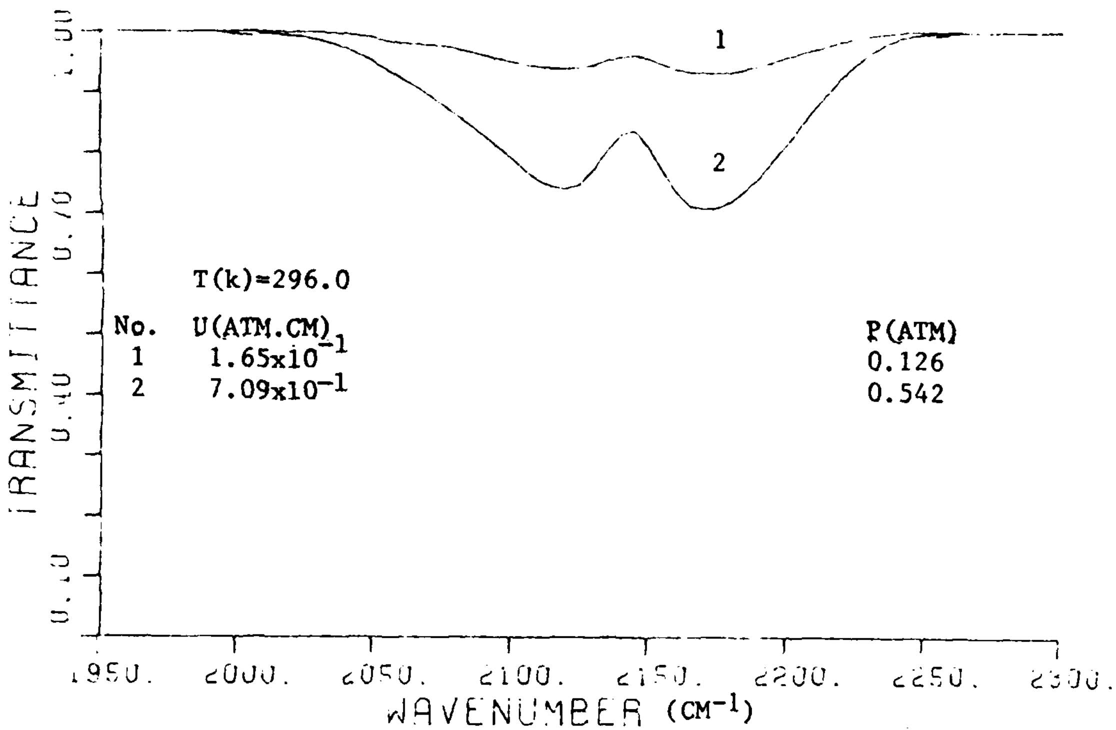


Figure D1(b). Medium resolution CO line-by-line calculated spectra at the conditions of Fig. D1(a).

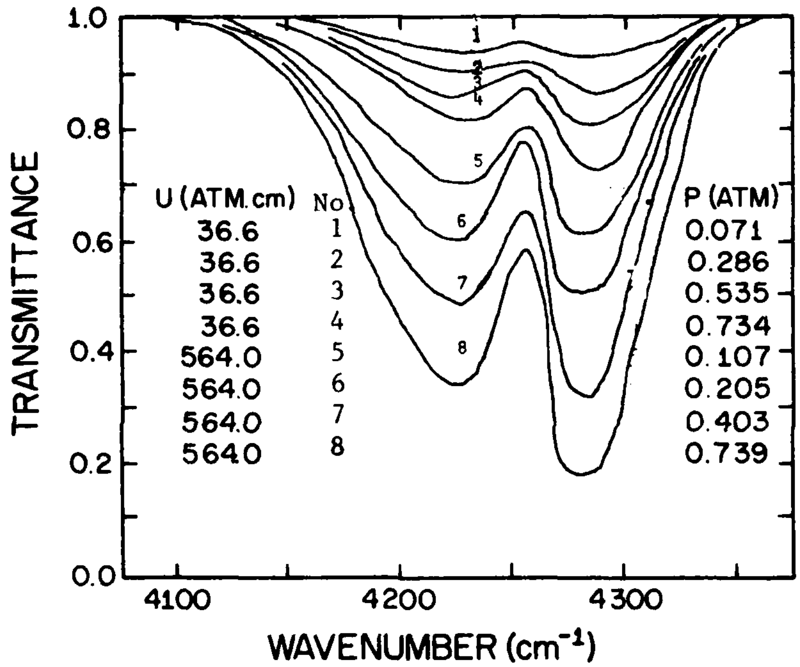
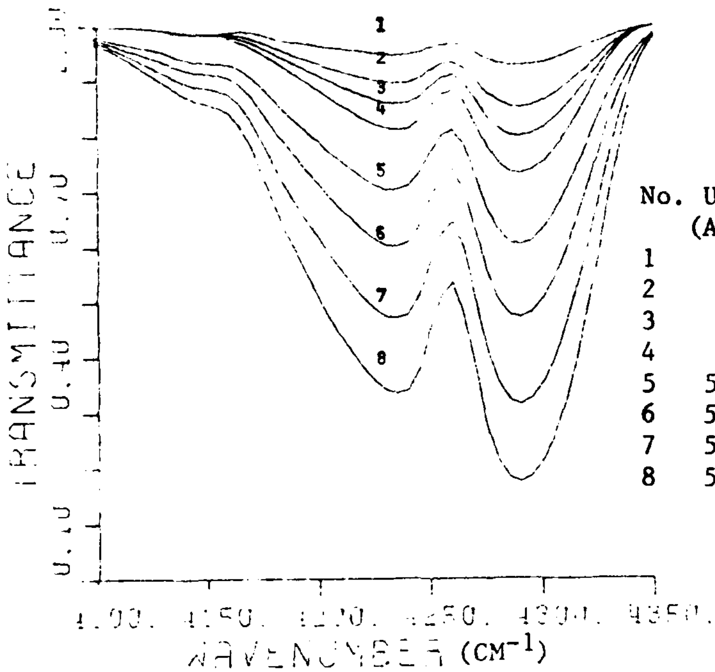


Figure D2(a). Medium resolution CO measured Transmittance spectra.



No.	U (ATM.CM)	P (ATM)
1	36.6	0.071
2	36.6	0.286
3	36.6	0.535
4	36.6	0.734
5	564.0	0.107
6	564.0	0.205
7	564.0	0.403
8	564.0	0.739

Figure D2(b). Medium resolution CO line-by-line calculated spectra at the conditions of Fig. D2(a).

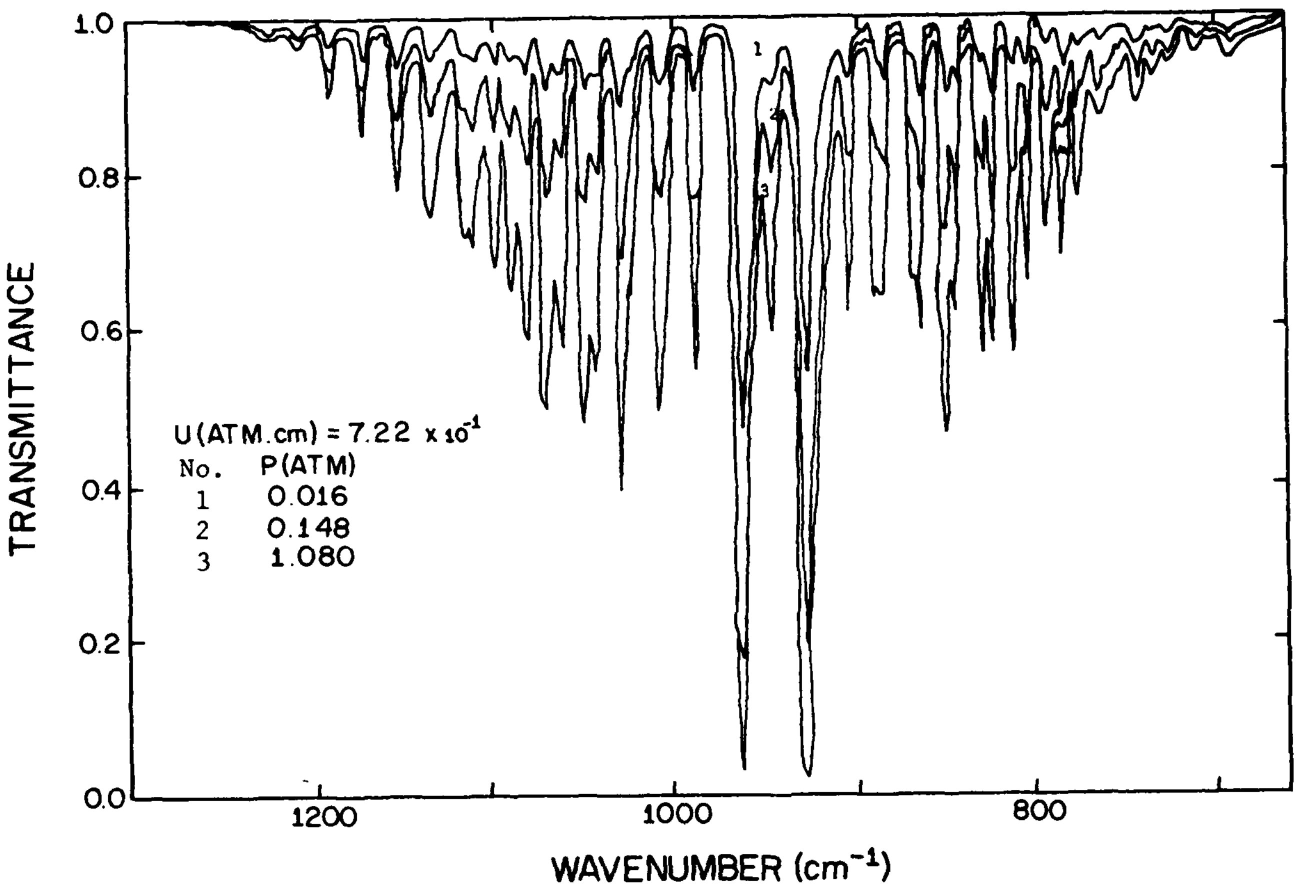


Figure D3(a). High resolution NH_3 measured transmittance spectra.

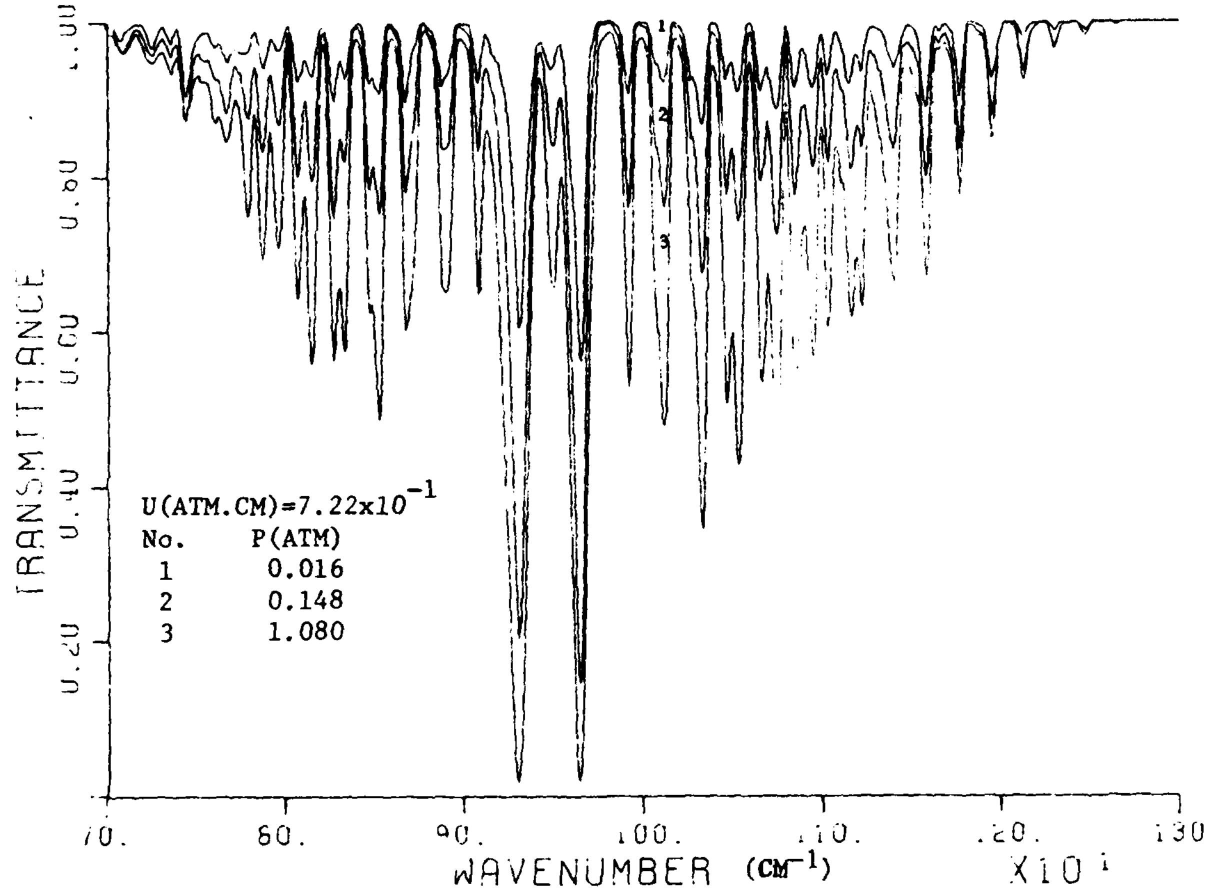


Figure D3(b). High resolution NH_3 line-by-line calculated spectra at the conditions of Fig.D3(a).

