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Engineering procedure for calculating the transfer of the selective radiation of molecular gases

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Abstract

A procedure for calculating radiation transfer along strongly nonisothermal paths is presented successively. It is orientated to the estimation of transmission and self-radiation of the products of combustion of hydrocarbon fuels. The procedure is based on a new approach to averaging spectral parameters by introducing distribution of lines in a given spectral interval over the energies of lower states and matrix elements. Practically it means that the combination of all spectral lines in the preset frequency is substituted by a combination of J groups of lines with averaged values of quantum mechanical characteristics. This approach is intermediate between one-group description with the use of s/d, γ/d and exact account of each line. A multigroup model is generalized for the cases of vibrational nonequilibrium state and calculations of transmission within the limits of a filter. An error of calculation of the spectral characteristics of molecular gases in the spectral interval of 2–25 μm does not exceed 10% for a two-group model, i.e. by means of six parameters, in the temperature range $T = 250$–1000 K, and 12% for a three-group model, i.e. by means of 9 parameters, in the temperature range $T = 250$–2500 K. The calculated parameters of the three-group model are presented for CO_2 in the 4.3 and 2.7 μm bands, CO in the 4.6 μm band and H_2O in the range 2–10 μm.

Keywords: Selective radiation; Radiation transfer; Vibrational–rotational bands; Multigroup model

1. Introduction

The procedures available at the present time for calculating the transfer of selective radiation are based on different models of vibrational–rotational bands of molecular gases [1–5]. Each of these procedures is orientated, as a rule, to a specific narrow range of problems. Usually, the method proposed by Curtis and Godson (the CG method) [6,7] is used for calculations. Its essence consists in replacement of transmittance along a nonuniform path by transmittance of a certain equivalent uniform layer. In the limited cases of 'strong' and 'weak' lines, the transmittance of a real layer and of a uniform layer equated to the first one coincide exactly and intermediate cases are described by approximation dependences based on simple model representations of the character of line distribution in the considered spectral interval. The CG method showed its effectiveness in the problems of atmospheric optics in application to slightly nonuniform isothermal atmospheric paths. Thereafter the method was extended also to nonisothermal volumes of molecular gases [8].

The CG method is most commonly used together

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Nomenclature

A_ν	spectral absorption of a layer	X	geometrical length of path
C	concentration of absorbing gas	Z	coefficient of nonequilibrium state.
d	distance between spectral lines		
e	energy of the lower state	*Greek symbols*	
F	contour of a line	γ	half-width of a spectral line
K	spectral absorption coefficient	ν	spectral frequency
k	absorption coefficient of isolated line	ω	absorbing mass.
L	width of a layer		
M	matrix element	*Subscripts*	
N	the number of lines in unit spectral interval	a	atmospheric
		h	a hot layer
P	pressure	L	Lorentzian
Q	statistical sum	v	vibrational characteristic.
R	transmittance of a layer		
S	strength of a line	*Superscript*	
T	temperature	F	filter characteristic.

with the statistical model of a vibrational–rotational band [8], which assumes the assignment of a certain law for the distribution of intensities of spectral lines in the considered frequency interval and the absence of correlation between the position of the spectral line and its intensity. The bands of the molecules CO_2, H_2O, N_2O and others at high temperatures are sufficiently well described by means of this model. In the case of the statistical model the transmittance R of a uniform layer is described as a dependence on two parameters: the mean absorption coefficient s/d and the parameter of line density γ/d

$$R = \exp\left(- \frac{s/d \times \omega}{\sqrt{1 + (s/d \times \omega)/(4 \times \gamma/d)}} \right), \tag{1}$$

where ω is the absorbing mass.

The merit of this approximation is the possibility to use data for s/d and γ/d obtained experimentally for isothermal layers. The standard procedure of the extension of results, which are valid for uniform layers, to the case of a nonuniform path consists in the use of the values $\overline{s/d}$ and $\overline{\gamma/d}$ averaged along the optical path. The temperature dependence of s/d and γ/d is determined by all the lines entering into the given spectral interval. The introduction of such a two-parameter description is equivalent to the replacement of a combination of real spectral lines by a set of identical lines with a certain model dependence of equivalent width on line strength and optical thickness, as well as with a dependence of line strength on temperature. With such a replacement in calculations along strongly nonuniform paths, the radiation of 'hot lines', i.e. of the lines which correspond to transitions between states with high energy values and which are weakly adsorbed in the low-temperature parts of the path, turns out to be not taken into account.

In the present work a procedure for calculation of radiation transfer along strongly nonisothermal paths is successively presented. The procedure is orientated to the estimation of transmittance and self-radiation of the products of combustion of hydrocarbon fuels in fluxes, including the case of observation through the atmosphere.

2. Multigroup model for calculating transfer of selective radiation

The procedure is based on a new approach [9,10] to averaging spectral parameters by means of introducing line distribution in the given spectral interval over the energies of lower states and matrix elements. Practically this means that the combination of all the spectral lines in the preset frequency interval is replaced by the combination of J groups of lines with averaged values of quantum mechanical characteristics. This approach is intermediate between a one-group description with the use of s/d, γ/d and an exact account for each line. Within the limits of this approach the transmittance of the layer of length X with the Lorentz broadening of lines is written in the form

$$R(x) = \exp\left\{ - \sum_{j=1}^{J} \frac{W_j}{\sqrt{1 + W_j^2/(4V_j)}} \right\}, \tag{2}$$

$$W_j = N_j M_j \int_0^X \exp\{-E_j/T(x)\} C(x)\, \mathrm{d}x, \tag{3}$$

$$V_j = N_j N_j M_j \int_0^X \gamma(x) \exp\{-E_j/T(x)\} C(x)\ \mathrm{d}x. \tag{4}$$

Here $C(x)$ is the concentration of an absorbing gas, $\gamma(x)$ is the effective half-width of spectral lines; N_j, M_j, and E_j are the parameters of groups with the following physical sense: N_j is the number of lines in a unit spectral interval, M_j is the matrix element, E_j is the energy of the lower state. With such a possibility to preset exactly the parameters of each line entering into the considered spectral interval, it is possible, in principle, to calculate the parameters for an arbitrary number of groups and arbitrary division into energies depending on the required accuracy and desired speed of calculation.

It is possible to propose several different methods for determining group parameters that differ in both the character of the input information used and the form of the system of equations in these parameters, as well as in the method of solving this system [9,11]. In the present work an algorithm for finding the parameters of the multilevel model was used, which was especially adapted to the problems of thermal-power engineering and filter diagnostics of flames of thermal-power engineering equipment in terms of the results of radiometric measurements. Let a range of the possible values of thermodynamic characteristics of objects investigated be assigned. It is necessary to find such model parameters, which would describe the spectral characteristics of these objects with a certain estimated accuracy. This requirement is identical to finding the global minimum relative to Y_j for the functional of the following form

$$F(Y_j) = \sum_i g_i \left[\frac{1 - a_i}{R_i(Y_j)} - 1 \right]^2, \tag{5}$$

where R_i is the spectral transmittance of the ith object expressed via a certain functional dependence (model) on a set of the parameters Y_j; a_i is the spectral absorption of the same object measured experimentally or calculated theoretically from a more exact model; g_i is the characteristic of the authenticity of the quantity a_i. In other words, it is necessary to achieve minimization of the discrepancy of the parametric dependence of R_i for all the objects from the range of possible parameters. A mean-square deviation will characterize an error of the description of all the objects from the selected range by the given parametric dependence $R_i(Y_j)$. The formulated problem of multiparameter optimization is a rather difficult one even for the modern level of the development of calculating technique. Moreover, there is a danger of finding a local rather than a global minimum. We used a modification of the program from the NAG library which combines the Gaussian–Newtonian and Newtonian gradient methods of the search for the functional minimum, as well as SVD factorization.

We will dwell in detail on the algorithm of determining group parameters. At the first stage, a bank of reference points was created in the entire range of temperatures and absorbing masses of interest. It is necessary that the bank include the data on the transmittance of the layers with maximum absorbing masses, as well as the data on the transmittance with minimum absorbing masses, for which an approximation of an optically thin layer can be used a priori. In the present work, the values of maximum absorbing masses were determined depending on temperature: at low temperatures from the calculation up to the distances of several tens kilometers with concentrations characteristic for the atmosphere; at high temperatures from the calculation for the layers of several meters with percentage of radiating gases up to 100%.

The algorithm for finding model parameters was divided into three stages to eliminate all kinds of instabilities and local minima. Here, for determining the limit and starting values of the parameters determined, their physical sense was used. At the first stage of optimization a functional was constructed in the approximation of an optically thin layer. In this case the transmittance of a uniform layer within the limits of the group model is written in a simplified form:

$$R = \exp\left\{ -\sum_{j=1}^{J} W_j \right\}, \qquad W_j = N_j M_j \exp\{-E_j/T(x)\}\omega. \tag{6}$$

At this stage the values of the energy E_j and of product $N_j M_j$ were determined. The starting values of the given quantities in this case can be approximately estimated using the sharp change in the exponential term in Eq. (6) for W_j as a function of temperature.

At the second stage, optimization was carried out over all the reference points with the variation of the parameters N_j and M_j. The value of the energy of the level E_j was considered here to be fixed. The value $N_j = 1$ was used as the starting values. And, finally, total optimization of the functional (5) over the entire base of the reference points was made at the third stage. After the determination of the model parameters, an additional control was made over the entire field of the reference points, where the mean-square and maximum deviations were determined for the values calculated in terms of the group model with the parameters found.

The range of the absorbing masses and temperatures, selected for the reference points, was orientated to the class of problems on the transfer of radiation of heated gas layers through the bulk of the atmosphere. This corresponds to the problems of radiation transfer in the flames of heat–power installations and to observation of flames from considerable distances. The temperature varied in the range 250–2500 K. The absorbing masses changed within the limits from an optically thin layer ($L = 10^{-3}$ m, $C = 10^{-3}$) to maximum absorbing masses ($L = 10^{4}$ m, $C = C_a$ at atmospheric temperatures and $L = 2.5$ m, $C = 0.1$ for hot layers). The data for four absorbing masses at eight temperatures, i.e. 32 points in all entered into the bank of the reference points. The calculations showed that an acceptable accuracy of the description of the spectral characteristics of molecular gases in the spectral range 5–25 μm can be reached with a mean-square error not exceeding 10% by means of a two-group (two-level) model (6 parameters) in the temperature range $T = 250$–1000 K and with an error not exceeding 12% with the use of a three-group (three-level) model (nine parameters) in the temperature range $T = 250$–2500 K.

3. Methods of the assignment of reference points

The determination of the values for absorption of layers at the reference points needs a special description. It is precisely the range of the coverage of all the possible experimental situations and the degree of the authenticity of the initial information used that determine both the area of the applicability of the model with the found parameters of groups and the accuracy with which the spectral characteristics of absorption and radiation are described.

As initial information one can use: calculations by the 'line-by-line' method in terms of the bank of spectral lines (BSL) for the temperatures below 600–1000 K; calculations in terms of the models of bands; data on the results of experimental measurements of transmittance at different temperatures and absorbing masses. Below we consider each of these methods.

3.1. Calculation of the spectral transmittance of uniform gas layers by the 'line-by-line' method in terms of the bank of spectral lines

Rapid development of theoretical and experimental methods of the high-resolution spectroscopy led to the creation of voluminous atlases of spectral lines of molecular gases. The modern versions of the atlases GEISA [12], HITRAN [13] and ATMOS [14] contain data from 21 to 48 atmospheric and admixtures gases. Numerous checkings confirmed the good reliability of calculation results for the spectral characteristics of molecular gases in terms of the BSL in the temperature range 300–850 K.

The cumbersomeness of direct numerical integration of transmittance functions over frequency is well known. But since the reference points are calculated once, a question concerning the economy of computational expenditures did not arise, and it was possible to carry out calculations of spectral transmittance with a preliminary specified high accuracy not fearing the extra amount of calculations.

The spectral absorption of a uniform layer of thickness L is defined by expression

$$A_\nu = 1 - \exp\{-K_\nu L\}, \tag{7}$$

where K_ν is the spectral absorption coefficient resulting from the summation of the contributions of all the lines:

$$K_\nu = \sum_i \sum_{\nu''j''-\nu'j'} k_{ij}(\nu, T, P, C_i). \tag{8}$$

Here k_{ij} is the coefficient of absorption of an isolated line of the absorbing component i with the centre at ν_{0j}. This coefficient depends on the frequency ν, temperature T, total pressure P, and the concentration of the absorbing component C_i. The absorption coefficient of the isolated line is determined by the correlation

$$K_\nu = S_{\nu i} f(\nu_i, \nu). \tag{9}$$

We are interested in a range of problems, in which the contour of a spectral line is determined, as a rule, by shock broadening. The form of the Lorentzian line is defined by the following expression:

$$f = \frac{1}{a\gamma_L} \times \frac{1}{1 + ((\nu - \nu_i)/\gamma_L)^2}. \tag{10}$$

Here a is the coefficient determined from the normalization condition, γ_L is the Lorentzian half-width of a line defined by the formula

$$\gamma_L = \gamma_0 \left(\frac{296}{T}\right)^{\delta} \frac{P}{P_0}, \tag{11}$$

where the values of γ_0 and of the coefficient of temperature dependence δ for each line are taken from BSL. In calculation of absorption of large absorbing masses of gases with weakly overlapping lines the question concerning the form of the line contour at large distances from the centre becomes topical. Different experimental data on the absorption coefficient indicate that the distribution of intensity in the tails of the lines differs from Lorentzian one. For distances of 20–40

half-widths from the line centre a certain excess above the Lorentzian contour is observed and at larger distances the decrease occurs much more quickly than it follows from Eq. (10). In our calculations at distances smaller than $\Delta = g\gamma_L$ the line contour was supposed to be the Lorentzian one and for larger distances to be equal to zero. The coefficient a is defined as

$$a = \arctan(\Delta). \tag{12}$$

The value of the parameter g was determined from the condition of the best coincidence with experimental or calculated data for large absorbing masses. Fig. 1 demonstrates the influence of the value of g, that characterizes the 'truncation' of the contour, on the absorption spectrum for considerable absorbing masses. The calculations were carried out by the method based on the model of randomly overlapping Elsasser transitions [15] and by the 'line-by-line' method with different parameters g. This parameter exerts the significant influence due to the fact that the equivalent width of the strong line is practically proportional to g. In our calculations of reference points in terms of BSL, after numerous comparisons we selected the following values of the parameter: g = 40

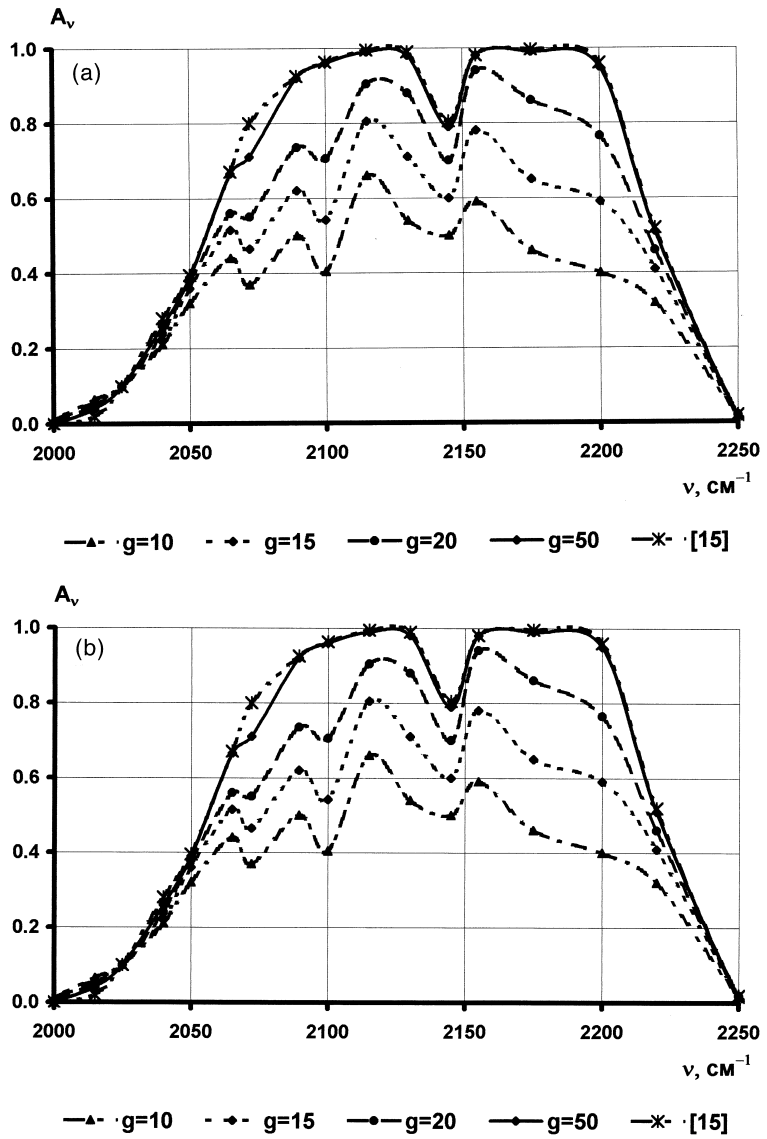

Fig. 1. Absorption spectra for P = 1 atm, L = 2.5 m, C = 0.1. (a) 4.6 μm band of a CO layer with T = 250 K, (b) 2.7 μm band of a CO_2 layer with T = 500 K.

for the H_2O and CO molecules and $g = 20$ for the CO_2 molecule.

The strength of the line was determined from the parameters of lines from BSL in the following way:

$$S_k = S_{0k}\left(\frac{296}{T}\right)^{d_k}\frac{Q_v(296)}{Q_v(T)}\,exp\left\{E_k\left(\frac{1}{296}-\frac{1}{T}\right)\right\} \times\left(1-\exp\left\{-\frac{E_k}{T}\right\}\right), \quad (13)$$

where $Q_v(T)$ is the vibrational statistical sum.

Eqs. (7)–(13) define the algorithm of calculation of absorption by molecular gases by the 'line-by-line' method. BSL GEISA [13] was used for calculation. For each line the following parameters were taken from BSL: the position of the line ν, the half-width of the line γ, the energy of the lower state E_k, the power coefficient of the temperature dependence of rotational statistical sum d_k.

In calculation by the 'line-by-line' method a question arises concerning the averaging of the spectral characteristics obtained. To decrease the influence of the position of the boundaries of spectral cells and to smooth spectral information, averaging with the spread function of type of the Gaussian contour was used:

$$a_{\nu k} = \frac{1}{A}\int_{\nu_k-\Delta\nu}^{\nu_k+\Delta\nu} a_\nu \exp\left\{-\left(\frac{\nu_k-\nu}{\Delta\nu_{0.5}}\right)^2\right\} d\nu,$$

where A and $\Delta\nu$ are determined from the conditions of normalization and reduction of the spread function to 10^{-3}–10^{-4}, i.e. $\Delta\nu = (3 \div 4)\ \Delta\nu_{0.5}$. The spectra of the absorption of H_2O calculated by the 'line-by-line' method with different widths of averaging are presented in Fig. 2. The optimal distance between the neighboring spectral points ν_k, and the relationship between $\Delta\nu_k$ and $\Delta\nu_{0.5}$ are determined by the width of the vibrational–rotational band and by the sharpness of the change of spectral characteristics. The following values were selected in calculation: $\Delta\nu_k = 5\ cm^{-1}$, $\Delta\nu_{0.5} = 2.5\ cm^{-1}$ for CO_2, $\Delta\nu_k = \Delta\nu_{0.5} = 5\ cm^{-1}$ for CO, $\Delta\nu_k = \Delta\nu_{0.5} = 10\ cm^{-1}$ for H_2O.

Comparison of the results of calculations of the spectral transmittance of uniform layers of molecular gases (H_2O, CO_2, CO, HCl) by the 'line-by-line' method with experimental data and results of calculations according to the model of randomly overlapping Elsasser transitions showed that BSL GEISA contains a sufficient number of lines to calculate the spectral characteristics of gases with the temperatures $T \leq 700$–800 K.

3.2. Calculations by band models

Calculations by band models represent another source of reference points [1–5]. They allow one to describe the temperature range from 250 to 3000 K. The method based on the model of randomly overlapping Elsasser transitions [15] was used for calculations of spectral characteristics in the basic bands of diatomic molecules (CO, HCl, etc.) and in the 4.3 and 2.7 μm CO_2 bands. The statistical model with the parameters s/d and γ/d taken from [5] was applied to calculate the spectral characteristics of an H_2O molecule

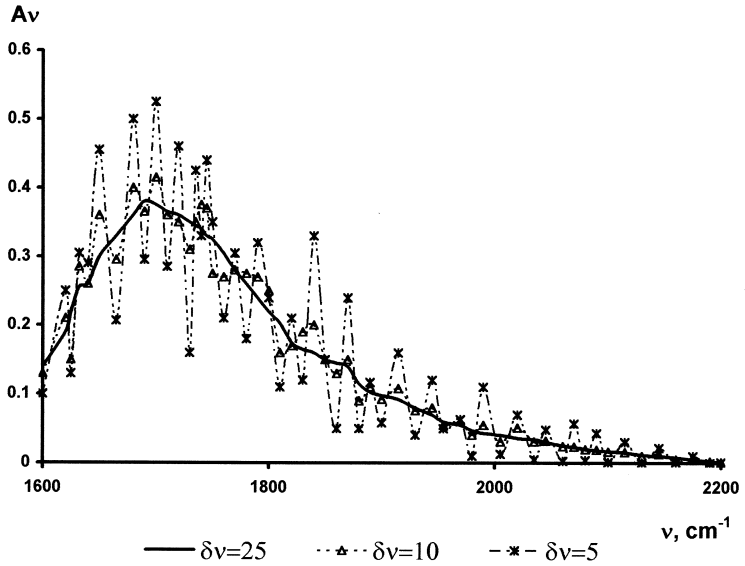

Fig. 2. Absorption spectra for H_2O, calculated by the 'line-by-line' method, with different widths of averaging.

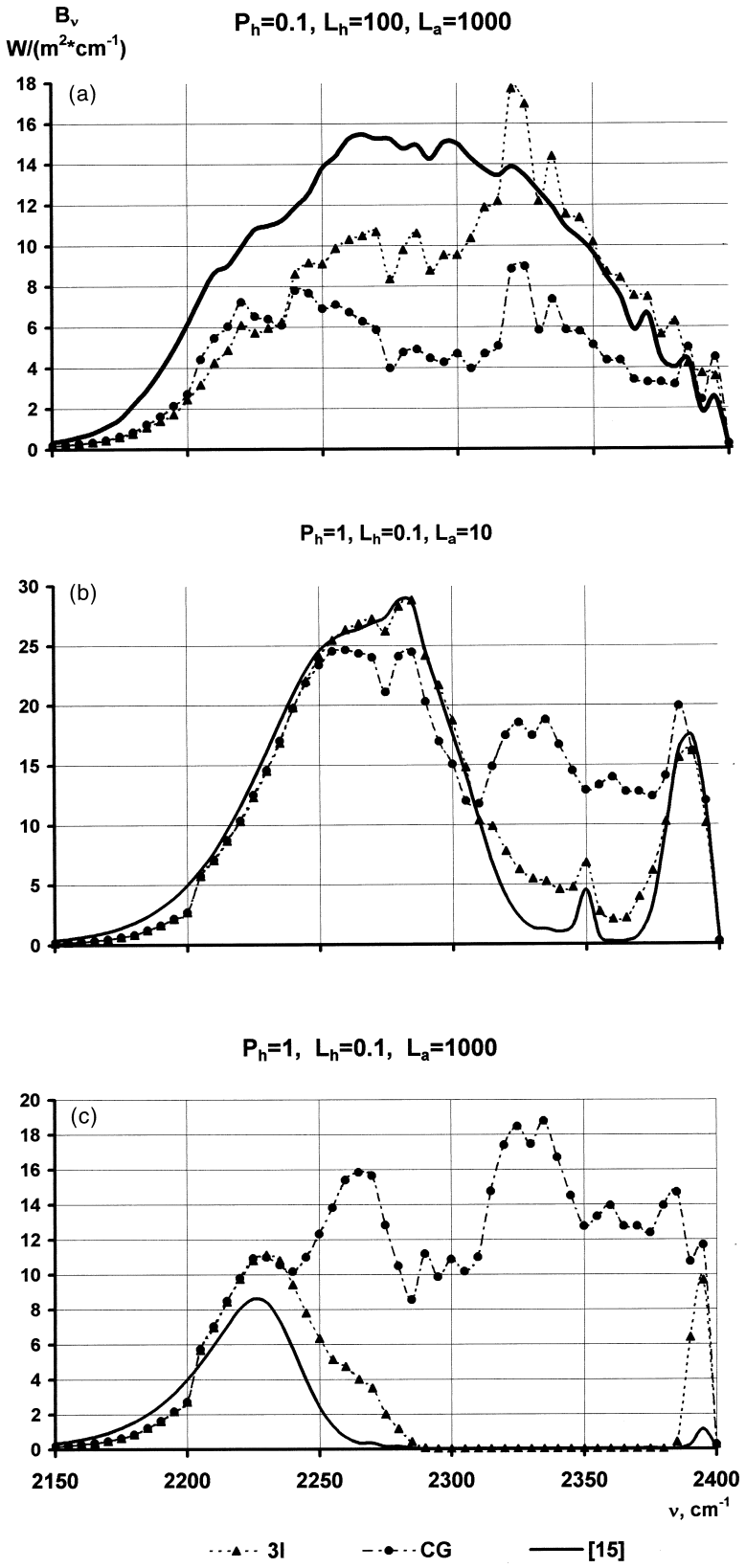

Fig. 3. Radiation spectra of heated equilibrium layers of CO_2, passed through the atmosphere, in the 4.3 μm band for $P_a = 0.1$ atm, $C_a = 0.0003$, $T_a = 270$ K, $T_h = 1000$ K, $C_h = 0.1$, calculated by different methods.