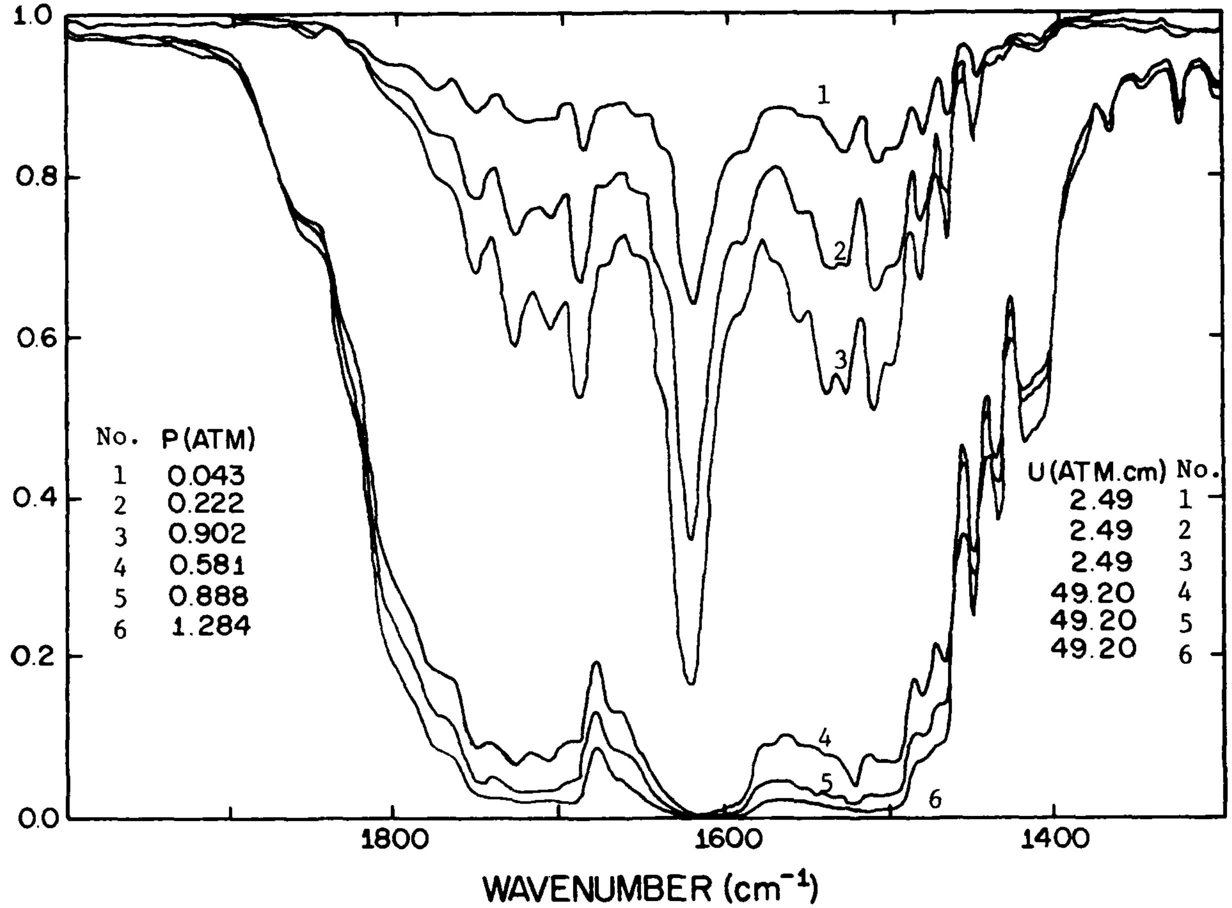


Figure D4(a). High resolution NH_3 measured transmittance specta.

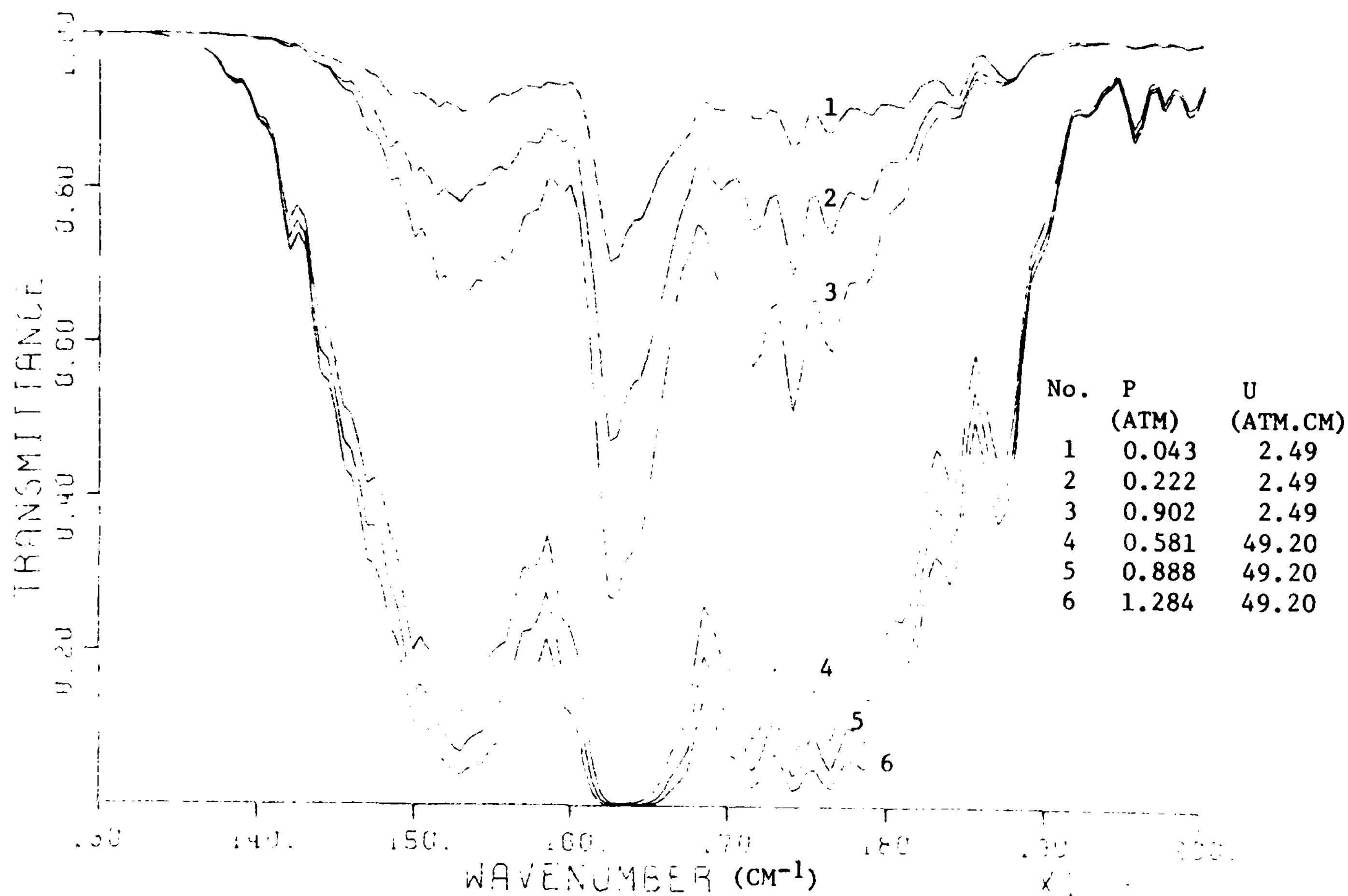


Figure D4(b). High resolution NH_3 line-by-line calculated spectra at the conditions of Fig.D4(a). (The third, fifth, and sixth traces were not included in either the model development nor model validation).

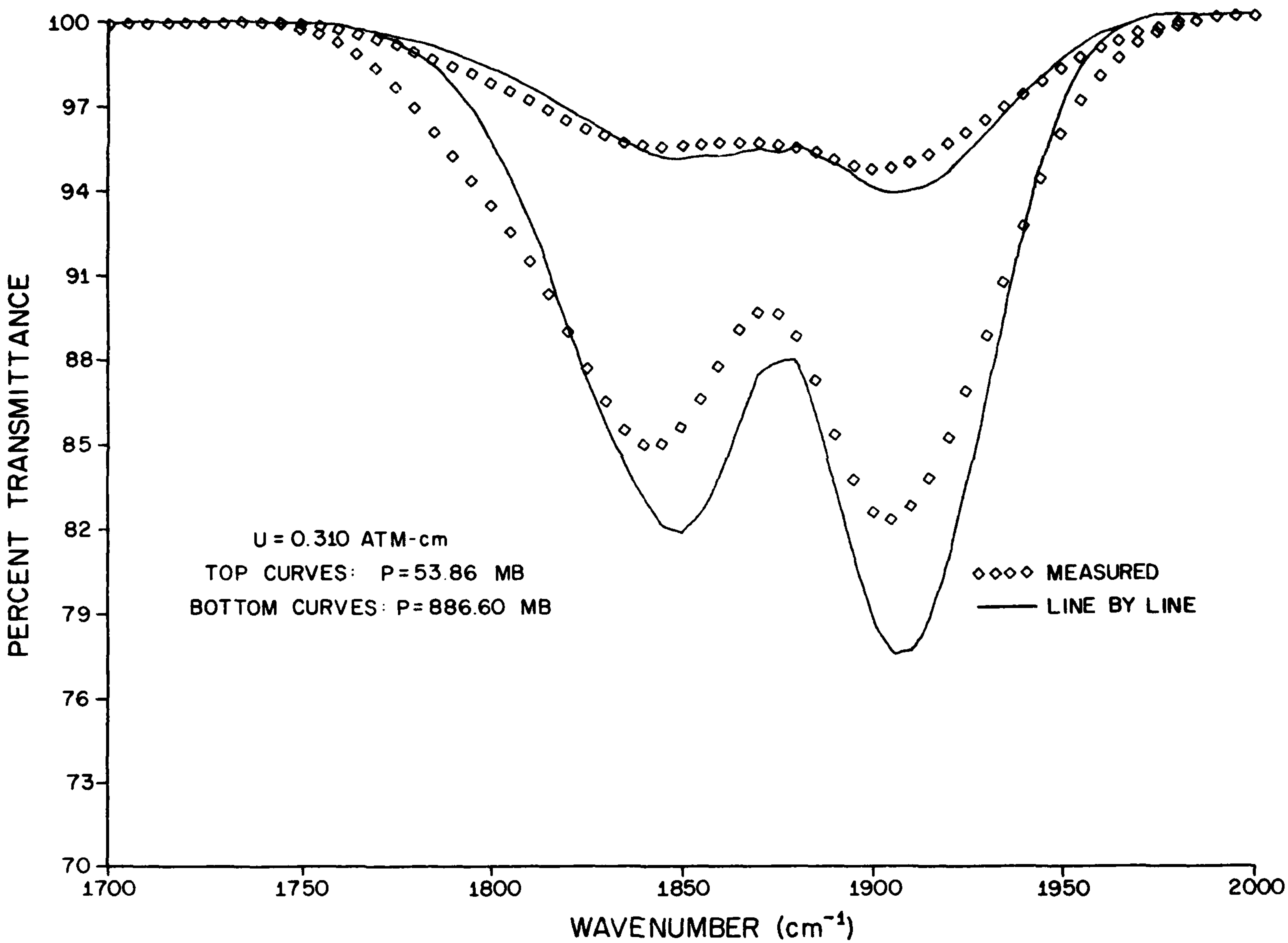


Figure D5. Comparison between 20 cm^{-1} degraded NO measured transmittance spectra (0) and line-by-line calculations (-).

No.	P (ATM)	T (K)	U (ATM.CM)
1	0.94	296.3	1.092×10^5
2	1.88	297.2	2.177×10^5

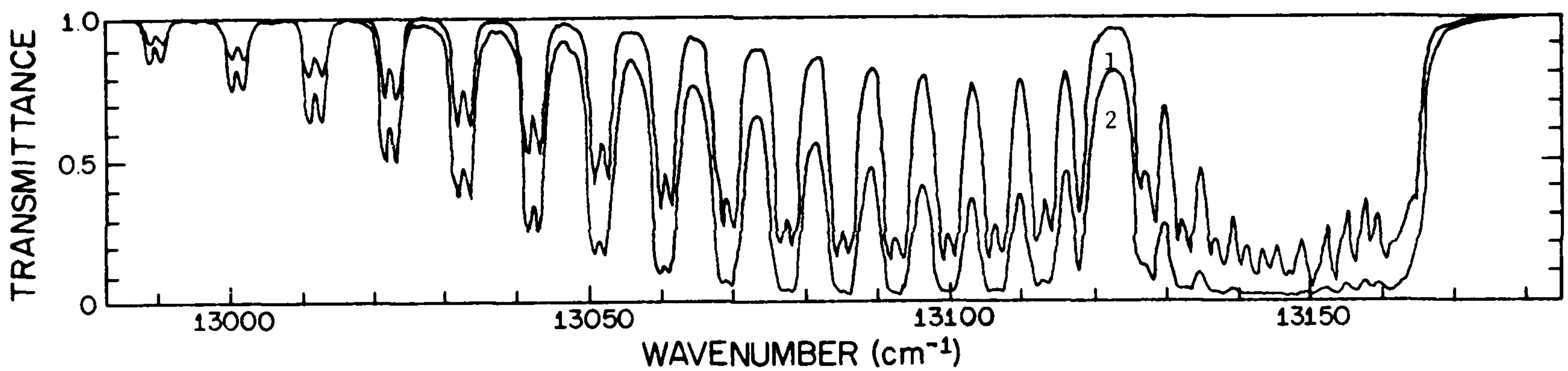


Figure D6(a). High resolution O_2 measured transmittance specta. (The lower figure was not included in either the model development or model validation).

No.	P (ATM)	T (K)	U (ATM.CM)
1	0.94	296.3	1.092×10^5
2	1.88	297.2	2.177×10^5

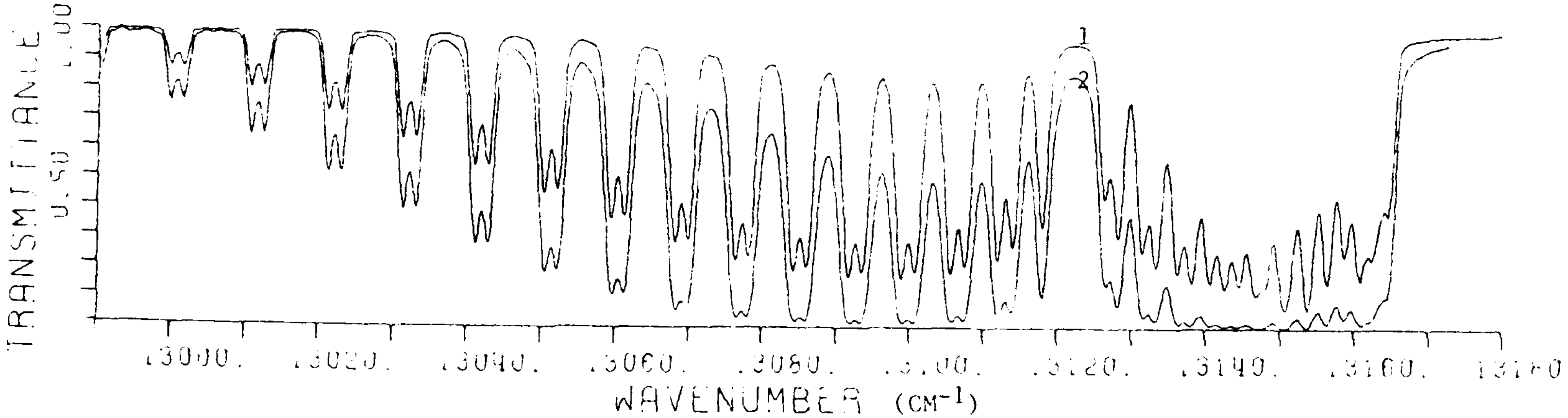


Figure D6(b). High resolution O_2 line-by-line calculated spectra at the conditions of Fig.D6(a). (The lower figure was not included in either the model delopment or model validation).

APPENDIX E

Sample Comparisons Between Degraded Line-By-Line or Measured Transmittance Spectra and Band Model Calculations for CO, NH_3, and O_2.

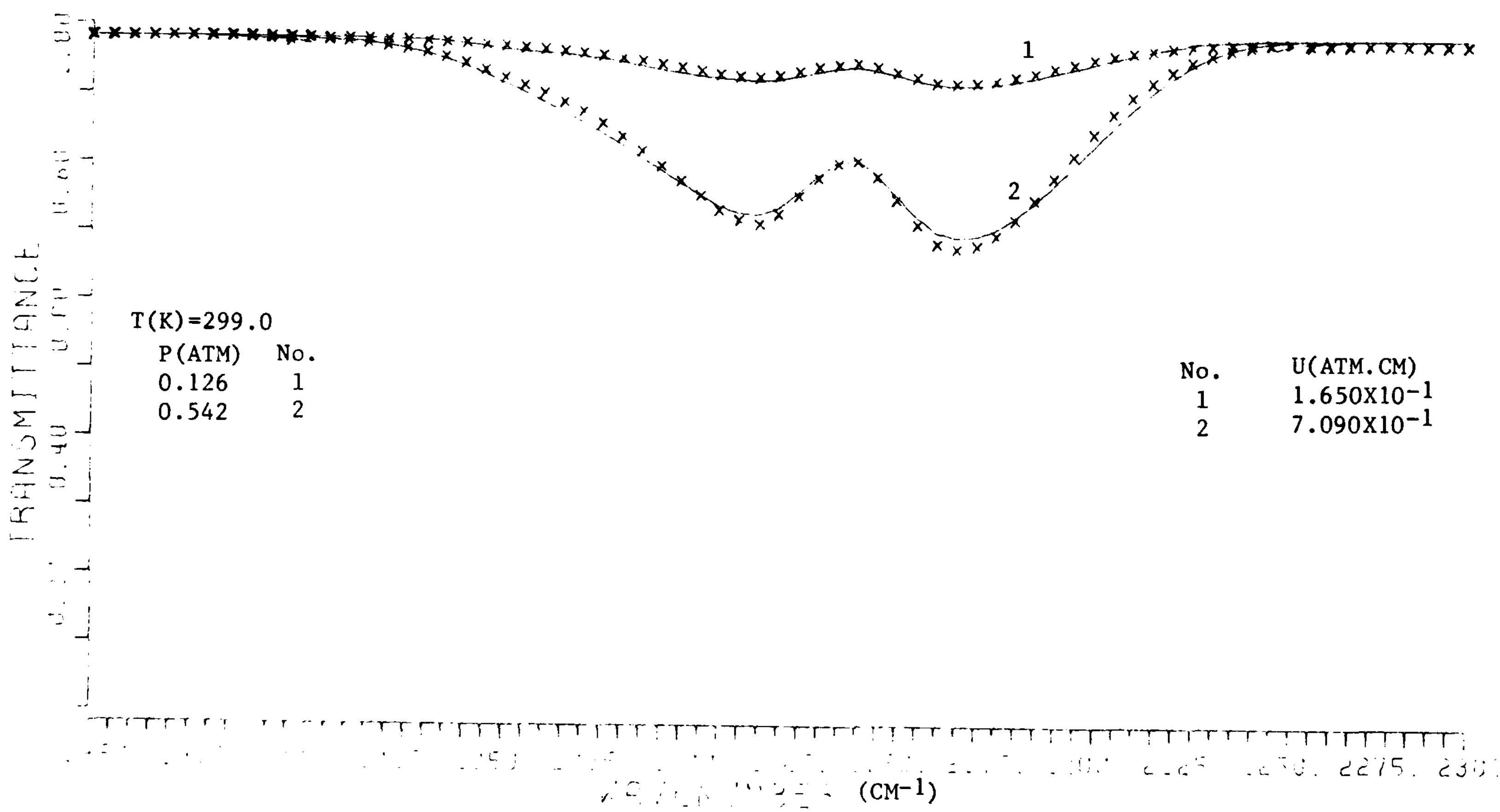


Figure E1. Comparison between 20 cm^{-1} degraded CO line-by-line transmittance spectra (—) and proposed band model calculations (X).

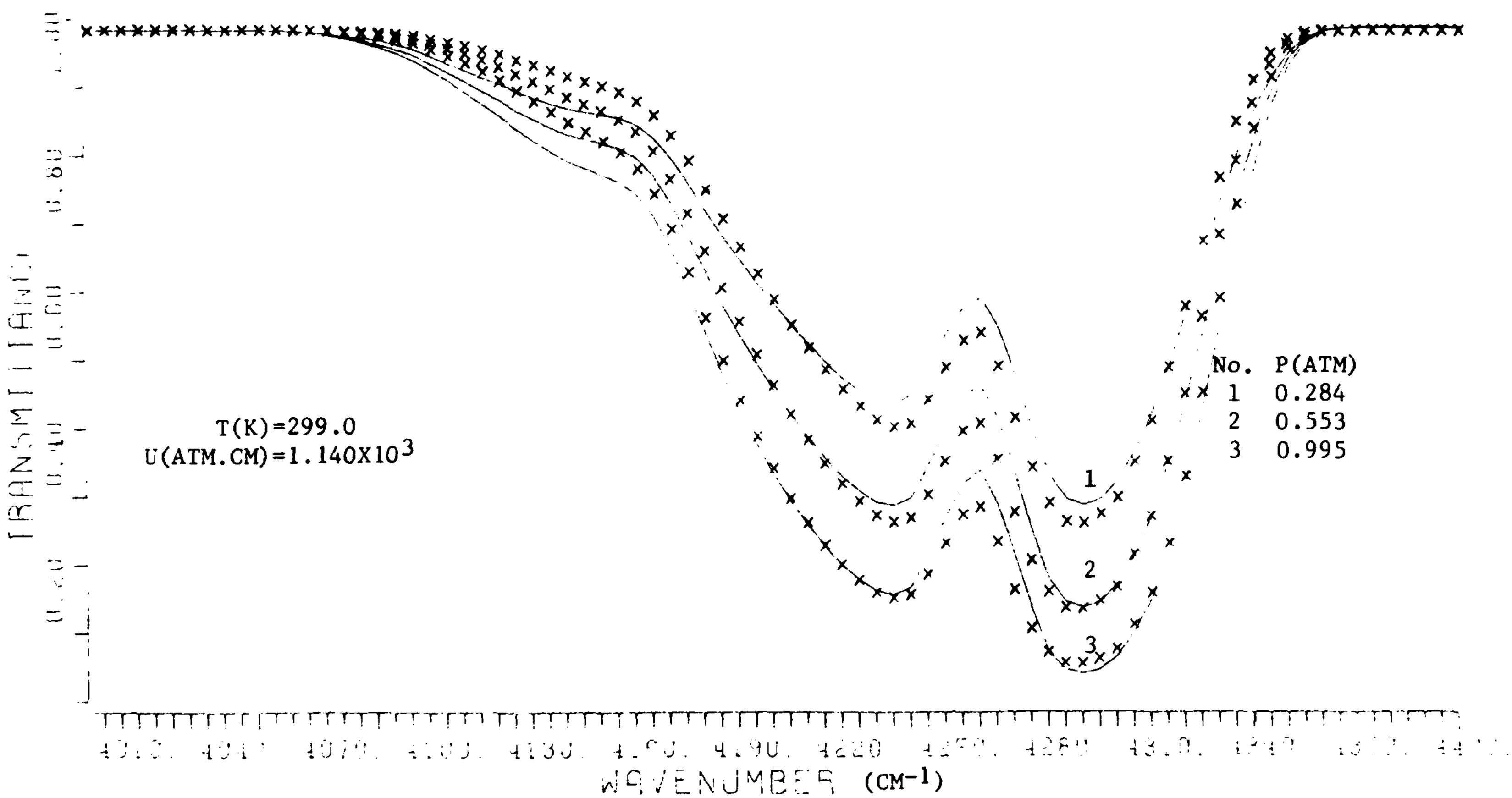


Figure E2. Comparison between 20 cm^{-1} degraded CO line-by-line transmittance spectra (—) and proposed band model calculations (X).