at temperatures above 600 K. The intervals and method of spectral averaging for $T > 600$ K are not so important, and here the values of parameters were interpolated.

3.3. Results of experimental measurements of transmittance

The data of different experiments with measurement of the transmission spectra of molecular gases can also be used as reference points for determining the parameters of groups. But the difference in the values of the parameters of averaging in calculations and experimental measurements hinders direct use of the results of measurements as reference points. It is more preferable to use these values in final tests of the obtained parameters of groups.

Figure 3 presents as an example the spectra of radiation of heated uniform layers of CO_2 in the 4.3 μm band that passed through the atmosphere. Calculations were carried out by the CG method using Eq. (1) with the beam-average parameters from [5], by the method described in [15], and by the procedure proposed in the present work (the curves 3*l*). It is seen that for these kinds of problems the use of the CG method without essential corrections in the centres of the bands is inadmissible. The multigroup model even in such specially selected cases, which are difficult for numerical modelling, gives satisfactory results. The errors obtained in describing the spectral characteristics of equilibrium objects by the three-group model with 9 parameters in the form of Eqs. (2)–(4) for the temperature range 250–2500 K, pressure range 0.01–100 atm and arbitrary absorbing masses did not exceed 10–12%.

4. Calculation of transmittance within the limits of a filter

In numerical simulation of the measured spectral characteristics of objects it is necessary to carry out averaging over the spread function of a specific measuring device. So, the spectral transmittance of the layer R^{F} measured by a device with the spread function U_ν is equal to

$$R^{\mathrm{F}} = \frac{1}{A}\int_{-\infty}^{+\infty} R_\nu U_\nu \, \mathrm{d}\nu,$$

where A is determined from the conditions of the normalization of the spread function. A necessity in taking account of the spread function of the device makes the numerical procedure of calculation of radiation transfer more complex.

As shown above, the determined values of the parameters of the group model depend not only on the range of temperatures and absorbing masses, but also on the method of averaging spectral characteristics. Therefore, generally speaking, reference points should be calculated with account for a specific spread function. But in such an approach generality is lost, and for each spread function it would have been necessary to recalculate the entire initial material on reference points and to solve again the optimization problem in order to find the parameters of groups. Therefore, it is more advisable to determine the parameters of groups with maximum detailed spectral division, with filter parameters of the model being calculated for each specific spread function by means of the following procedure.

We will write the transmittance within the limits of the filter, using certain parameters of the multigroup procedure which are weighted mean over the filter:

$$R^{\mathrm{F}} = \exp\left\{ -\sum_{j=1}^{J} \frac{W_j^{\mathrm{F}}}{\sqrt{1 + (W_j^{\mathrm{F}})^2/(4V_j^{\mathrm{F}})}} \right\}, \tag{14}$$

where the values of W and V are determined from Eqs. (3) and (4) in terms of the filter parameters of the multigroup model. To determine these parameters, we will require the minimization of discrepancy for transmittance within the limits of the filter in the limiting cases of thin and thick lines, i.e. of the following two functionals:

$$F_1 = \sum_i \left(\sum_{j=1}^{J} N_j^{\mathrm{F}} M_j^{\mathrm{F}} \exp\{-E_j^{\mathrm{F}}/T\} - \frac{1}{A}\int_{-\infty}^{+\infty} T_\nu \sum_{j=1}^{J} N_j M_j \exp\{-E_j/T\} \, \mathrm{d}\nu \right),$$

$$F_2 = \sum_i \left(\sum_{j=1}^{J} N_j^{\mathrm{F}} \sqrt{M_j^{\mathrm{F}}} \exp\{-E_j^{\mathrm{F}}/2T\} - \frac{1}{A}\int_{-\infty}^{+\infty} T_\nu \sum_{j=1}^{J} N_j \sqrt{M_j} \exp\{-E_j/2T\} \, \mathrm{d}\nu \right),$$

where the summation over i signifies summation over all the reference points.

The filter parameters of the model N, M, E obtained as a result of optimization, can be used to calculate spectral characteristics of a specific device with the spread function U_ν.

5. Account for nonequilibrium in the multigroup model

We will use the procedure given above to describe radiation transfer in vibrationally-nonequilibrium gases. We will generalize the multigroup model of the description of the spectral composition of radiation by having divided the energy of the lower level for each group into several constituents, each of which corresponds to its own type of motion:

$$E_j = E_j^{\text{trans}} + E_j^{\text{vibr}}.$$

We will consider only such vibrationally-nonequilibrium states for which the Boltzmann distribution over levels with the vibrational temperature T_{vi} is set inside each type of the vibrations of molecules. This is the vibrational temperature T_{v} for diatomic molecules, for CO_2 we will limit ourselves by the case when the temperatures of symmetrical and deformation modes coincide with translational one ($T_1 = T_2 = T$), and vibrational temperature is equal to the temperature of an asymmetric mode ($T_{\text{v}} = T_3$).

Introduce the coefficient Z_j for convenience of notation in the following way:

$$E_j^{\text{trans}} = (1 - Z_j)E_j, \quad E_j^{\text{vibr}} = Z_j E_j.$$

With account for the accepted functional dependence, the transmittance of the layer of length X will be written in the same form (2), as for the uniform case, with the parameters determined in the following way

$$W_j = \int_0^X N_j M_j \exp\left\{ -\frac{(1 - Z_j)E_j}{T(x)} - \frac{Z_j E_j}{T_{\text{v}}(x)} \right\} C \, \mathrm{d}x, \quad (15)$$

$$V_j = N_j \int_0^X \gamma N_j M_j \exp\{-(1 - Z_j)E_j/T(x) - Z_j E_j/T_{\text{v}}(x)\} C \, \mathrm{d}x, \quad (16)$$

where N_j, M_j, E_j are the parameters of groups found for the case of equilibrium states and Z_j is the new parameter introduced for the description of radiation transfer in nonequilibrium gases. It is understood that physically the parameter Z_j can take values in the range from 0 to 1.

The reference points for vibrationally-nonequilibrium objects were calculated for CO_2 molecules in the 2.7 and 4.3 μm bands and for CO molecules in the 4.6 μm band by the method suggested in [15]. The vibrational temperatures T_3 for CO_2 and T_{v} for CO were selected from the range 250–2500 K. Three values of the vibrational temperature were taken for each equilibrium variant. Thus, the total number of the reference points amounted to 96.

Figure 4 presents a comparison of the results of calculations for the transfer of radiation of vibrationally-nonequilibrium CO through a cold absorbing layer, carried out in terms of Eqs. (2), (15) and (16) and on the basis of the model described in [15]. The errors of the description of spectral characteristics of vibrationally-nonequilibrium objects by the three-level model with 12 parameters in the above range of thermodynamic parameters did not exceed 15%.

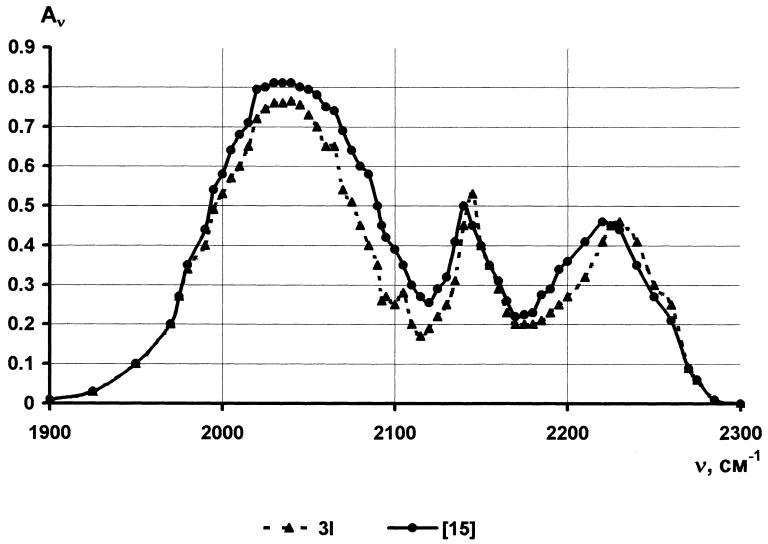

Fig. 4. Radiation spectra of vibrationally-nonequilibrium CO, passed through a cold absorbing layer, calculated by different methods.

Table 1
Parameters of the three-group model for H_2O

ν (cm^{-1})	A_1	B_1	C_1	A_2	B_2	C_2	A_3	B_3	C_3
5000	2.33E−03	3.39E−02	1.27E+00	3.97E+00	1.96E−01	5.48E+00	7.85E+02	9.23E+01	2.75E+01
4980	1.94E−03	3.01E−02	1.37E+00	4.71E+00	2.25E−01	5.90E+00	8.52E+02	1.54E+02	2.81E+01
4960	2.49E−03	1.00E+00	1.45E+00	6.07E+00	1.00E+00	6.50E+00	2.44E+18	1.00E+00	1.46E+02
4940	1.29E−03	3.93E−02	1.48E+00	4.90E+00	1.76E+02	8.00E+00	4.04E+00	7.24E−02	6.84E+00
4920	2.36E−03	3.67E−02	1.74E+00	1.46E+01	5.55E−01	8.70E+00	5.03E+01	1.00E+00	8.66E+01
4900	1.90E−03	3.79E−02	1.71E+00	1.10E+00	8.29E−03	6.06E+00	1.12E+01	3.77E+01	8.80E+00
4880	6.91E−04	4.19E−02	1.70E+00	1.62E+00	2.61E−02	6.36E+00	1.47E+01	2.59E+02	9.92E+00
4860	2.25E−04	5.72E−02	1.19E+00	1.29E+00	2.54E−02	6.29E+00	1.90E+01	1.75E+02	1.06E+01
4840	2.46E−04	6.97E−02	1.30E+00	8.29E−01	1.80E−02	6.08E+00	2.29E+01	1.50E+02	1.10E+01
4820	1.12E−04	4.63E−02	1.12E+00	5.02E−01	1.39E−02	5.79E+00	2.74E+01	2.27E+01	1.14E+01
4800	8.57E−05	2.93E−02	1.09E+00	3.72E−01	1.14E−02	5.78E+00	3.26E+01	9.14E+00	1.19E+01
4780	3.70E−05	2.52E−02	8.79E−01	3.93E−01	1.52E−02	5.95E+00	4.06E+01	3.90E+01	1.27E+01
4760	2.69E−05	2.86E−02	5.66E−01	1.45E−01	7.43E−03	5.46E+00	3.66E+01	1.66E+00	1.25E+01
4740	1.47E−05	2.79E−02	6.90E−01	1.15E−01	6.06E−03	5.71E+00	3.67E+01	2.49E+00	1.27E+01
4720	1.48E−05	2.88E−02	5.06E−01	1.01E−01	9.84E−03	5.55E+00	4.22E+01	1.21E+01	1.34E+01
4700	4.43E−06	1.60E−02	2.00E−01	4.02E−01	2.83E−02	6.97E+00	5.70E+01	2.86E+00	1.46E+01
4680	1.28E−05	1.91E−02	9.09E−01	2.07E−01	1.97E−02	6.40E+00	5.22E+01	3.37E+00	1.45E+01
4660	8.21E−06	1.93E−02	6.91E−01	2.18E−01	1.86E−02	6.60E+00	6.15E+01	1.70E+00	1.52E+01
4640	9.84E−06	5.50E−02	3.73E−01	1.24E−01	1.59E−02	6.11E+00	6.08E+01	1.45E+00	1.53E+01
4620	1.08E−05	1.98E−02	3.00E−01	1.04E−01	1.97E−02	5.95E+00	5.62E+01	1.51E+00	1.53E+01
4600	1.04E−05	2.96E−02	3.89E−01	9.29E−02	1.51E−02	5.92E+00	5.76E+01	1.17E+00	1.56E+01
4580	3.03E−05	2.99E−02	4.44E−01	7.94E−02	2.90E−02	5.71E+00	4.41E+01	2.87E+00	1.51E+01
4560	2.50E−05	2.85E−02	5.49E−01	9.41E−02	2.90E−02	5.85E+00	4.58E+01	1.85E+00	1.54E+01
4540	5.13E−05	2.43E−02	7.31E−01	6.79E−02	3.10E−02	5.50E+00	4.17E+01	1.77E+00	1.52E+01
4520	6.76E−05	1.70E−02	1.03E+00	1.01E−01	4.32E−02	5.83E+00	4.08E+01	2.27E+00	1.54E+01
4500	1.57E−04	1.37E−02	1.43E+00	1.28E−01	1.23E−01	5.99E+00	3.57E+01	5.14E+00	1.53E+01
4480	7.15E−05	4.62E−03	1.52E+00	1.68E−01	4.76E−02	6.30E+00	4.05E+01	1.56E+00	1.58E+01
4460	1.13E−03	7.63E−03	2.33E+00	9.26E−02	5.21E−01	5.53E+00	2.81E+01	7.84E+00	1.49E+01
4440	8.17E−05	5.96E−03	1.82E+00	3.86E−01	1.15E−01	6.80E+00	5.47E+01	1.84E+00	1.74E+01
4420	1.09E−03	7.42E−03	2.37E+00	1.02E−01	2.83E−01	5.37E+00	2.52E+01	5.04E+00	1.49E+01
4400	1.81E−03	4.93E−03	2.42E+00	9.40E−02	2.65E−01	5.19E+00	2.29E+01	4.69E+00	1.47E+01
4380	1.07E−03	1.21E−02	2.36E+00	6.76E−02	5.32E−01	4.55E+00	1.95E+01	1.53E+02	1.43E+01
4360	6.36E−03	1.36E−02	2.30E+00	1.21E−01	1.41E+02	5.83E+00	1.87E+01	1.55E+02	1.42E+01
4340	3.36E−03	1.67E−02	2.40E+00	4.57E−02	1.34E−01	4.02E+00	1.46E+01	8.26E+00	1.33E+01
4320	1.09E−02	1.78E−02	2.43E+00	1.00E−01	1.29E+02	5.65E+00	1.43E+01	1.87E+02	1.31E+01
4300	1.11E−02	2.01E−02	2.16E+00	4.57E−01	1.51E+02	7.36E+00	2.22E+01	2.01E+02	1.44E+01
4280	3.49E−03	2.29E−02	1.84E+00	1.05E−01	1.37E−01	4.53E+00	2.39E+01	6.48E+00	1.37E+01
4260	1.14E−02	2.16E−02	1.88E+00	4.69E+00	3.76E+00	9.61E+00	3.77E+02	1.23E+00	2.38E+01
4240	1.24E−02	2.48E−02	1.99E+00	3.72E+00	1.60E+00	8.88E+00	9.16E+02	2.69E+01	2.54E+01
4220	9.08E−03	2.92E−02	1.68E+00	2.80E+00	1.56E+00	8.07E+00	1.81E+03	4.65E+01	2.65E+01
4200	1.21E−02	3.15E−02	1.54E+00	2.86E+00	1.09E+00	7.78E+00	1.54E+03	4.91E+01	2.55E+01
4180	8.18E−03	1.96E−02	1.40E+00	2.13E+00	6.61E−01	6.89E+00	8.71E+02	9.91E−01	2.30E+01
4160	1.00E−02	2.86E−02	1.44E+00	1.49E+00	2.58E−01	5.92E+00	1.59E+02	1.23E+02	1.73E+01
4140	1.13E−02	3.31E−02	1.17E+00	2.19E+00	2.58E−01	6.00E+00	1.43E+02	1.31E+02	1.68E+01
4120	2.67E−03	1.59E−02	9.53E−01	1.80E+00	1.54E−01	5.02E+00	1.73E+02	8.27E+01	1.67E+01
4100	5.48E−03	1.00E−02	8.48E−01	1.99E+00	2.27E−01	4.69E+00	1.82E+02	1.89E+02	1.66E+01
4080	1.09E−02	2.41E−02	9.66E−01	2.14E+00	9.47E−02	4.35E+00	5.01E+01	3.57E+02	1.22E+01
4060	5.78E−03	1.57E−02	9.24E−01	3.38E+00	1.46E−01	4.36E+00	1.07E+02	1.58E+02	1.46E+01
4040	7.74E−03	1.81E−02	7.47E−01	2.76E+00	1.00E−01	3.65E+00	1.54E+02	2.11E+02	1.47E+01
4020	4.34E−03	3.01E−02	4.57E−01	2.60E+00	8.93E−02	3.16E+00	2.61E+02	6.69E+01	1.55E+01
4000	4.67E−02	1.45E−02	1.13E+00	2.76E+00	7.16E−02	3.00E+00	8.35E+01	2.73E+01	1.19E+01
3980	4.86E−02	8.44E−03	1.00E+00	2.78E+00	8.94E−02	2.57E+00	4.17E+02	1.50E+00	1.59E+01
3960	3.26E−01	2.33E−02	1.23E+00	3.88E+00	9.68E−02	3.07E+00	6.70E+02	3.65E+00	1.78E+01
3940	7.65E−01	2.51E−02	1.19E+00	2.87E+00	1.01E−01	2.88E+00	2.06E+03	2.09E+00	2.10E+01
3920	9.68E−01	2.14E−02	1.09E+00	4.30E+00	2.47E−01	3.88E+00	4.75E+03	2.12E+01	2.40E+01

Table 1 (*continued*)

ν (cm^{-1})	A_1	B_1	C_1	A_2	B_2	C_2	A_3	B_3	C_3
3900	8.94E−01	2.24E−02	7.74E−01	7.94E+00	5.59E−01	5.35E+00	2.49E+03	7.86E−01	2.31E+01
3880	6.29E−01	3.60E−02	6.47E−01	5.28E+00	2.72E−01	4.66E+00	2.45E+03	1.77E+00	2.27E+01
3860	5.34E−01	3.44E−02	4.22E−01	1.13E+01	5.63E−01	6.52E+00	1.98E+03	1.48E+02	2.34E+01
3840	3.07E−01	3.54E−02	2.94E−01	2.97E+00	1.45E−01	4.19E+00	2.26E+02	7.33E+00	1.55E+01
3820	1.39E−01	2.80E−02	8.20E−02	7.72E−01	4.00E−02	2.11E+00	5.36E+01	8.01E+00	1.07E+01
3800	1.22E−01	2.39E−02	9.58E−02	4.59E+00	2.43E−01	4.64E+00	1.58E+03	1.42E+02	2.23E+01
3780	3.82E−02	2.43E−02	1.38E−01	1.68E+00	8.96E−02	2.83E+00	7.84E+01	1.90E+02	1.27E+01
3760	2.54E−01	4.35E−02	3.15E−01	1.09E+01	4.28E−01	6.75E+00	1.49E+03	1.33E+02	2.48E+01
3740	5.43E−01	5.68E−02	3.32E−01	6.62E+00	8.21E+00	6.25E+00	1.54E+03	1.57E+02	2.44E+01
3720	4.16E+00	1.50E+01	4.89E+00	1.11E+00	5.22E−02	8.71E−01	5.18E+05	2.81E+01	4.23E+01
3700	1.58E−01	1.00E+00	3.54E−01	5.19E+00	1.00E+00	2.93E+00	9.09E+31	1.00E+00	2.24E+02
3680	1.71E−01	2.13E−02	1.33E−01	3.62E+00	9.37E−02	2.60E+00	2.82E+02	1.63E+01	1.54E+01
3660	2.07E−01	1.53E−02	3.34E−01	3.26E+00	7.88E−02	2.81E+00	9.15E+01	3.52E+00	1.16E+01
3640	2.98E−01	2.62E−02	4.92E−01	3.75E+00	7.14E−02	3.26E+00	8.08E+01	8.65E+00	1.13E+01
3620	7.10E−01	4.31E−02	6.89E−01	8.65E+00	2.11E−01	5.49E+00	1.66E+02	3.73E+00	1.42E+01
3600	4.53E−01	4.12E−02	7.71E−01	2.44E+00	6.35E−02	2.76E+00	9.48E+01	7.18E+01	1.15E+01
3580	4.59E−01	2.72E−02	8.77E−01	3.38E+00	9.30E−02	2.90E+00	2.72E+02	1.83E+02	1.46E+01
3560	3.98E−01	2.43E−02	8.87E−01	2.85E+00	7.40E−02	2.30E+00	3.17E+02	9.84E+01	1.47E+01
3540	1.63E−01	1.17E−02	8.73E−01	4.12E+00	7.84E−02	2.39E+00	7.51E+02	1.53E+02	1.74E+01
3520	1.72E−01	2.03E−02	9.34E−01	5.73E+00	9.45E−02	2.85E+00	1.18E+03	2.65E+01	1.87E+01
3500	1.18E−01	2.86E−02	8.94E−01	6.29E+00	9.82E−02	2.98E+00	8.46E+02	3.70E+00	1.76E+01
3480	7.46E−02	2.04E−02	9.45E−01	7.69E+00	1.02E−01	3.22E+00	1.50E+03	9.54E+01	1.96E+01
3460	1.23E−01	2.55E−02	1.24E+00	9.99E+00	1.15E−01	3.70E+00	4.40E+03	9.36E+01	2.27E+01
3440	6.20E−02	2.22E−02	9.57E−01	1.07E+01	1.15E−01	3.82E+00	2.80E+03	2.16E+01	2.12E+01
3420	5.59E−02	2.73E−02	1.04E+00	1.19E+01	1.25E−01	4.11E+00	2.24E+03	8.49E+01	2.03E+01
3400	4.52E−02	2.83E−02	1.08E+00	1.56E+01	1.36E−01	4.55E+00	1.52E+04	1.57E+02	2.64E+01
3380	3.21E−02	3.31E−02	1.11E+00	1.76E+01	1.59E−01	4.89E+00	8.29E+03	5.30E+01	2.49E+01
3360	4.21E−02	5.53E−02	1.06E+00	1.62E+01	1.42E−01	4.95E+00	3.58E+03	1.47E+02	2.19E+01
3340	4.59E−02	2.19E−02	1.29E+00	1.47E+01	1.37E−01	4.98E+00	1.73E+03	2.01E+02	1.94E+01
3320	1.73E−02	4.31E−02	9.95E−01	1.24E+01	9.57E−02	4.97E+00	2.38E+02	2.20E+02	1.34E+01
3300	1.21E−02	4.36E−02	8.42E−01	1.26E+01	1.05E−01	5.20E+00	2.52E+02	5.60E+01	1.37E+01
3280	1.47E−02	5.17E−02	7.94E−01	4.46E+00	3.21E−02	4.23E+00	8.83E+01	1.61E+00	9.94E+00
3260	5.54E−03	4.13E−02	6.03E−01	6.10E+00	4.68E−02	4.76E+00	9.44E+01	5.21E+00	1.05E+01
3240	3.90E−03	4.53E−02	4.58E−01	3.56E+00	3.29E−02	4.42E+00	8.94E+01	2.38E+00	1.02E+01
3220	3.12E−03	4.63E−02	3.46E−01	2.50E+00	2.95E−02	4.31E+00	9.38E+01	2.08E+00	1.04E+01
3200	1.49E−03	2.23E−02	2.68E−01	1.56E+00	1.99E−02	4.07E+00	7.87E+01	1.44E+00	9.94E+00
3180	1.35E−03	2.34E−02	2.73E−01	1.45E+00	2.65E−02	4.08E+00	9.31E+01	1.85E+00	1.05E+01
3160	2.03E−03	2.76E−02	1.01E+00	2.11E+00	3.13E−02	4.68E+00	9.22E+01	3.37E+00	1.08E+01
3140	1.16E−03	1.31E−02	3.83E−01	1.04E+00	2.74E−02	4.09E+00	8.84E+01	1.68E+00	1.07E+01
3120	6.96E−03	7.15E−02	4.96E−01	2.98E−01	1.21E−02	3.27E+00	7.53E+01	1.17E+00	1.03E+01
3100	3.44E−03	4.54E−02	3.43E−01	4.27E−01	1.75E−02	3.68E+00	8.04E+01	1.70E+00	1.08E+01
3080	2.96E−03	2.10E−02	4.50E−01	5.51E−01	2.70E−02	4.03E+00	1.01E+02	1.98E+00	1.18E+01
3060	2.81E−03	2.63E−02	3.62E−01	3.46E−01	2.23E−02	3.74E+00	8.44E+01	2.30E+00	1.14E+01
3040	3.56E−03	1.10E−02	5.44E−01	2.55E−01	1.74E−02	3.53E+00	7.70E+01	2.17E+00	1.13E+01
3020	7.02E−03	2.44E−02	7.16E−01	1.95E−01	1.82E−02	3.60E+00	8.13E+01	2.15E+00	1.17E+01
3000	1.27E−02	2.15E−02	1.04E+00	1.43E+00	4.71E−02	6.11E+00	9.23E+01	6.16E+00	1.26E+01
2980	1.44E−02	4.97E−02	1.19E+00	3.48E+00	1.18E−01	7.16E+00	1.25E+02	1.79E+02	1.41E+01
2960	1.65E−02	3.77E−02	1.49E+00	1.78E+00	8.10E−02	6.46E+00	1.08E+02	1.07E+02	1.36E+01
2940	9.57E−03	2.91E−02	1.54E+00	3.29E−01	3.76E−02	4.46E+00	7.87E+01	4.35E+00	1.26E+01
2920	9.13E−03	2.07E−02	1.91E+00	5.12E−01	5.48E−02	4.97E+00	8.53E+01	8.18E+00	1.32E+01
2900	3.98E−03	3.69E−02	1.72E+00	3.67E−01	5.19E−02	4.66E+00	7.24E+01	4.48E+00	1.28E+01
2880	9.69E−04	5.02E−02	1.50E+00	4.78E−01	7.58E−02	4.95E+00	7.54E+01	7.09E+00	1.32E+01
2860	5.63E−04	1.10E−01	1.39E+00	5.19E−01	8.11E−02	5.18E+00	8.04E+01	8.61E+00	1.36E+01
2840	1.73E−04	1.44E−01	9.20E−01	6.53E−01	9.85E−02	5.54E+00	8.93E+01	6.98E+00	1.41E+01
2820	1.08E−04	1.26E−01	6.40E−01	9.28E−01	1.38E−01	6.01E+00	9.94E+01	8.82E+00	1.48E+01
2800	3.76E−05	7.73E−02	2.99E−01	1.28E+00	1.55E−01	6.52E+00	1.06E+02	7.50E+00	1.53E+01