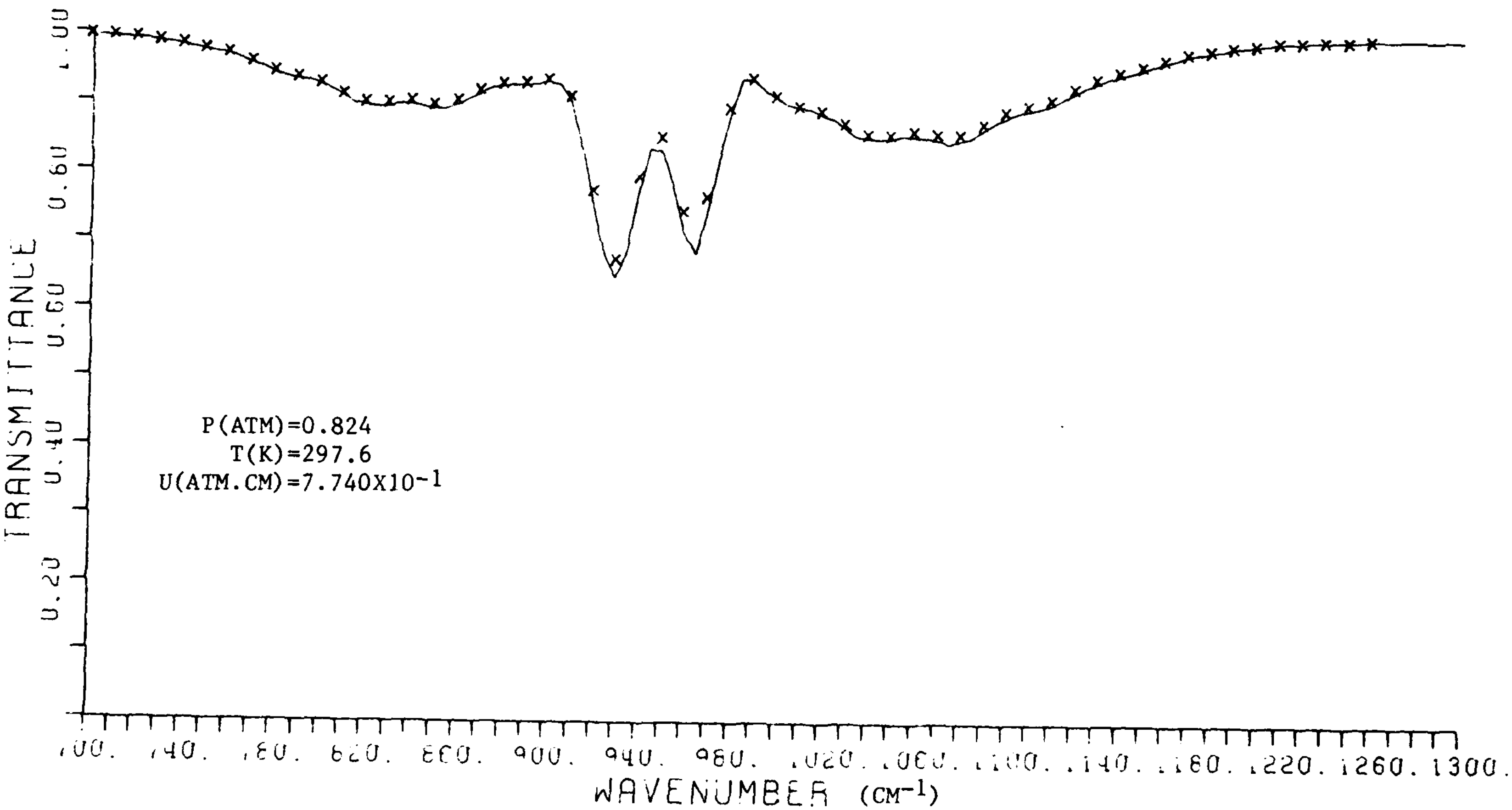


Figure E3. Comparison between 20 cm^{-1} degraded NH_3 line-by-line transmittance spectra (—) and proposed band model calculations (X).

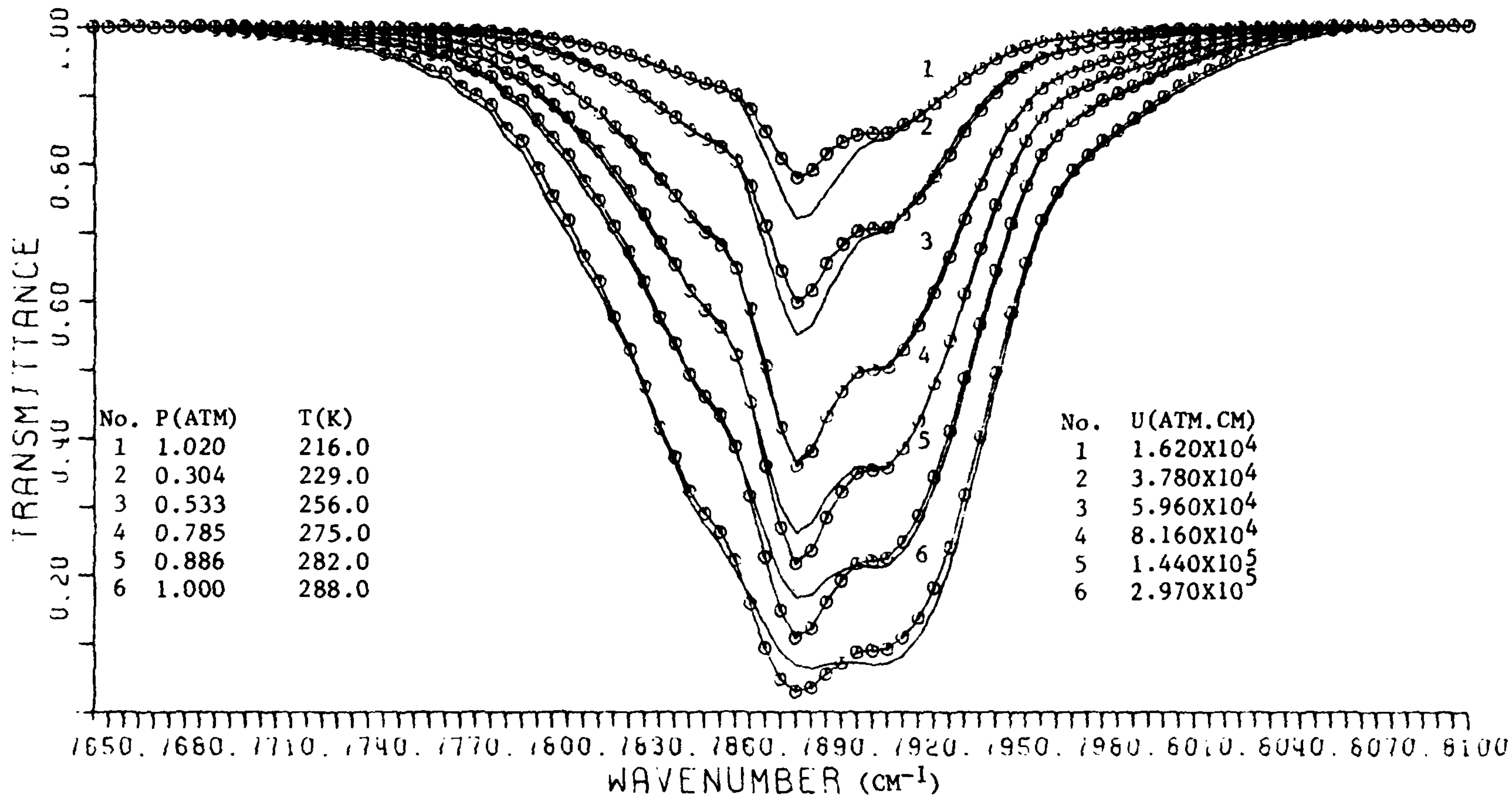


Figure E4. Comparison between 20 cm^{-1} degraded O_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

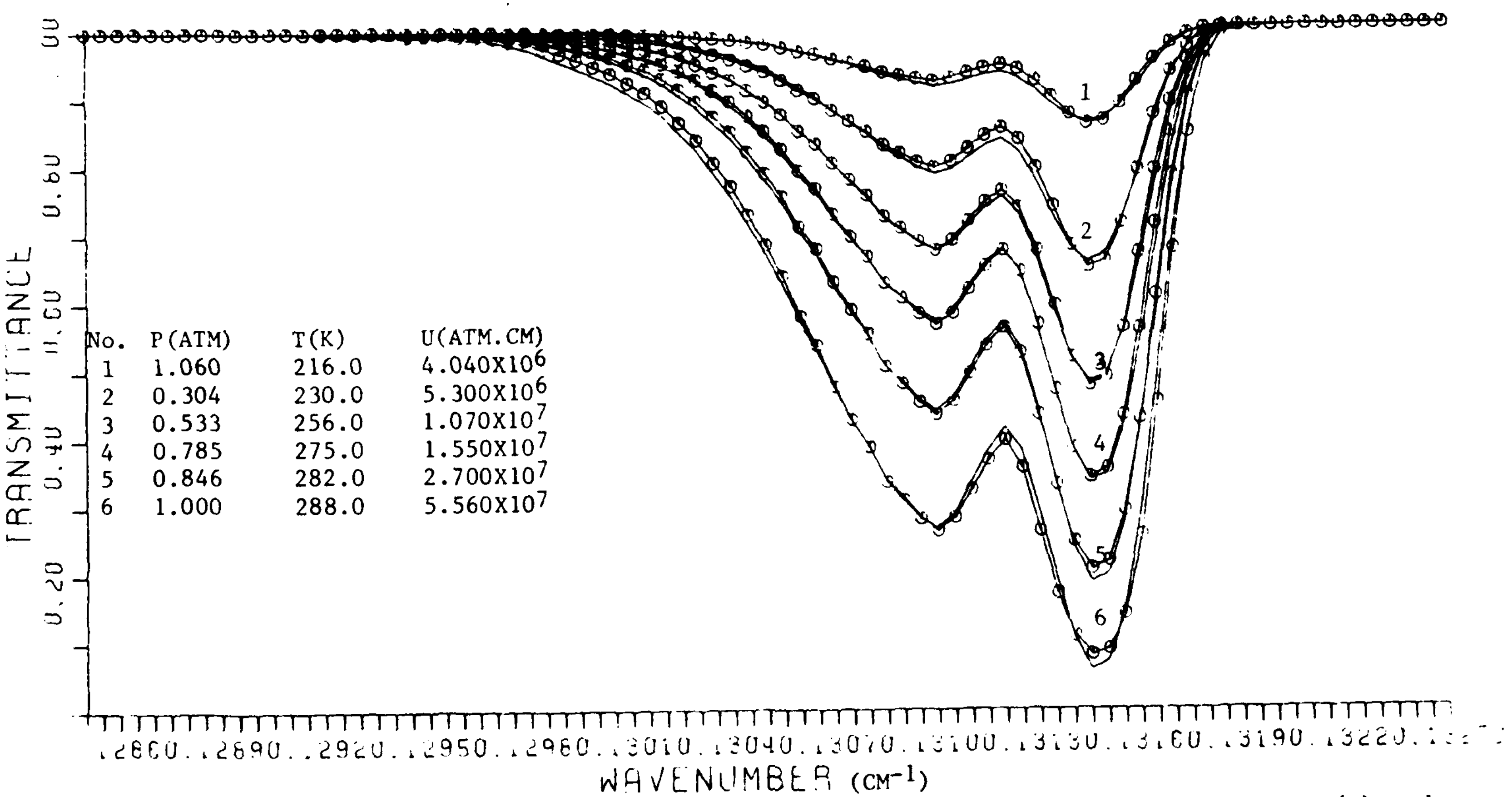


Figure E5. Comparison between 20 cm^{-1} degraded O_2 line-by-line transmittance spectra (—) and proposed band model calculations (X).

APPENDIX F

Sample Comparisons Between the Proposed Individual Models for the Uniformly Mixed Gases (N_2O, CH_4, CO, O_2, and CO_2) and the Present LOWTRAN 6 Single Model.