(continued on next page)

Table 1 (*continued*)

ν (cm^{-1})	A_1	B_1	C_1	A_2	B_2	C_2	A_3	B_3	C_3
2780	2.54E−05	7.14E−02	2.09E−01	9.53E−01	1.17E−01	6.47E+00	9.61E+01	4.72E+00	1.51E+01
2760	1.39E−05	5.73E−02	1.51E−01	9.24E−01	9.91E−02	6.70E+00	8.45E+01	3.18E+01	1.49E+01
2740	1.19E−05	6.17E−02	2.42E−01	1.02E+00	1.17E−01	6.98E+00	8.52E+01	6.36E+00	1.52E+01
2720	1.20E−04	1.09E−01	4.70E−01	3.54E−01	9.65E−02	6.01E+00	6.77E+01	6.90E+00	1.45E+01
2700	2.93E−05	6.82E−02	4.80E−01	2.85E−01	6.90E−02	5.91E+00	8.46E+01	3.53E+00	1.52E+01
2680	1.91E−05	5.13E−02	2.31E−01	2.17E−01	5.38E−02	5.90E+00	9.13E+01	2.65E+00	1.55E+01
2660	2.77E−05	6.31E−02	2.69E−01	1.55E−01	5.20E−02	5.72E+00	9.72E+01	2.24E+00	1.58E+01
2640	4.16E−05	5.37E−02	4.00E−01	1.12E−01	4.12E−02	5.55E+00	9.61E+01	2.77E+00	1.58E+01
2620	6.74E−05	5.39E−02	6.25E−01	6.57E−02	3.82E−02	5.18E+00	8.72E+01	2.72E+00	1.56E+01
2600	9.47E−05	5.19E−02	8.63E−01	1.33E−01	9.65E−02	5.88E+00	1.11E+02	9.66E+00	1.65E+01
2580	1.31E−04	6.09E−02	1.13E+00	1.12E−01	1.36E−01	5.70E+00	1.07E+02	9.62E+00	1.64E+01
2560	1.78E−04	5.04E−02	1.43E+00	1.12E−01	1.53E−01	5.69E+00	1.11E+02	5.51E+01	1.65E+01
2540	2.82E−04	5.39E−02	1.78E+00	7.91E−02	5.36E−01	5.34E+00	1.02E+02	1.32E+02	1.62E+01
2520	5.19E−04	5.67E−02	2.18E+00	6.90E−02	2.51E−01	5.25E+00	9.67E+01	1.41E+02	1.61E+01
2500	5.85E−04	6.56E−02	2.38E+00	1.16E−01	5.76E−02	5.78E+00	1.11E+02	3.54E+00	1.64E+01
2480	7.21E−04	4.24E−02	2.54E+00	7.45E−02	2.29E−02	5.31E+00	9.52E+01	1.57E+00	1.58E+01
2460	3.93E−04	2.62E−02	2.37E+00	9.69E−02	1.87E−02	5.45E+00	8.59E+01	1.34E+00	1.54E+01
2440	1.02E−03	3.11E−02	2.60E+00	8.02E−02	1.96E−02	5.16E+00	6.89E+01	1.49E+00	1.47E+01
2420	3.15E−04	3.01E−02	2.19E+00	5.58E−02	3.11E−02	4.55E+00	5.41E+01	2.12E+00	1.39E+01
2400	1.72E−07	4.12E+00	1.41E−01	2.98E−02	1.02E−02	3.66E+00	4.32E+01	1.57E+00	1.32E+01
2380	3.36E−01	6.92E+00	1.30E+01	2.14E−02	1.13E−01	3.25E+00	3.82E+01	1.87E+00	1.28E+01
2360	3.67E−02	1.88E−02	3.28E+00	9.85E+00	7.81E+00	1.26E+01	2.74E+01	1.11E+00	1.26E+01
2340	4.38E−02	2.26E−02	3.12E+00	1.52E+01	1.00E+00	8.11E+01	3.30E+01	2.18E+00	1.22E+01
2320	5.27E−02	2.94E−02	2.97E+00	5.86E+00	1.00E+00	9.85E+01	3.04E+01	2.16E+00	1.18E+01
2300	7.26E−02	3.73E−02	2.90E+00	3.66E−01	3.36E+00	5.22E+01	3.01E+01	1.87E+00	1.17E+01
2280	6.71E−02	4.32E−02	2.73E+00	1.36E−01	3.32E+01	5.54E+01	2.66E+01	1.67E+00	1.12E+01
2260	6.28E−02	4.03E−02	2.56E+00	1.33E+01	1.00E+00	8.68E+01	2.77E+01	1.60E+00	1.11E+01
2240	9.18E−02	5.67E−02	2.72E+00	3.46E+01	1.94E+01	6.21E+01	2.74E+01	1.25E+00	1.08E+01
2220	8.64E−06	9.18E−03	4.20E−01	1.37E−01	4.48E−02	2.84E+00	2.53E+01	1.44E+00	1.05E+01
2200	4.51E−02	2.19E−02	2.34E+00	2.98E−01	3.56E−02	3.91E+00	3.13E+01	1.31E+00	1.09E+01
2180	3.72E−02	2.32E−02	2.24E+00	5.59E−01	3.93E−02	4.30E+00	4.12E+01	2.16E+00	1.15E+01
2160	1.12E−01	2.46E−02	2.31E+00	7.93E+00	7.54E−01	7.57E+00	1.46E+03	1.17E+02	2.35E+01
2140	1.25E−01	1.66E−02	2.06E+00	1.11E+01	5.40E−01	7.79E+00	1.55E+03	3.30E+00	2.39E+01
2120	1.65E−01	1.38E−02	2.23E+00	1.12E+01	3.47E−01	7.47E+00	1.39E+03	1.74E+02	2.33E+01
2100	6.30E−02	9.29E−03	1.82E+00	4.36E+00	1.76E−01	5.46E+00	1.37E+03	1.74E+02	2.13E+01
2080	1.03E−01	1.10E−02	1.79E+00	4.12E+00	1.49E−01	5.31E+00	4.08E+02	8.76E+01	1.73E+01
2060	1.24E−01	6.12E−03	1.58E+00	4.26E+00	1.35E−01	5.18E+00	2.34E+02	2.04E+02	1.53E+01
2040	1.18E−01	9.90E−03	1.55E+00	4.43E+00	9.75E−02	4.89E+00	3.06E+02	1.96E+02	1.55E+01
2020	2.24E−01	1.12E−02	1.48E+00	1.16E+01	1.93E−01	6.26E+00	8.99E+02	1.56E+02	1.93E+01

Table 2
Parameters of the three-group model for CO_2 and CO including a vibrationally-nonequilibrium state

CO_2 ν	A_1	B_1	C_1	Z_1	A_2	B_2	C_2	Z_2	A_3	B_3	C_3	Z_3
3745	7.10E−01	4.80E+01	1.10	0.00	3.70E+00	2.30E+00	1.50	0.00	1.90E+00	2.60E+02	2.30	0.00
3740	2.10E+00	3.10E+00	0.85	0.00	6.40E+00	6.50E+00	2.20	0.02	4.10E+01	1.10E+01	5.40	0.08
3735	1.30E+00	2.30E+00	0.51	0.00	3.40E+00	4.70E+00	1.80	0.00	2.80E+01	1.30E+01	4.50	0.00
3730	9.00E−01	2.00E+00	0.30	0.00	1.10E+01	1.10E+01	2.80	0.01	7.90E+01	2.00E+01	8.70	0.04
3725	4.90E−01	1.60E+00	0.13	0.00	1.40E+01	1.50E+01	3.20	0.00	2.90E+02	4.80E+01	8.80	0.04
3720	2.50E−01	1.60E+00	0.08	0.00	7.10E+00	1.60E+01	2.60	0.02	1.60E+02	3.80E+01	7.20	0.05

Table 2 (*continued*)

CO_2 ν	A_1	B_1	C_1	Z_1	A_2	B_2	C_2	Z_2	A_3	B_3	C_3	Z_3
3715	2.40E−01	4.00E+00	0.68	0.00	6.60E+00	8.10E+00	2.50	0.01	2.50E+02	6.10E+01	7.80	0.13
3710	2.60E−01	1.70E+00	0.14	0.00	6.10E+00	1.00E+01	2.30	0.06	2.00E+02	5.10E+01	7.40	0.16
3705	4.30E−01	1.50E+00	0.17	0.00	8.90E+00	1.20E+01	2.50	0.11	2.30E+02	5.70E+01	7.80	0.18
3700	5.70E−01	1.30E+00	0.26	0.00	1.20E+01	1.20E+01	2.70	0.17	3.30E+02	9.30E+01	8.10	0.12
3695	6.70E−01	1.20E+00	0.37	0.00	1.40E+01	1.20E+01	2.80	0.24	2.90E+02	9.00E+01	8.10	0.10
3690	7.80E−01	1.10E+00	0.53	0.00	1.80E+01	1.10E+01	3.00	0.29	4.10E+02	8.50E+01	9.00	0.09
3685	8.80E−01	9.80E−01	0.71	0.00	1.90E+01	1.10E+01	3.20	0.32	5.50E+02	5.00E+01	9.70	0.09
3680	9.80E−01	9.50E−01	0.92	0.00	1.90E+01	1.40E+01	3.30	0.30	4.70E+02	1.20E+02	9.30	0.09
3675	1.10E+00	9.60E−01	1.10	0.00	2.10E+01	1.40E+01	3.50	0.27	4.00E+02	1.10E+02	9.00	0.08
3670	1.20E+00	1.00E+00	1.40	0.00	2.50E+01	1.40E+01	3.80	0.17	5.10E+02	1.70E+02	9.50	0.11
3665	1.30E+00	1.00E+00	1.70	0.00	2.80E+01	1.60E+01	4.00	0.42	4.70E+02	1.20E+02	9.30	0.05
3660	1.40E+00	9.60E−01	2.00	0.00	3.50E+01	2.00E+01	4.30	0.50	4.70E+02	8.90E+01	9.30	0.01
3655	1.80E+00	1.10E+00	2.30	0.02	3.20E+01	2.60E+01	4.20	0.51	4.10E+02	6.30E+01	9.00	0.01
3650	2.80E+00	4.10E+00	2.20	0.18	2.70E+01	7.70E+00	4.30	0.63	4.00E+02	3.20E+02	8.90	0.03
3645	1.60E+00	2.50E+00	1.50	0.00	2.80E+01	8.20E+00	4.30	0.58	4.80E+02	2.20E+02	9.30	0.03
3640	1.20E+00	2.00E+00	0.94	0.00	3.50E+01	1.10E+01	4.70	0.38	5.80E+02	1.60E+02	10.00	0.06
3635	8.40E−01	1.70E+00	0.58	0.00	4.00E+01	1.20E+01	5.10	0.29	6.10E+02	1.30E+02	10.00	0.09
3630	5.80E−01	1.50E+00	0.32	0.00	4.80E+01	1.40E+01	5.50	0.28	6.30E+02	7.50E+01	10.00	0.07
3625	3.70E−01	1.30E+00	0.15	0.00	6.10E+01	2.00E+01	5.70	0.20	7.20E+02	8.10E+01	11.00	0.10
3620	2.00E−01	1.30E+00	0.06	0.00	2.60E+01	1.60E+01	4.60	0.17	6.60E+02	6.10E+01	10.00	0.13
3615	5.40E−02	1.10E+00	0.00	0.00	8.60E+00	9.20E+00	3.00	0.10	5.40E+02	6.90E+01	9.30	0.14
3610	7.90E−02	1.20E+00	0.05	0.00	6.00E+00	8.10E+00	2.50	0.09	5.60E+02	6.80E+01	9.40	0.16
3605	2.10E−01	1.20E+00	0.11	0.00	4.70E+00	7.00E+00	2.20	0.08	6.00E+02	7.40E+01	9.70	0.16
3600	3.60E−01	1.40E+00	0.22	0.00	3.80E+00	6.40E+00	2.10	0.10	6.60E+02	7.00E+01	9.90	0.15
3595	5.50E−01	1.50E+00	0.36	0.00	4.10E+00	8.50E+00	2.40	0.18	6.60E+02	6.70E+01	10.00	0.16
3590	6.70E−01	1.60E+00	0.50	0.00	5.20E+00	1.30E+01	3.00	0.30	7.30E+02	6.10E+01	11.00	0.15
3585	6.80E−01	1.40E+00	0.64	0.00	5.60E+00	1.60E+01	3.10	0.40	8.40E+02	6.40E+01	11.00	0.16
3580	6.10E−01	9.40E−01	0.80	0.00	4.60E+00	8.70E+00	2.90	0.48	8.90E+02	6.70E+01	11.00	0.16
3575	9.40E−01	2.00E+00	1.00	0.00	7.90E+00	1.30E+01	3.00	0.40	8.50E+02	6.60E+01	11.00	0.13
3570	1.20E+00	3.20E+00	1.20	0.00	7.60E+00	9.10E+00	3.10	0.40	7.80E+02	6.10E+01	11.00	0.15
3565	1.40E+00	3.80E+00	1.30	0.00	7.20E+00	7.20E+00	3.20	0.25	8.10E+02	7.00E+01	12.00	0.19
3560	1.50E+00	3.80E+00	1.40	0.00	7.00E+00	6.70E+00	3.20	0.38	8.80E+02	6.60E+01	12.00	0.18
3555	1.50E+00	3.50E+00	1.50	0.00	1.20E+01	9.90E+00	3.70	0.51	1.00E+03	8.70E+01	12.00	0.11
3550	1.60E+00	3.50E+00	1.70	0.00	1.20E+01	1.10E+01	3.60	0.54	1.00E+03	7.00E+01	12.00	0.12
3545	2.00E+00	4.30E+00	1.90	0.00	1.20E+01	1.20E+01	3.70	0.56	8.80E+02	6.00E+01	12.00	0.13
3540	2.40E+00	5.10E+00	2.10	0.28	1.30E+01	1.20E+01	3.80	0.61	8.30E+02	5.80E+01	12.00	0.14
3535	3.30E+00	6.50E+00	2.40	0.16	3.00E+01	1.80E+01	4.80	0.05	9.10E+02	6.40E+01	13.00	0.22
3530	3.00E+00	5.90E+00	2.50	0.16	2.30E+01	1.50E+01	4.40	0.06	7.20E+02	5.90E+01	12.00	0.20
3525	3.10E+00	5.80E+00	2.70	0.34	2.20E+01	1.60E+01	4.40	0.55	8.70E+02	7.60E+01	12.00	0.11
3520	3.40E+00	6.10E+00	2.90	0.37	2.30E+01	1.70E+01	4.50	0.53	7.80E+02	5.00E+01	12.00	0.12
3515	3.70E+00	6.70E+00	3.10	0.34	2.30E+01	1.70E+01	4.70	0.52	7.40E+02	4.40E+01	12.00	0.12
3510	4.20E+00	7.40E+00	3.30	0.31	3.10E+01	2.00E+01	5.00	0.51	8.00E+02	6.90E+01	12.00	0.06
3505	4.10E+00	7.40E+00	3.50	0.32	3.10E+01	1.90E+01	5.10	0.49	9.10E+02	8.00E+01	12.00	0.08
3500	4.40E+00	7.90E+00	3.70	0.31	3.40E+01	2.10E+01	5.20	0.48	8.90E+02	6.80E+01	12.00	0.10
3495	1.20E−02	1.30E+00	0.96	0.00	2.00E+01	2.30E+01	4.50	0.20	4.20E+02	7.10E+01	9.50	0.73
3490	1.70E−02	2.30E+00	1.20	0.00	2.90E+01	3.00E+01	4.90	0.08	4.90E+02	6.90E+01	10.00	0.19
3485	1.80E−02	4.00E+00	1.30	0.00	3.80E+01	3.40E+01	5.20	0.06	5.10E+02	6.20E+01	11.00	0.25
3480	1.70E−02	4.30E+00	1.40	0.00	4.50E+01	3.20E+01	5.50	0.05	5.00E+02	3.50E+01	11.00	0.77
3475	1.90E−02	3.70E+00	1.50	0.00	7.00E+01	5.00E+01	6.00	0.09	1.10E+03	5.70E+01	13.00	0.18
3470	1.90E−02	2.20E+00	1.60	0.00	9.20E+01	5.60E+01	6.40	0.12	2.00E+03	6.10E+01	15.00	0.14
3465	1.90E−02	1.90E+00	1.80	0.00	1.20E+02	7.80E+01	6.80	0.16	2.50E+03	2.10E+01	16.00	0.09
3460	1.90E−02	1.50E+00	1.90	0.00	1.40E+02	6.00E+01	7.10	0.17	1.50E+03	1.20E+01	16.00	0.06
3455	1.90E−02	1.00E+00	2.10	0.14	1.50E+02	2.10E+02	7.40	0.24	1.10E+03	3.20E+01	15.00	0.03
3450	2.20E−02	6.00E+00	2.30	0.17	1.50E+02	1.90E+02	7.50	0.21	1.60E+03	6.30E+00	16.00	0.02
3445	2.80E−02	4.50E−01	2.50	0.17	1.60E+02	5.00E+01	7.80	0.18	2.00E+03	2.10E+01	16.00	0.07

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Table 2 (*continued*)