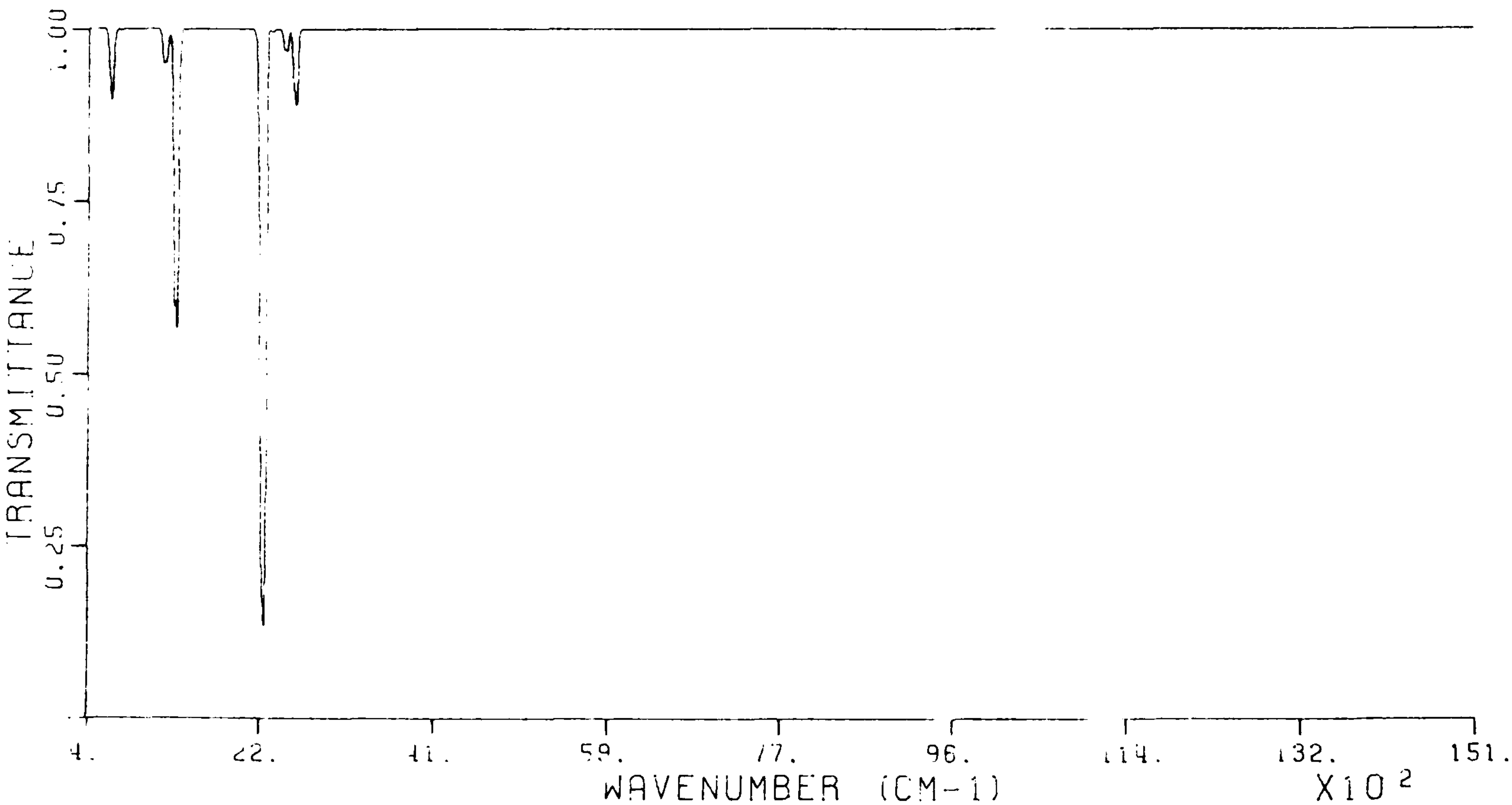


Fig. F1. Transmittance of N_2O calculated with the proposed model for a vertical path through the U.S. Standard atmosphere.

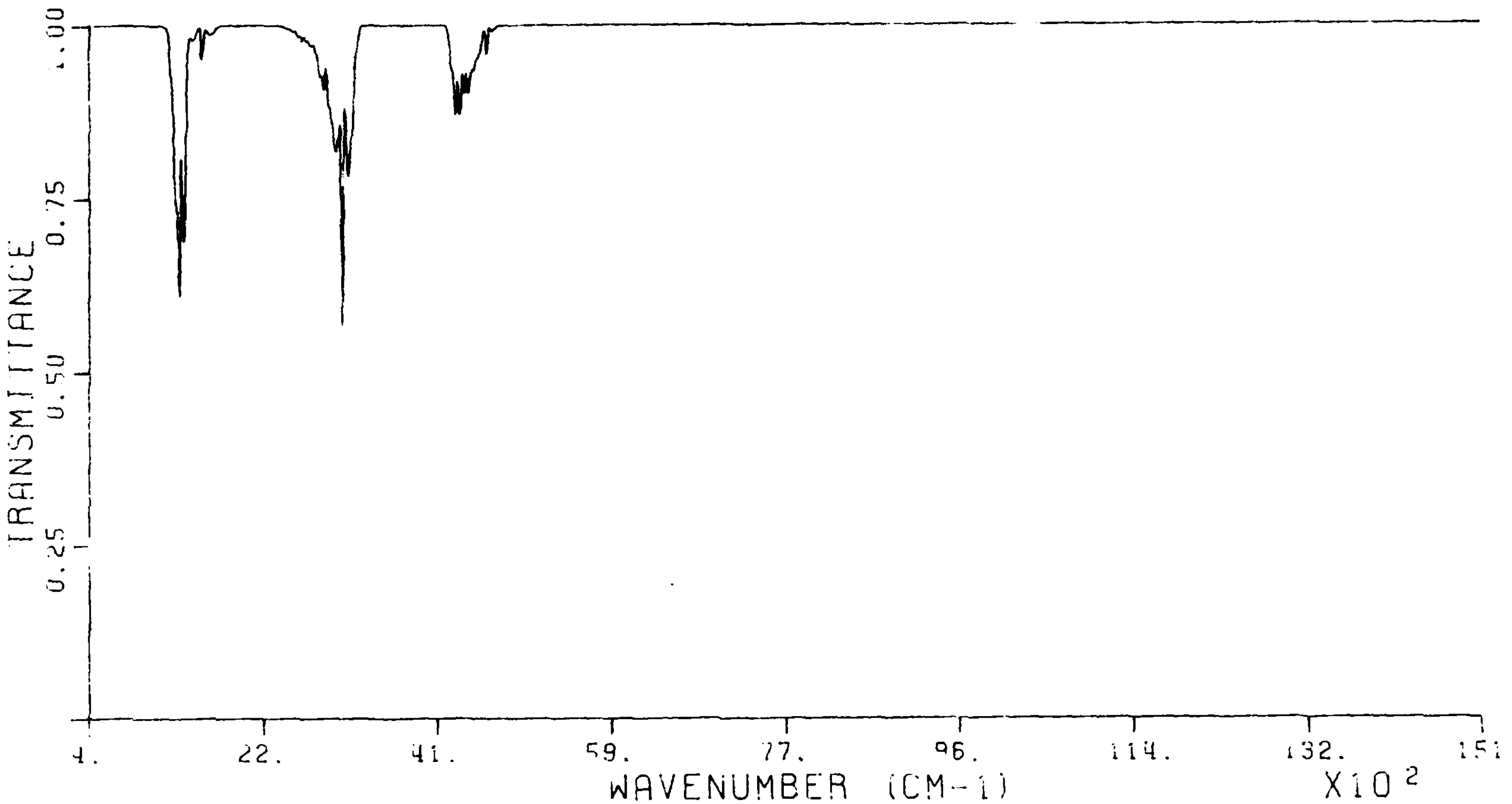


Fig. F2. Transmittance of CH_4 calculated with the proposed model for a vertical path through the U.S. Standard atmosphere.

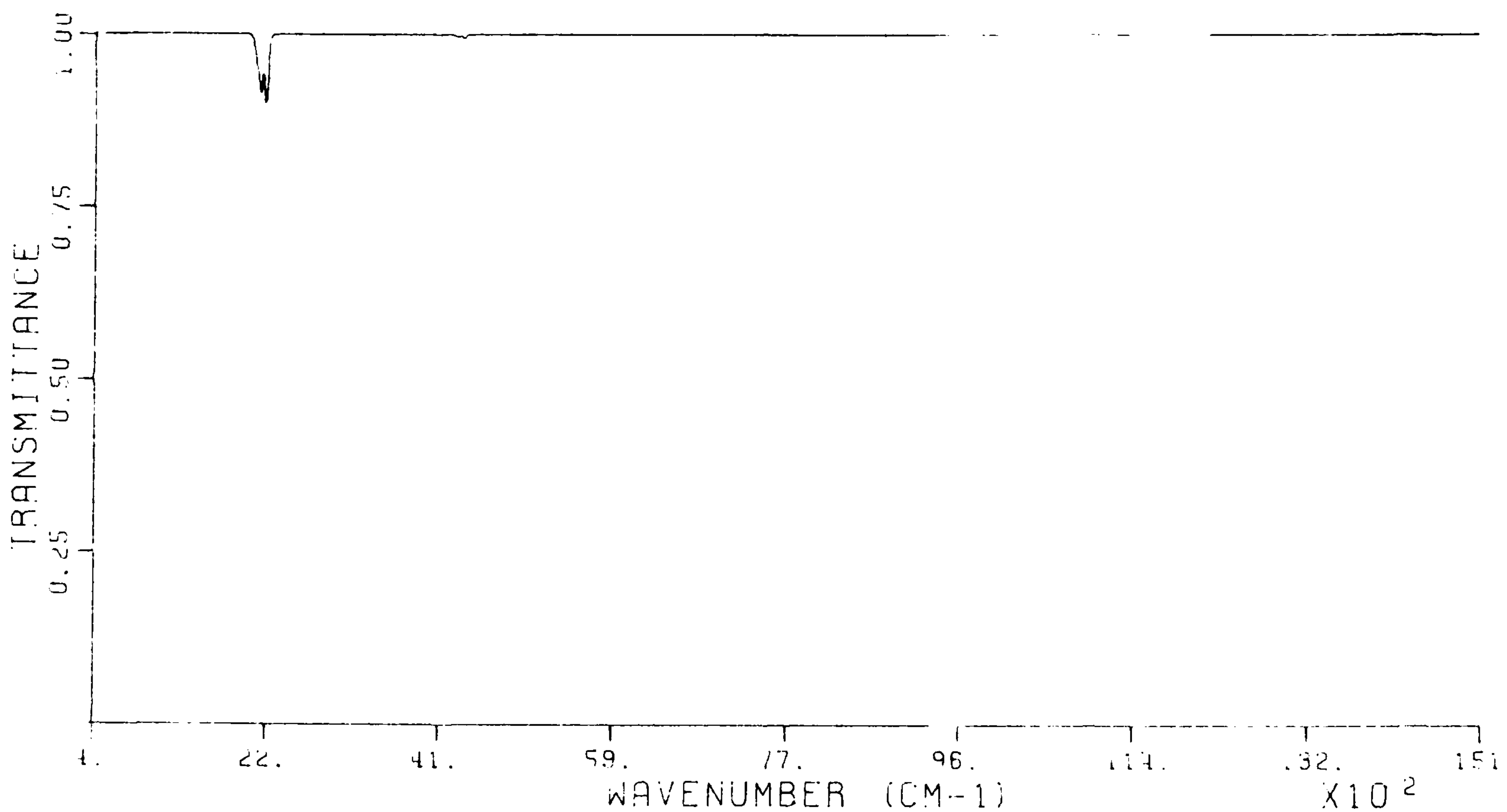


Fig. F3. Transmittance of CO calculated with the proposed model for a vertical path through the U.S. Standard atmosphere.

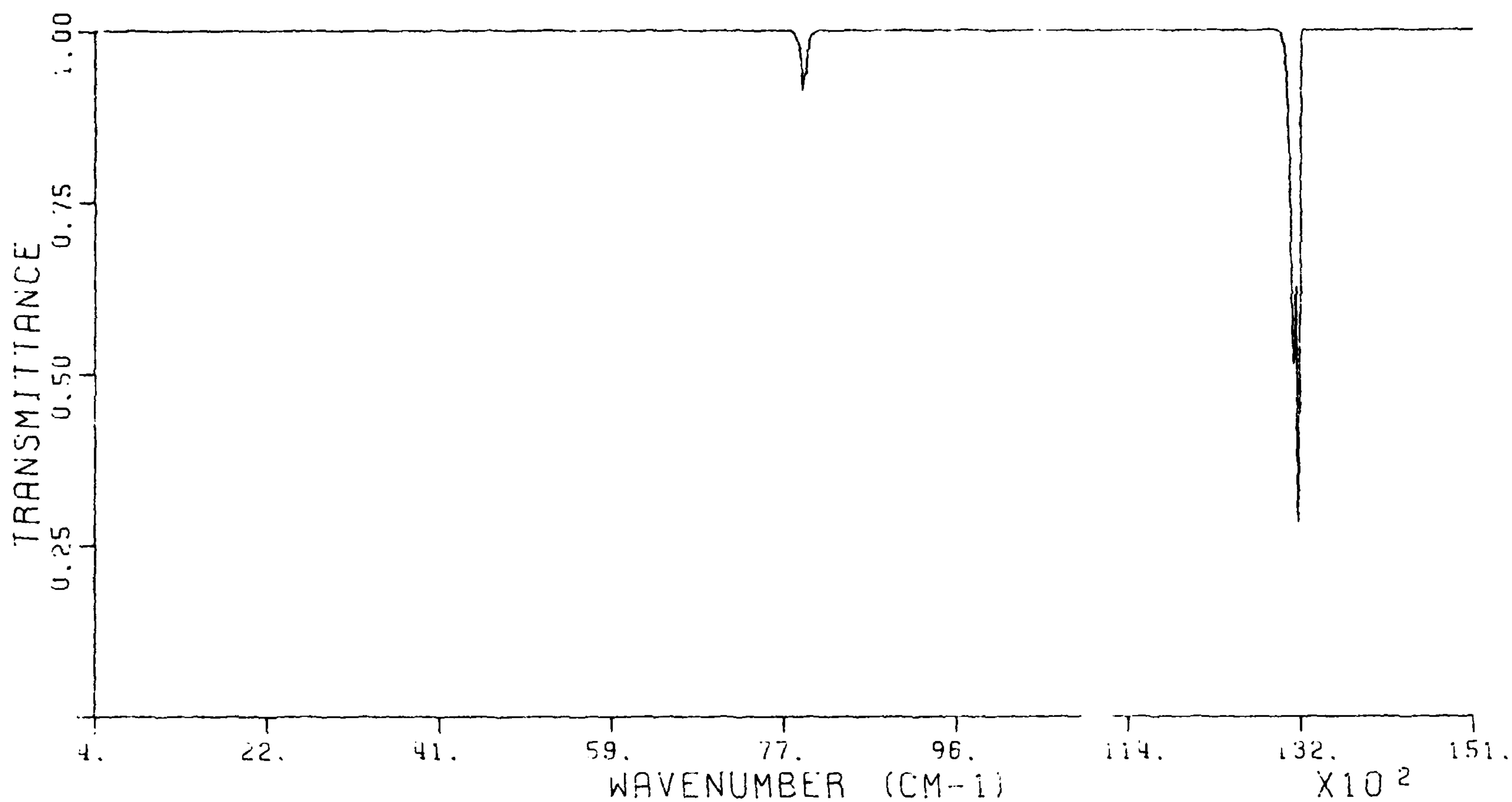


Fig. F4. Transmittance of O_2 calculated with the proposed model for a vertical path through the U.S. Standard atmosphere.

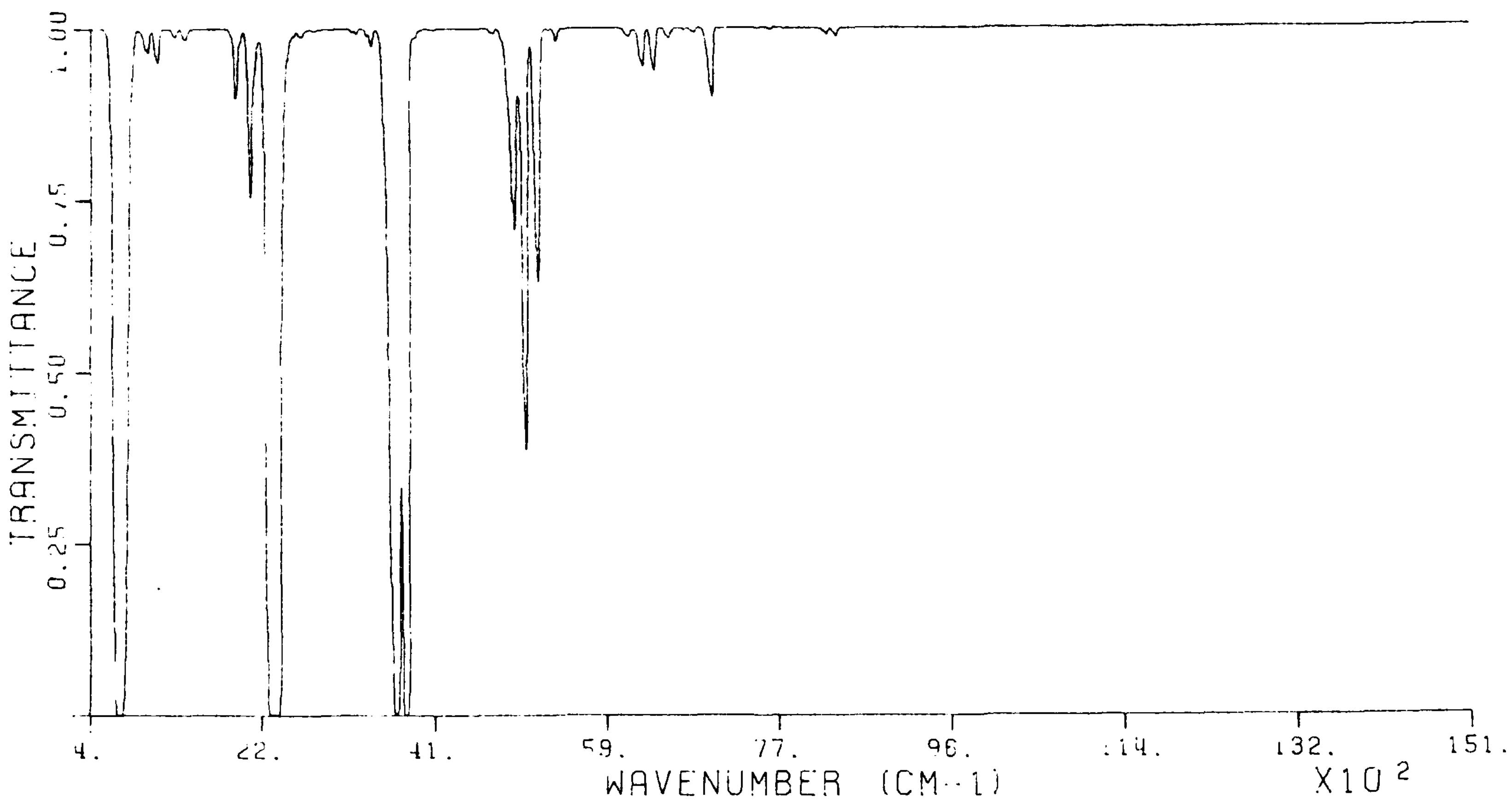


Fig. F5. Transmittance of CO_2 calculated with the proposed model for a vertical path through the U.S. Standard atmosphere.

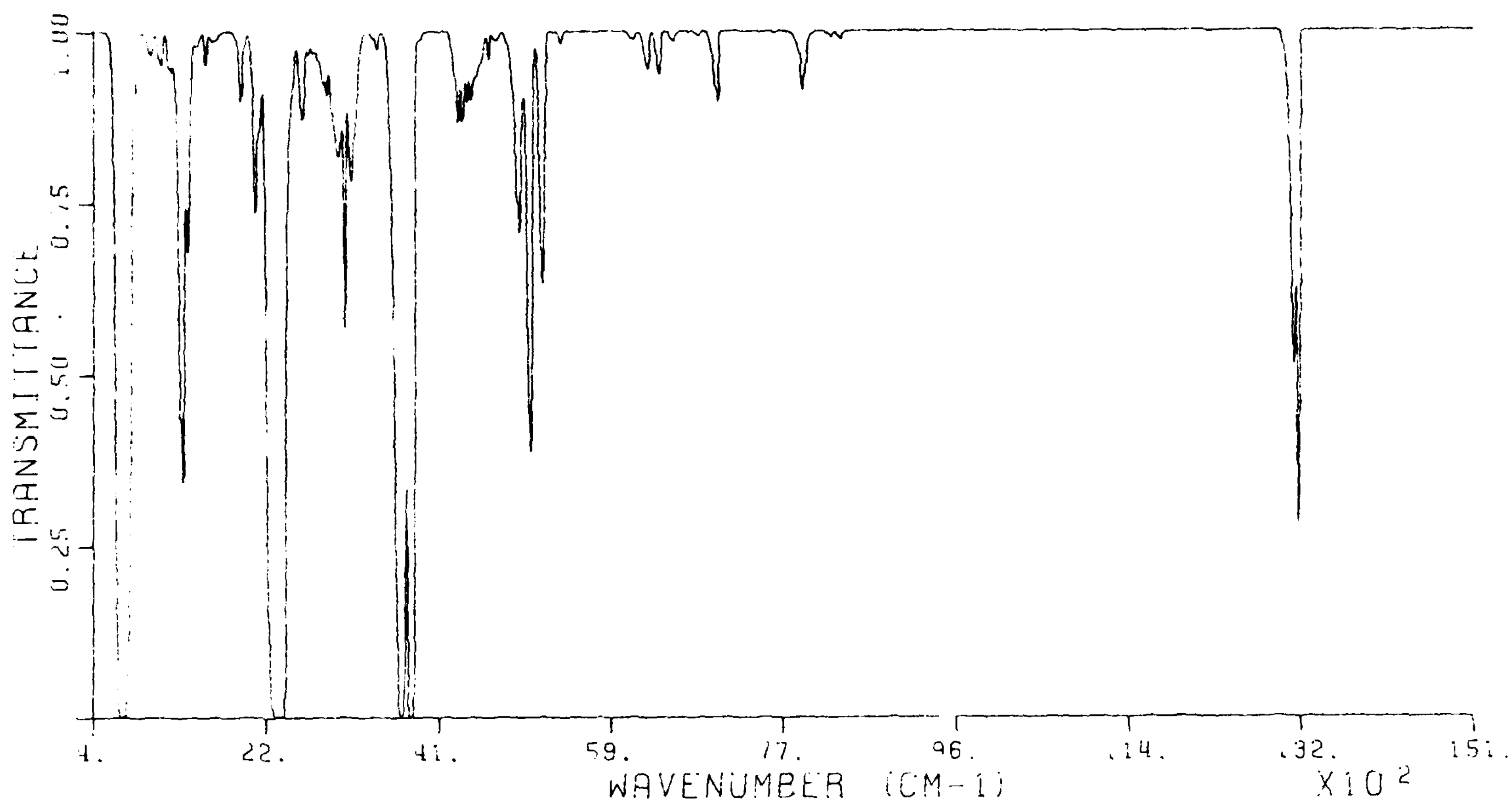


Fig. F6. Transmittance of the uniformly mixed gases (N_2O, CH_4, CO, O_2, and CO_2) calculated with the proposed models for a vertical path through the U.S. Standard atmosphere.

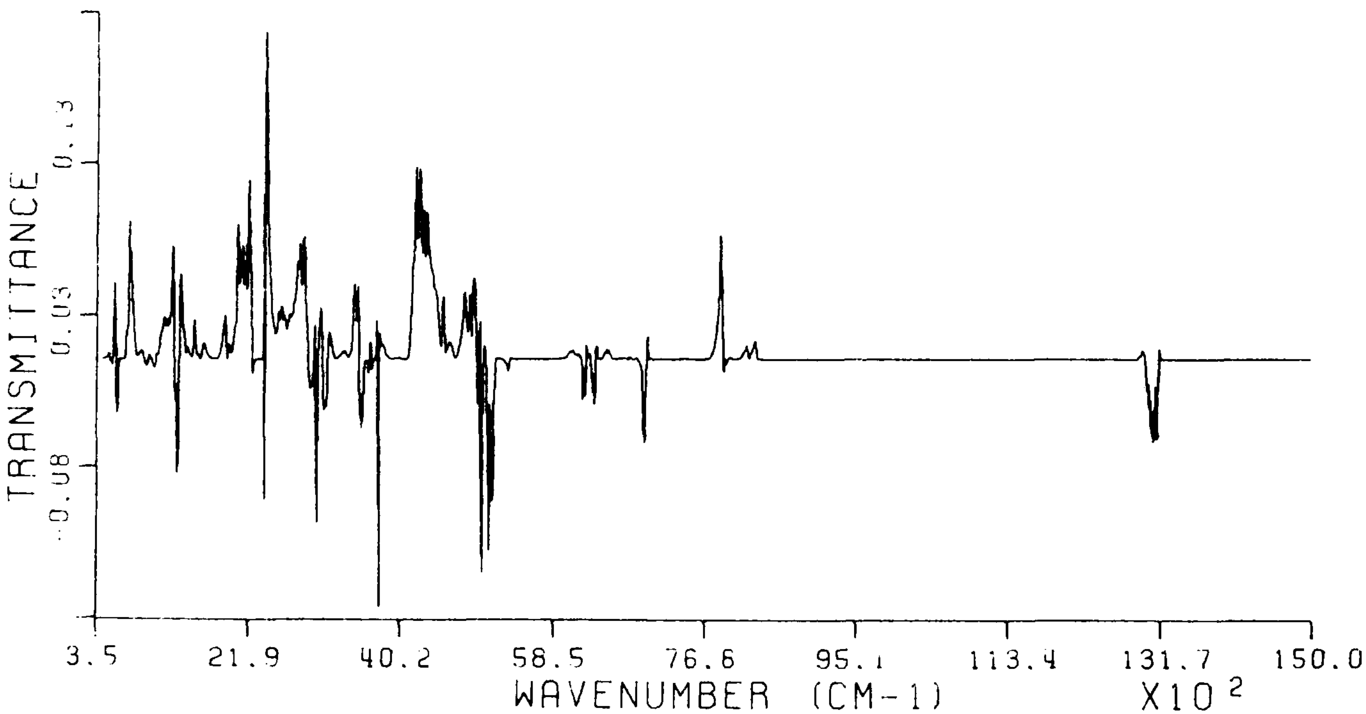


Figure F7. Transmittance difference between the proposed and the existing models for the uniformly mixed gases for a vertical path through the U.S. Standard atmsophere.