CO_2 ν	A_1	B_1	C_1	Z_1	A_2	B_2	C_2	Z_2	A_3	B_3	C_3	Z_3
3440	3.30E−02	2.20E−01	2.70	0.34	1.50E+02	5.70E+01	7.90	0.14	2.80E+03	5.10E+00	17.00	0.13
3435	3.80E−02	1.90E−01	2.90	0.28	1.70E+02	4.10E+01	8.20	0.14	2.70E+03	3.70E+01	17.00	0.15
3430	2.90E−02	2.10E−01	2.90	0.21	1.90E+02	8.20E+01	8.50	0.20	2.20E+03	5.60E+01	17.00	0.06
3425	7.70E−03	4.70E−02	2.50	0.33	1.30E+01	4.80E+02	6.80	0.08	4.50E+02	1.80E+01	10.00	0.37
3420	1.70E−04	2.00E−01	1.50	0.00	4.20E−02	2.00E+02	3.50	0.50	3.30E+02	1.80E+01	9.40	0.25
3415	4.90E−04	3.20E−02	1.80	0.00	2.30E+01	3.90E+02	7.50	0.04	5.60E+02	2.00E+01	11.00	0.45
3410	1.60E−04	2.50E−02	1.50	0.00	1.60E+02	4.10E+02	9.10	0.05	1.30E+03	3.80E+01	15.00	0.79
3405	5.70E−05	1.00E−02	1.50	0.00	2.60E+02	2.40E+01	9.80	0.11	1.90E+03	2.10E+02	18.00	0.89
3400	8.40E−06	1.90E−03	1.40	0.00	2.90E+02	6.70E+01	10.00	0.07	2.00E+03	1.00E+00	16.00	0.83
3395	3.40E−04	6.10E−03	2.20	0.00	4.20E+01	2.60E+02	8.90	0.04	6.70E+02	1.00E+02	12.00	0.49
3390	2.00E−03	5.60E−02	2.40	0.80	3.40E−01	1.50E+02	6.20	0.17	5.50E+02	1.30E+02	11.00	0.21
3385	9.40E−05	2.10E+00	1.40	0.00	3.00E−03	3.80E+01	2.40	0.68	5.40E+02	1.30E+02	12.00	0.18
3380	1.30E−06	6.90E+00	0.28	0.00	1.60E−03	1.20E+02	1.80	0.00	5.80E+02	2.60E+01	12.00	0.00
3375	7.30E−07	4.10E−01	0.00	0.00	9.50E−04	1.70E+00	1.40	0.00	5.90E+02	1.90E+01	12.00	0.00
3370	1.30E−06	4.70E+01	0.00	0.00	5.40E−04	1.00E+00	1.00	0.00	5.80E+02	4.80E+01	12.00	0.00
3365	3.40E−06	3.20E+01	0.00	0.00	3.40E−04	8.80E−01	0.80	0.00	5.90E+02	6.40E+01	12.00	0.00
3360	7.80E−06	3.00E+00	0.00	0.00	2.00E−04	6.80E−01	0.67	0.00	6.10E+02	7.40E+01	13.00	0.00
3355	1.10E−05	5.60E+00	0.00	0.00	1.00E−04	3.80E−01	0.60	0.00	6.50E+02	6.20E+01	13.00	0.00
3350	3.40E−05	1.10E+00	0.24	0.00	7.00E+02	2.70E+01	14.00	0.24	1.50E+00	2.20E+01	37.00	0.00
3345	9.30E−06	8.90E−01	0.15	0.00	5.60E−03	5.10E+01	4.30	0.72	7.70E+02	7.00E+01	14.00	0.24
3340	3.80E−05	1.30E+00	0.34	0.00	2.00E−03	6.40E+00	3.50	0.67	7.10E+02	2.40E+02	14.00	0.24
3335	4.20E−07	1.80E−02	0.02	0.00	6.10E+01	8.60E+01	11.00	0.25	3.40E+03	9.30E+00	18.00	0.18
3330	2.10E−06	1.50E−01	0.16	0.00	2.00E+01	7.50E+01	9.70	0.21	1.80E+03	3.50E+01	17.00	0.21
2400	1.10E−03	1.10E+02	1.70	0.00	7.30E−01	3.10E−01	3.70	0.55	7.00E+02	2.40E+00	9.40	0.03
2395	1.70E+02	1.50E+01	4.20	0.00	5.60E+02	3.30E+00	5.60	0.04	1.60E+03	2.00E+00	11.00	0.20
2390	1.10E+02	3.30E+00	2.70	0.00	2.30E+02	9.60E−01	3.40	0.04	7.20E+01	9.30E+00	13.00	0.57
2385	1.30E+02	3.10E+00	1.90	0.00	1.00E+02	2.40E−01	2.60	0.12	2.80E+03	3.70E+02	8.30	0.09
2380	1.20E+02	2.50E+00	1.30	0.00	5.90E+01	2.70E−01	2.30	0.30	9.40E+02	8.90E+00	5.20	0.17
2375	9.60E+01	2.00E+00	0.83	0.00	4.50E+02	4.50E+00	3.30	0.05	4.60E+03	6.60E+01	9.20	0.13
2370	7.20E+01	1.80E+00	0.51	0.00	5.50E+02	8.10E+00	3.00	0.04	5.60E+03	2.90E+01	8.50	0.06
2365	4.90E+01	1.70E+00	0.28	0.00	3.00E+02	4.60E+00	2.20	0.25	1.70E+03	1.50E+01	5.40	0.12
2360	3.70E+01	1.70E+00	0.18	0.00	6.20E+02	1.10E+01	2.60	0.09	1.30E+04	6.20E+01	9.10	0.06
2355	2.20E+01	1.60E+00	0.13	0.00	4.90E+02	1.30E+01	2.20	0.14	5.10E+03	2.10E+01	7.10	0.05
2350	1.80E+01	2.80E+00	0.47	0.00	6.30E+02	1.60E+01	2.50	0.27	1.50E+04	4.50E+01	8.90	0.06
2345	1.80E+01	1.60E+00	0.18	0.00	6.80E+02	2.40E+01	2.60	0.21	1.20E+04	3.90E+01	8.30	0.01
2340	2.40E+01	1.30E+00	0.15	0.00	9.40E+02	3.00E+01	3.10	0.21	1.50E+04	5.50E+01	9.00	0.04
2335	3.10E+01	1.10E+00	0.22	0.00	1.10E+03	3.90E+01	3.40	0.21	2.00E+04	7.00E+01	9.40	0.00
2330	4.70E+01	1.20E+00	0.37	0.00	1.10E+03	5.50E+01	3.50	0.22	1.70E+04	5.80E+01	9.10	0.01
2325	6.20E+01	1.30E+00	0.54	0.00	1.10E+03	5.20E+01	3.70	0.24	2.70E+04	1.10E+02	9.80	0.00
2320	8.30E+01	1.30E+00	0.75	0.00	9.80E+02	8.70E+01	3.50	0.38	2.40E+04	9.50E+01	9.50	0.01
2315	1.10E+02	1.50E+00	0.98	0.00	9.50E+02	7.60E+01	3.50	0.54	3.70E+04	1.70E+02	10.00	0.02
2310	1.30E+02	1.70E+00	1.20	0.00	9.30E+02	8.40E+01	3.50	0.57	3.20E+04	1.30E+02	10.00	0.00
2305	1.30E+02	2.10E+00	1.40	0.00	8.20E+02	3.60E+01	3.20	0.52	3.60E+04	1.20E+02	10.00	0.01
2300	3.20E+01	2.00E+00	1.10	0.00	7.20E+02	1.10E+01	2.60	0.32	4.60E+04	1.70E+02	10.00	0.05
2295	3.60E+00	2.20E+00	0.66	0.00	7.60E+02	3.90E+00	2.60	0.28	4.10E+04	5.40E+02	10.00	0.02
2290	1.10E+00	2.20E+00	0.45	0.00	8.70E+02	6.70E+00	2.80	0.26	5.20E+04	4.20E+02	11.00	0.03
2285	6.20E−01	2.50E+00	0.56	0.00	1.10E+03	9.10E+00	3.10	0.27	4.50E+04	3.90E+02	11.00	0.04
2280	3.40E−01	2.30E+00	0.36	0.00	1.20E+03	1.20E+01	3.40	0.27	5.90E+04	2.00E+02	11.00	0.03
2275	3.60E−01	1.70E+00	0.22	0.00	1.60E+03	1.40E+01	3.80	0.26	5.60E+04	2.30E+02	11.00	0.03
2270	3.80E−01	1.20E+00	0.23	0.00	2.00E+03	1.80E+01	4.20	0.25	6.10E+04	2.80E+02	11.00	0.02
2265	5.60E−01	1.40E+00	0.37	0.00	2.40E+03	2.40E+01	4.50	0.24	6.70E+04	2.00E+02	12.00	0.02
2260	7.50E−01	1.50E+00	0.54	0.00	2.80E+03	3.00E+01	4.90	0.23	6.50E+04	2.50E+02	12.00	0.01
2255	1.00E+00	1.70E+00	0.74	0.00	3.30E+03	3.40E+01	5.30	0.23	7.10E+04	3.20E+02	12.00	0.02
2250	1.30E+00	1.90E+00	0.97	0.00	3.20E+03	2.70E+01	5.50	0.23	6.60E+04	1.90E+02	12.00	0.01
2245	1.60E+00	2.40E+00	1.20	0.00	3.20E+03	1.20E+01	5.70	0.24	7.60E+04	2.90E+02	12.00	0.00

Table 2 (*continued*)

CO_2 ν	A_1	B_1	C_1	Z_1	A_2	B_2	C_2	Z_2	A_3	B_3	C_3	Z_3
2240	2.00E+00	3.10E+00	1.50	0.00	3.20E+03	2.20E+01	5.90	0.24	7.30E+04	2.00E+02	12.00	0.00
2235	2.50E+00	4.00E+00	1.80	0.00	3.10E+03	1.90E+01	6.20	0.26	8.20E+04	2.80E+02	12.00	0.00
2230	3.30E+00	4.30E+00	2.00	0.00	3.40E+03	1.40E+01	6.50	0.28	8.30E+04	3.10E+02	12.00	0.01
2225	4.20E+00	5.00E+00	2.40	0.12	3.40E+03	1.20E+01	6.70	0.21	8.20E+04	3.60E+01	12.00	0.02
2220	5.40E+00	5.90E+00	2.70	0.13	3.50E+03	1.20E+01	7.00	0.20	9.40E+04	1.80E+02	12.00	0.02
2215	6.70E+00	7.00E+00	3.00	0.15	3.60E+03	2.00E+01	7.30	0.06	1.00E+05	1.80E+02	13.00	0.60
2210	8.30E+00	9.50E+00	3.40	0.13	3.60E+03	1.70E+01	7.60	0.06	1.10E+05	5.50E+01	13.00	0.60
2205	1.00E+01	8.10E+00	3.70	0.17	3.70E+03	1.50E+01	7.90	0.06	1.30E+05	4.80E+01	13.00	0.55
2200	1.30E+01	1.10E+01	4.10	0.15	4.00E+03	1.60E+01	8.30	0.06	1.30E+05	9.90E+01	13.00	0.54
2195	1.50E+01	8.80E+00	4.40	0.21	4.10E+03	1.30E+01	8.60	0.06	1.40E+05	7.50E+01	14.00	0.45
2190	1.90E+01	6.50E+00	4.80	0.18	4.20E+03	1.40E+01	8.90	0.06	1.60E+05	1.80E+02	14.00	0.47
2185	2.20E+01	6.80E+00	5.10	0.20	4.70E+03	1.40E+01	9.30	0.06	1.70E+05	7.30E+01	14.00	0.45
2180	2.60E+01	3.60E+00	5.50	0.19	4.70E+03	6.70E+01	9.60	0.06	1.90E+05	5.70E+01	15.00	0.43
2175	2.90E−02	4.10E−02	2.90	0.70	2.10E+03	2.20E+01	9.00	0.06	1.80E+05	3.10E+01	14.00	0.43
2170	1.20E−02	5.20E−02	2.60	0.50	1.60E+03	1.70E+01	9.00	0.27	1.80E+05	3.60E+01	15.00	0.03
2165	2.00E−02	4.60E−01	2.30	0.25	1.10E+03	1.70E+01	8.80	0.22	1.90E+05	3.40E+01	15.00	0.04
2160	1.40E−02	2.20E−01	2.40	0.52	8.10E+02	1.70E+01	8.80	0.04	2.00E+05	3.90E+01	15.00	0.12
2155	1.80E−02	3.80E−01	2.40	0.37	7.00E+02	8.30E+01	9.00	0.01	2.10E+05	1.00E+02	16.00	0.15
2150	3.90E−02	1.30E+01	2.70	0.76	6.80E+02	2.60E+01	9.50	0.23	2.20E+05	3.70E+01	16.00	0.08
2145	4.40E−02	3.90E+00	2.70	0.48	6.40E+02	2.20E+02	9.90	0.27	2.30E+05	4.50E+01	16.00	0.07
2140	2.80E−02	9.40E−01	2.50	0.53	4.90E+02	2.10E+02	10.00	0.27	2.40E+05	4.90E+01	16.00	0.08
2135	1.20E−04	1.70E−01	1.00	0.00	6.00E−02	6.30E+00	2.80	0.02	2.20E+05	1.40E+01	16.00	0.10
2130	4.70E+03	2.80E+02	12.00	0.20	2.50E+02	2.50E+02	14.00	0.49	5.80E+05	4.80E+01	19.00	0.08
2125	4.90E+03	5.30E+01	12.00	0.20	1.40E+02	8.90E+01	15.00	0.55	6.30E+05	3.80E+01	19.00	0.08
2120	5.10E+03	2.00E+02	13.00	0.12	1.20E+02	1.40E+02	15.00	0.76	6.70E+05	3.40E+01	20.00	0.08
2115	5.20E+03	3.30E+02	13.00	0.22	4.60E+02	1.10E+02	15.00	0.39	7.30E+05	4.40E+01	20.00	0.09
2110	5.60E+03	2.40E+02	14.00	0.04	2.20E+02	3.80E+01	15.00	0.79	7.90E+05	3.90E+01	21.00	0.12
2105	6.00E+03	3.30E+02	14.00	0.09	2.20E+02	4.30E+01	16.00	0.80	8.50E+05	2.30E+01	21.00	0.09
2100	6.40E+03	2.80E+02	14.00	0.09	8.60E+01	3.50E+00	16.00	0.84	9.20E+05	2.20E+01	21.00	0.09
2095	7.00E+03	1.80E+01	15.00	0.07	9.80E+05	1.90E+02	22.00	0.10	9.20E+01	4.80E+01	62.00	0.09
2090	7.40E+03	2.20E+02	15.00	0.09	2.70E+02	1.50E+02	16.00	0.73	1.10E+06	3.00E+01	22.00	0.09
2085	8.00E+03	6.10E+02	16.00	0.25	1.10E+06	1.70E+01	23.00	0.06	4.60E+01	1.50E+02	70.00	0.50
2080	8.90E+03	6.10E+01	16.00	0.24	1.20E+06	5.20E+01	23.00	0.07	3.70E+01	4.60E+01	70.00	0.50
2075	9.80E+03	1.10E+01	17.00	0.07	1.30E+06	2.40E+02	24.00	0.11	1.20E+02	1.40E+02	68.00	0.50
2070	1.10E+04	6.00E+02	17.00	0.03	1.40E+06	1.60E+01	24.00	0.11	3.50E+01	1.50E+02	63.00	0.40
2065	3.20E+04	4.20E+02	18.00	0.21	3.40E+02	2.20E+02	20.00	0.59	2.80E+06	7.60E+00	26.00	0.13
2060	3.70E+04	4.80E+02	19.00	0.04	3.10E+06	5.00E+00	27.00	0.12	7.50E+01	4.10E+02	51.00	0.14
2055	4.40E+04	5.30E+02	20.00	0.05	3.60E+06	5.70E+00	28.00	0.14	1.90E+01	4.50E+02	44.00	0.14
CO												
2275	8.40E+00	4.90E−01	4.80	0.00	5.80E+00	8.70E−02	5.80	0.09	6.00E+01	8.80E−01	13.00	0.03
2270	2.00E+00	1.90E−01	4.10	0.01	9.80E+00	3.50E−01	4.60	0.03	4.00E+01	7.30E−01	11.00	0.02
2265	7.20E+00	4.60E−01	3.90	0.00	4.40E+00	7.70E−02	4.60	0.10	4.40E+01	8.60E−01	11.00	0.07
2260	5.70E+00	4.00E−01	3.50	0.00	4.40E+00	1.10E−01	4.00	0.08	3.00E+01	8.00E−01	9.20	0.08
2255	3.60E+00	3.20E−01	3.10	0.01	5.60E+00	1.80E−01	3.40	0.05	2.30E+01	8.70E−01	8.20	0.10
2250	4.80E+00	4.50E−01	2.80	0.02	3.80E+00	8.50E−02	3.10	0.10	5.40E+01	7.20E−01	9.70	0.14
2245	4.50E+00	3.90E−01	2.40	0.00	4.30E+00	1.00E−01	3.10	0.05	4.10E+01	9.40E−01	9.10	0.17
2240	5.50E+00	3.90E−01	2.20	0.03	6.90E+00	1.60E−01	4.20	0.08	3.90E+01	1.30E+00	9.80	0.24
2235	6.10E+00	4.30E−01	2.00	0.03	2.70E+00	1.80E+00	5.90	0.25	3.50E+01	3.50E−01	7.80	0.21
2230	5.90E+00	4.30E−01	1.70	0.01	1.80E+00	2.10E+00	5.40	0.24	3.80E+01	4.40E−01	7.80	0.24
2225	5.60E+00	4.30E−01	1.50	0.00	2.00E+00	6.00E+03	5.90	0.32	3.60E+01	4.50E−01	7.50	0.26
2220	4.70E+00	3.90E−01	1.30	0.03	1.90E+01	5.00E−01	5.70	0.28	3.50E+01	6.00E+03	12.00	0.39
2215	4.90E+00	4.10E−01	1.20	0.03	1.90E+01	5.60E−01	5.80	0.29	3.80E+01	5.90E+03	13.00	0.44
2210	4.10E+00	4.20E−01	0.96	0.02	1.20E+00	1.30E+01	4.70	0.60	3.00E+01	5.00E−01	6.50	0.33
2205	3.60E+00	4.20E−01	0.79	0.02	1.20E+01	1.70E−01	4.80	0.36	2.50E+01	1.60E+00	8.30	0.40

(continued on next page)

Table 2 (*continued*)

CO_2 ν	A_1	B_1	C_1	Z_1	A_2	B_2	C_2	Z_2	A_3	B_3	C_3	Z_3
2200	3.10E+00	4.10E−01	0.64	0.02	1.00E+01	1.70E−01	4.30	0.40	1.30E+01	2.30E+00	6.80	0.42
2195	3.00E+00	4.20E−01	0.54	0.00	9.70E+00	1.10E−01	4.70	0.15	1.90E+01	1.50E+00	6.90	0.72
2190	2.90E+00	4.10E−01	0.49	0.00	8.70E+00	1.60E−02	5.80	0.01	1.90E+01	1.40E+00	6.00	0.67
2185	2.40E+00	3.50E−01	0.36	0.00	1.30E+00	1.70E+00	3.00	0.11	3.10E+01	4.70E−01	6.50	0.83
2180	2.10E+00	4.10E−01	0.28	0.00	1.90E+00	1.60E+00	3.80	0.04	3.50E+01	4.00E−01	6.80	0.84
2175	1.60E+00	4.20E−01	0.19	0.00	2.90E+00	3.20E−02	3.10	0.09	2.30E+01	1.30E+00	6.40	0.84
2170	1.50E+00	4.10E−01	0.15	0.00	1.50E+00	8.60E+00	4.20	0.08	2.50E+01	4.30E−01	6.00	0.86
2165	1.10E+00	4.10E−01	0.10	0.00	8.50E+00	2.10E−01	4.30	0.46	1.40E+01	1.80E+00	6.90	0.95
2160	8.60E−01	4.00E−01	0.06	0.00	1.10E+01	4.70E−01	4.30	0.69	3.40E+01	2.20E+00	11.00	0.99
2155	6.20E−01	4.20E−01	0.05	0.00	1.30E+01	5.80E−01	4.80	0.79	2.00E+01	7.40E+00	11.00	0.99
2150	3.80E−01	4.90E−01	0.05	0.00	7.70E+00	3.60E−01	4.20	0.78	2.50E+01	1.90E+00	9.20	0.99
2145	1.70E−01	6.60E−01	0.26	0.00	8.00E+00	4.20E−01	4.50	0.95	3.70E+01	1.60E+00	11.00	0.42
2140	2.30E−01	5.90E−01	0.15	0.00	9.20E+00	5.00E−01	4.80	0.95	4.30E+01	2.40E+00	12.00	0.29
2135	4.00E−01	4.30E−01	0.04	0.00	6.50E+00	4.90E−01	4.40	0.93	4.00E+01	5.10E+02	12.00	0.31
2130	6.00E−01	4.00E−01	0.03	0.00	7.20E+00	5.40E−01	4.90	0.92	4.80E+01	6.70E+02	13.00	0.22
2125	7.70E−01	3.60E−01	0.04	0.00	6.80E+00	5.50E−01	5.20	0.91	5.40E+01	6.20E+02	14.00	0.19
2120	8.80E−01	3.10E−01	0.04	0.00	4.00E+00	4.20E−01	4.60	0.66	4.10E+01	7.10E+01	13.00	0.99
2115	1.00E+00	2.90E−01	0.07	0.00	1.60E+00	2.00E−01	3.40	0.33	2.80E+01	3.10E+00	11.00	0.99
2110	1.20E+00	1.90E−01	0.17	0.00	7.10E−01	8.90E−01	1.70	0.92	5.10E+01	1.10E+00	11.00	0.38
2105	1.50E+00	2.50E−01	0.30	0.00	5.10E−01	1.30E+00	1.90	0.99	3.80E+01	8.10E−01	10.00	0.39
2100	1.50E+00	1.50E−01	0.33	0.14	8.90E−01	6.00E−01	1.40	0.87	3.00E+01	1.40E+00	10.00	0.29
2095	1.50E+00	1.20E−01	0.40	0.00	1.10E+00	6.40E−01	1.30	0.74	3.90E+01	8.80E−01	11.00	0.99
2090	1.70E+00	2.90E−01	0.45	0.00	1.00E+00	1.90E−02	1.80	0.33	1.00E+00	5.70E−01	3.00	0.96
2085	1.80E+00	3.40E−01	0.54	0.00	1.60E+00	2.80E−02	2.00	0.18	6.00E+00	1.60E+00	6.20	0.99
2080	1.40E+00	3.40E−01	0.56	0.00	2.00E+00	6.10E−02	1.60	0.00	7.10E+00	1.50E+00	6.30	0.98
2075	1.70E+00	3.20E−01	0.68	0.00	2.10E+00	4.10E−02	1.90	0.00	4.80E+00	1.40E+00	5.20	0.96
2070	2.30E+00	3.70E−01	0.84	0.02	1.80E+00	5.80E−07	2.60	0.49	5.70E+00	9.80E−01	4.90	0.93
2065	2.30E+00	3.90E−01	0.96	0.08	1.90E+00	7.50E−03	2.40	0.35	4.90E+00	1.00E+00	5.10	0.94
2060	2.30E+00	3.50E−01	1.00	0.02	4.70E+00	5.30E−02	3.50	0.13	5.20E+00	1.60E+00	5.90	0.97
2055	1.80E−01	4.90E−01	0.69	0.29	3.10E+00	1.70E−01	1.40	0.14	8.60E+00	5.90E−01	4.80	0.88
2050	1.40E+00	5.00E−01	1.10	0.05	2.40E+00	9.90E−03	1.90	0.33	1.10E+01	6.40E−01	5.20	0.88
2045	1.70E−01	4.40E−01	0.87	0.29	2.80E+00	1.70E−01	1.60	0.22	1.20E+01	4.50E−01	4.90	0.83
2040	2.20E−01	4.20E−01	0.98	0.16	3.20E+00	1.50E−01	1.80	0.18	1.20E+01	5.20E−01	5.10	0.83
2035	1.50E−01	4.00E−01	0.99	0.14	3.40E+00	1.70E−01	1.90	0.16	1.10E+01	5.10E−01	4.90	0.81
2030	8.00E−02	3.80E−01	0.94	0.13	3.80E+00	2.10E−01	2.10	0.09	1.20E+01	6.50E−01	5.30	0.83
2025	6.80E−02	3.70E−01	1.00	0.10	4.40E+00	2.30E−01	2.30	0.05	1.30E+01	7.30E−01	5.80	0.84
2020	1.30E−01	4.00E−01	1.20	0.04	5.10E+00	2.00E−01	2.60	0.03	1.20E+01	8.40E−01	5.90	0.83
2015	7.00E−02	3.80E−01	1.20	0.05	4.90E+00	2.20E−01	2.70	0.05	1.40E+01	7.10E−01	6.00	0.82
2010	4.30E−02	3.70E−01	1.20	0.07	4.30E+00	2.40E−01	2.70	0.08	1.50E+01	6.40E−01	6.00	0.79
2005	7.00E−02	4.30E−01	1.50	0.02	5.00E+00	2.10E−01	3.00	0.07	1.40E+01	7.80E−01	6.10	0.78
2000	1.50E−01	3.30E−01	1.80	0.03	7.00E+00	2.20E−01	3.50	0.02	1.70E+01	9.50E−01	7.30	0.83
1995	1.20E−01	3.50E−01	1.90	0.02	6.80E+00	2.20E−01	3.60	0.00	1.70E+01	8.90E−01	7.20	0.81
1990	6.80E−02	4.10E−01	1.90	0.02	5.40E+00	2.20E−01	3.60	0.06	2.00E+01	7.00E−01	6.90	0.77
1985	5.90E−02	4.20E−01	2.00	0.01	4.50E+00	1.70E−01	3.70	0.11	1.50E+01	8.30E−01	6.20	0.68
1980	4.00E−02	2.70E+01	2.10	0.04	4.40E+00	2.00E−01	3.80	0.10	2.10E+01	6.70E−01	6.90	0.70
1975	4.30E−02	6.20E+00	2.20	0.03	4.70E+00	1.80E−01	4.00	0.10	2.00E+01	7.50E−01	7.00	0.68
1970	7.30E−02	3.00E+02	2.50	0.02	6.30E+00	2.00E−01	4.40	0.04	2.60E+01	7.70E−01	8.00	0.75
1965	5.80E−02	1.30E+02	2.70	0.03	5.00E+00	1.80E−01	4.50	0.08	2.40E+01	7.50E−01	7.60	0.68
1960	5.40E−02	1.90E+02	2.80	0.03	4.70E+00	1.70E−01	4.60	0.09	2.30E+01	7.50E−01	7.60	0.65
1955	3.80E−02	1.70E+02	2.90	0.05	3.90E+00	1.50E−01	4.70	0.11	2.30E+01	7.50E−01	7.50	0.60
1950	2.80E−02	3.60E+03	3.00	0.07	2.30E+00	8.40E−02	4.70	0.18	2.00E+01	8.30E−01	7.00	0.50

The results of the work are summarized in Tables 1 and 2 where the values of $A_j = N_j M_j$, $B_j = \gamma_0 N_j$, $C_j = E_j/1000$ are presented for fixed frequencies ν for each of three groups. Table 1 contains the values of the parameters of the three-level model for H_2O in the range 2–5 μm with the interval of 20 cm^{-1}. Table 2 contains the parameters of the three-level model for CO_2 in the 2.7 and 4.3 μm bands and for CO in the 4.6 μm band with an interval of 5 cm^{-1} with account for the possible nonequilibrium. Numerous calculations of optical characteristics of nonuniform objects with the use of parameters presented in the tables confirmed the reliability and efficiency of the proposed approach [16–18].

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