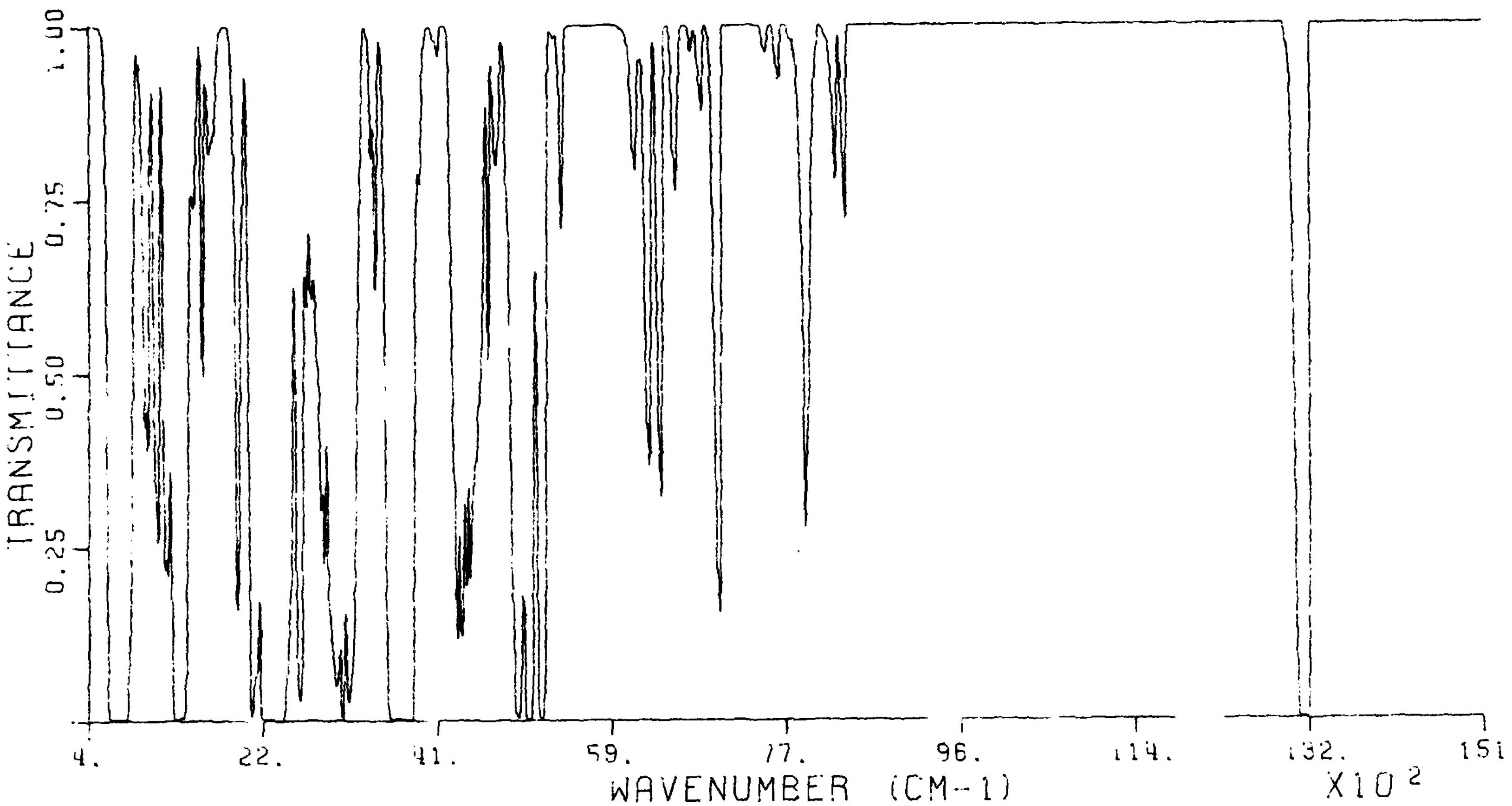


Fig. F8. Transmittance of the uniformly mixed gases (N_2O, CH_4, CO, O_2, and CO_2) calculated with the proposed models for a path tangent to the earth's surface and extending from one end to the other in the U.S. Standard atmosphere.

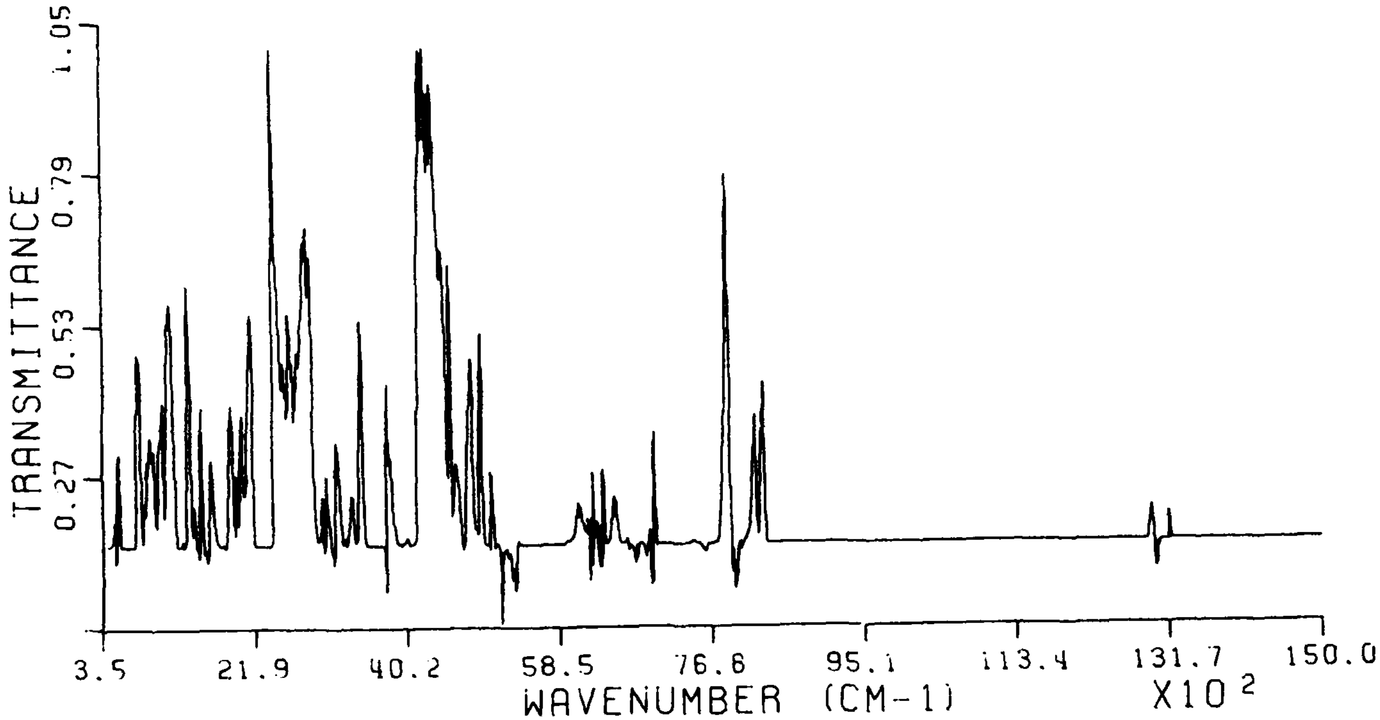


Fig. F9. Transmittance difference between the proposed and the existing models for the uniformly mixed gases for a path tangent to the earth's surface and extending from one end to the other in the U.S. Standard atmosphere.

APPENDIX G

Sample Calculations showing the Individual and Combined Effect of the Trace Gases along a Vertical and a Tangent Path in the U.S. Standard Atmosphere.

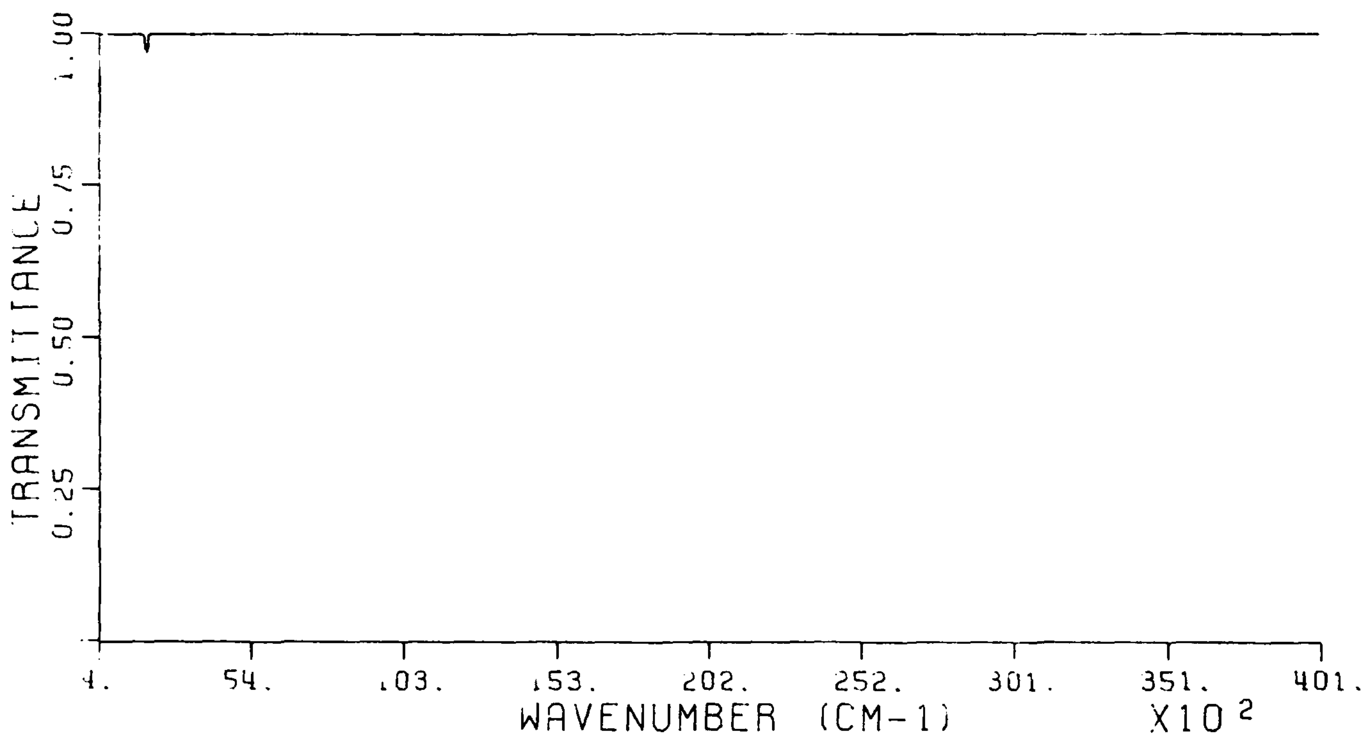


Fig. G1. Transmittance of NO using the proposed model for a path tangent to the earth's surface and extending from one end to the other in the U.S. Standard atmosphere.

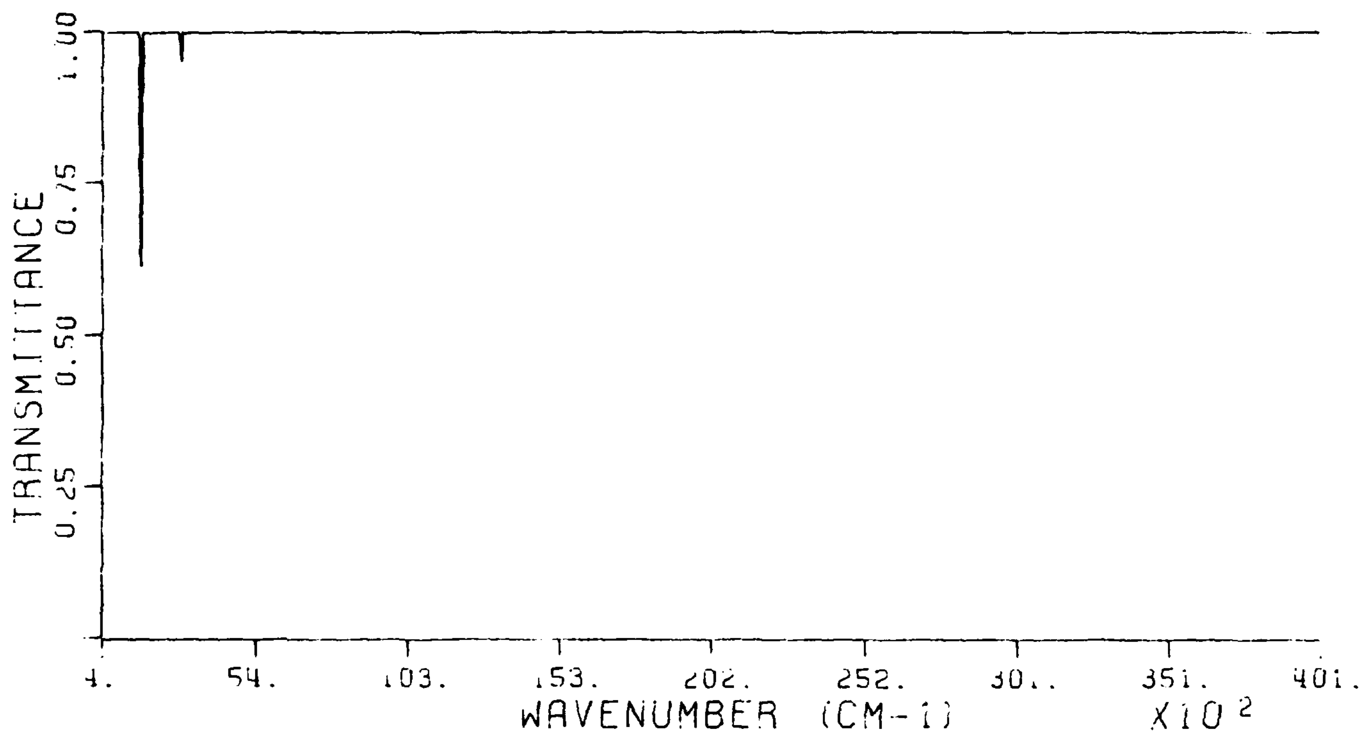


Fig. G2. Transmittance of NO_2 using the proposed model for a path tangent to the earth's surface and extending from one end to the other in the U.S. Standard atmosphere.

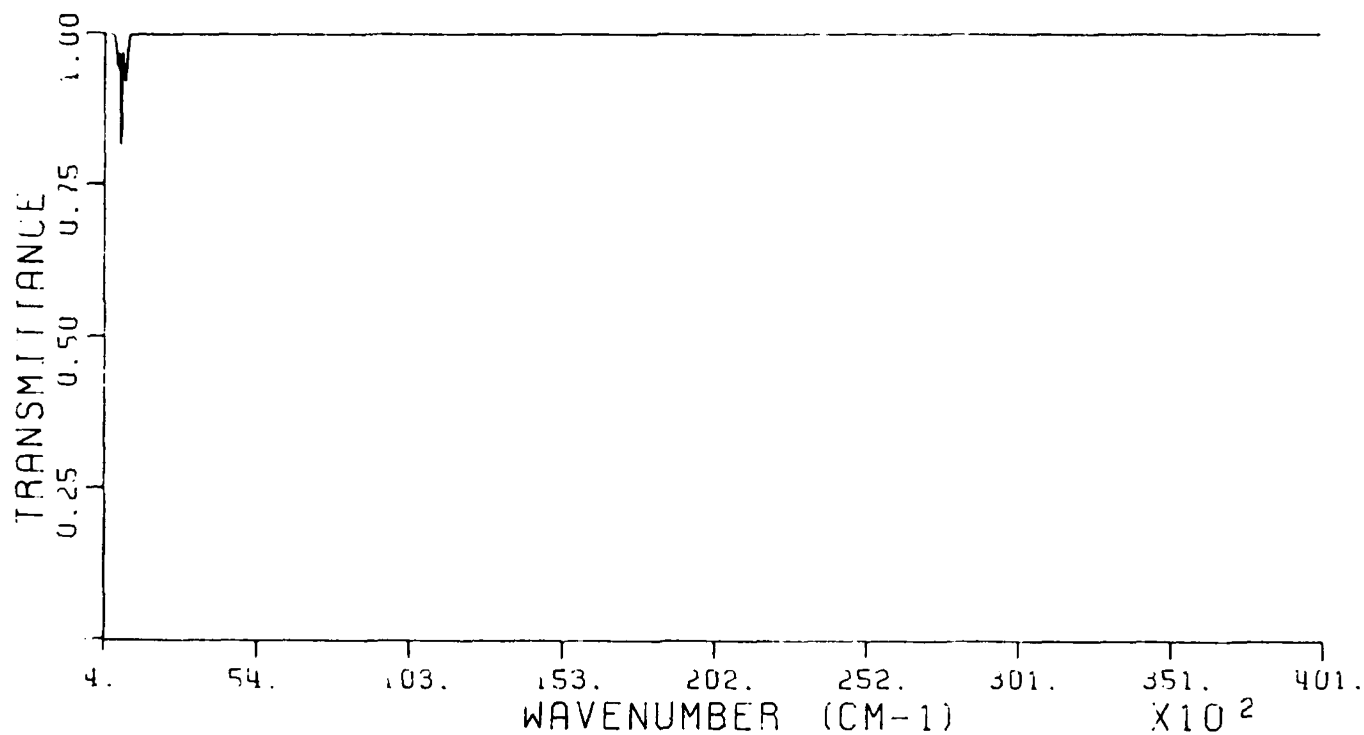


Fig. G3. Transmittance of NH_3 using the proposed model for a path tangent to the earth's surface and extending from one end to the other in the U.S. Standard atmosphere.

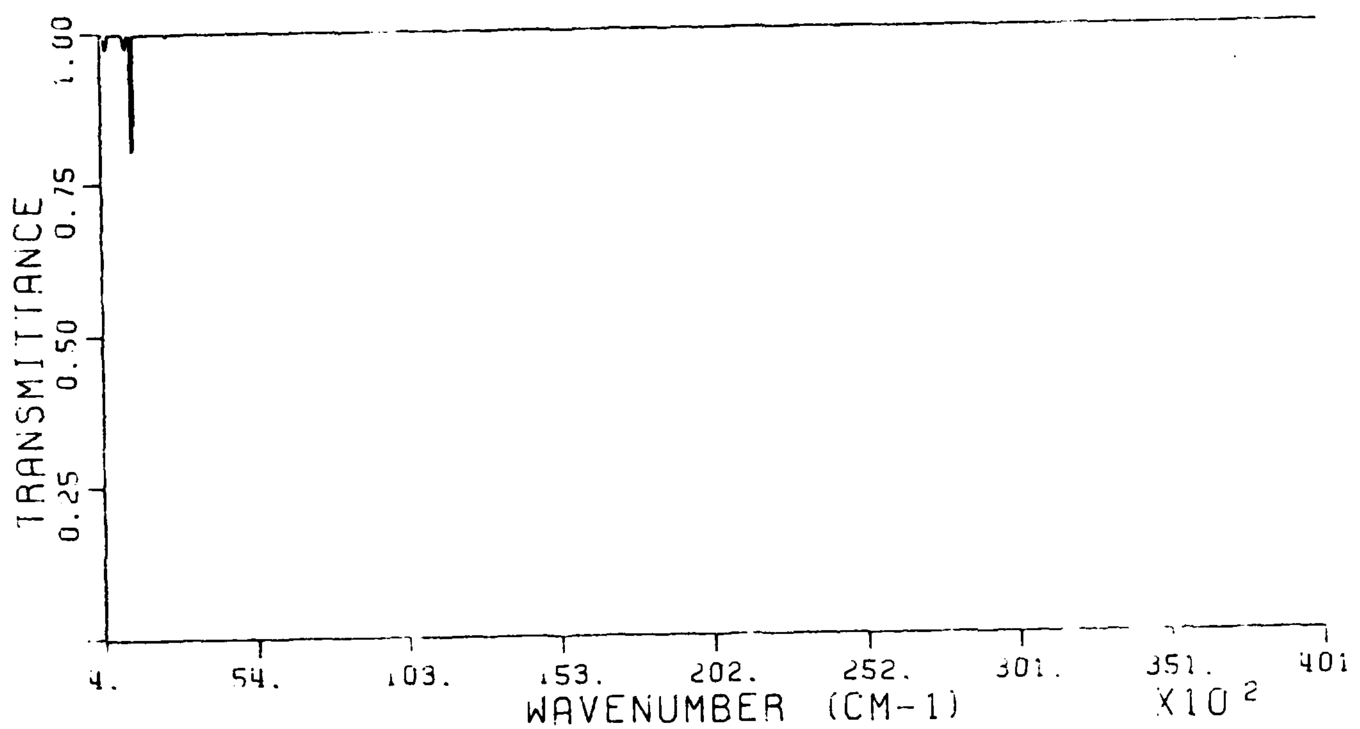


Fig. G4. Transmittance of SO_2 using the proposed model for a path tangent to the earth's surface and extending from one end to the other in the U.S. Standard atmosphere.

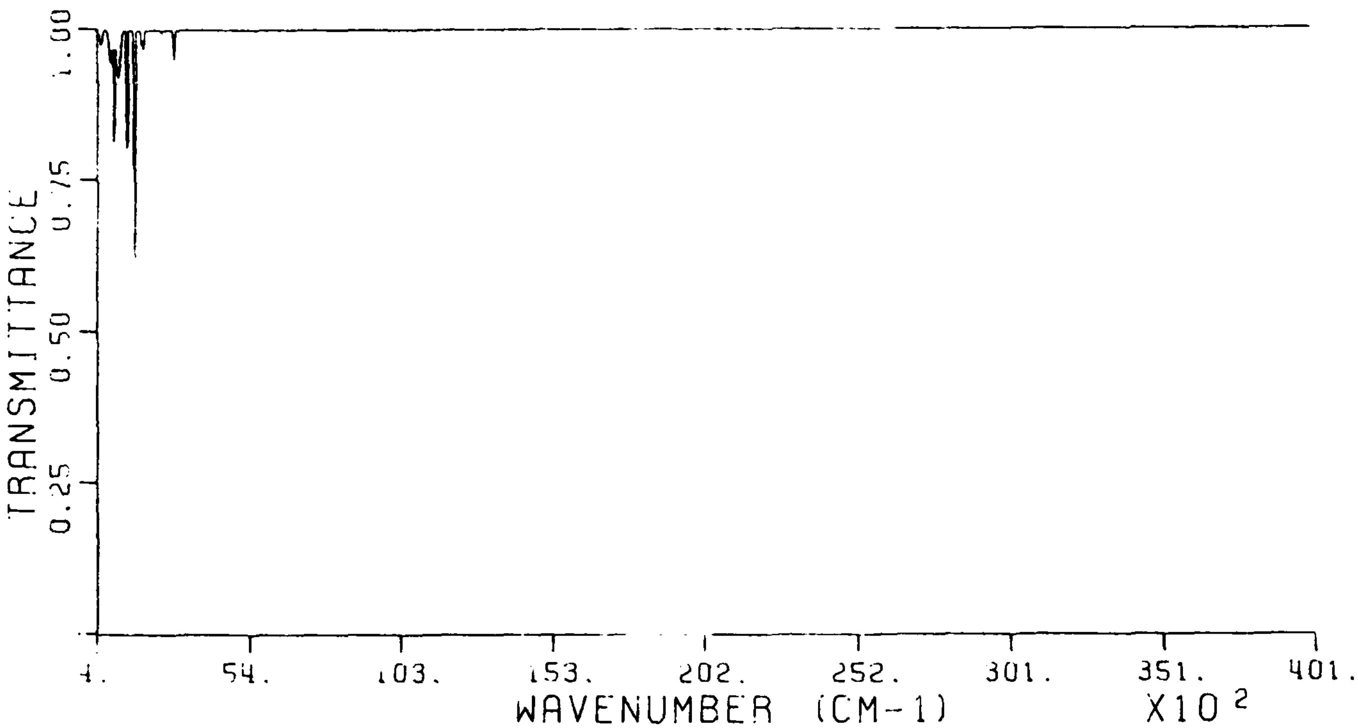


Fig. G5. Transmittance of the combined trace gases (NO, NO_2, NH_3, SO_2) with the proposed models for a path tangent to the earth's surface and extending from one end to the other in the U.S. Standard atmosphere.