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ON THE INFLUENCE OF ATMOSPHERIC TRANSMISSION FUNCTIONS ON INFRARED MEASUREMENTS IN PLANETARY ATMOSPHERES

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ABSTRACT

Realistic interpretations of atmospheric radiation spectra need an adequate theory. We give a critical discussion of the various methods to represent such spectra and discuss discrepancies in the results from 2 different methods: see Fig.1, Comparison of present calculations with such ones of GRAY and McCLATCHEY [26] in the 4.5 micron region, where the bands of CO_2, N_2O and CO are overlapping. The difference of calculated equivalent temperatures of the outgoing radiation are seen to be higher than 8 degrees Kelvin.

Approximate calculations in the NIMBUS I HRIR region (3.4 to 4.2 micron) show, that the bands of CO_2, N_2O can be regarded responsible for discrepancies between investigations of MARLATT and SAMUELSON. These gases account for about 2 degrees Kelvin of the equivalent temperature. Detailed results for clouds of various heights and emissivities are given in Table III.

Approximate calculations in the long wave length wing of the 6.3 micron H_2O-band show, that the neglection of N_2O and CH_4 against the H_2O transmission may cause an error of about 9 degrees Kelvin between 7.25 and 7.75 microns.

We give the development of a general method for the representation of atmospheric spectra. It is based on laboratory transmission functions and works very rational. We demonstrate its applicability to the 13o6/155o CH_4, 2563/2461 N_2O, 3o2o CH_4, 2143 CO, 2224 N_2O-bands and the 6.3 micron H_2O, the 4.3 micron CO_2-bands.

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I. INTRODUCTION

Infrared radiation measurements have turned out to be a very powerful tool in the study of many problems concerning the composition of the earth atmosphere, especially for investigations of vertical and horizontal structure and processes. Similar measurements shall be applied in the future also to atmospheres of other planets. The first and very prospective and comprehensive discussion of satellite measurements has been given by S. FRED SINGER (1956) [3] .

To arrange and interpret radiation measurements from satellites or space probes a theory becomes necessary, which at least must be as accurate, as the measurements themselves will be. In particular there will be a need of concrete and reliable knowledge of the transmission functions of atmospheric gases under atmospheric conditions, as well as procedures of calculation for the radiative transfer, which are rational and reflect the accuracy as it will be seen by the satellite instrument.

We can show the problem by means of figure 1: there are compared spectral distributions of the outgoing radiation obtained by GRAY and Mc CLATCHEY [26] with present calculations. Our results have been obtained by means of experimentally derived band model-parameters (section III c) while GRAY and Mc CLATCHEY applied theoretically derived band model parameters (section III b). Though the general course of the curves 1 and "Gray" is similar, it is evident, that there exists still a remarkable difference in the absolute values to be expected: for instance there is a difference of more than 8 degrees Kelvin at 2238 cm^{-1}, between the two methods.

In principle the question of accuracy of measurements and theory for inversion problems has been raised by KING [46]. Our special problem was to predict the overlapping effect of the bands of several atmospheric constituents on the outgoing

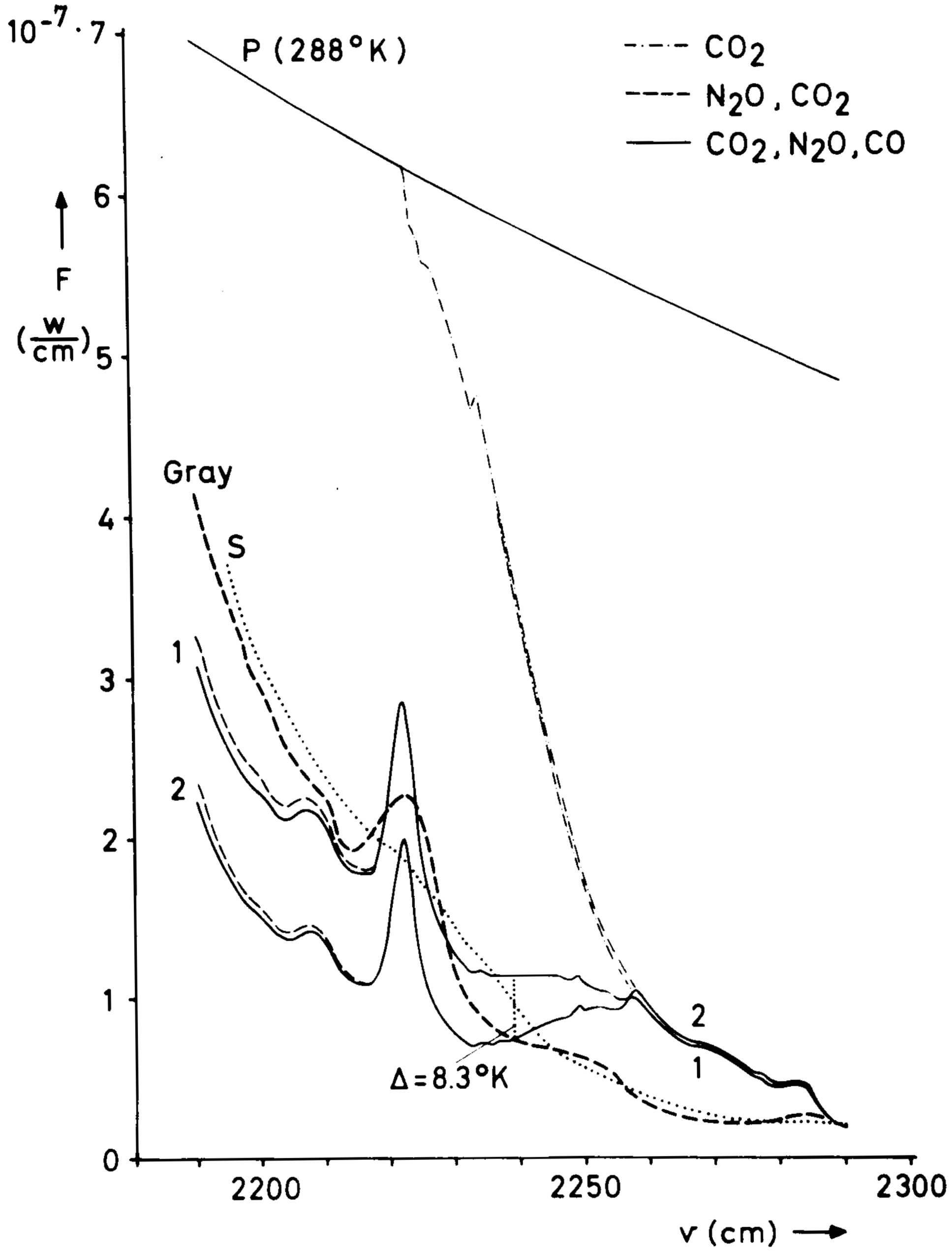

Fig. 1 Outgoing radiation: P (288°K) = Planck function at surface temperature. Curves 2 : calculated with our method (section III c) and using mixing ratios (see table III) according to US-Standard-Atmosphere 1962. - Curves 1 : calculated with our method and using mixing ratios according to GRAY and Mc CLATCHEY [26] . - Curves "GRAY": calculated by GRAY and Mc CLATCHEY [26] using theoretically derived band model-parameters (section II b) without slit function. At the wave number 2238 cm^{-1} our calculations would lead to an equivalent temperature which is 8,3°K higher than that obtained by GRAY and Mc CLATCHEY; curve S: obtained from curve "GRAY" by applying a slit function.

radiation and we were interested to find its influence on the deduction of vertical structures in the atmosphere. It is evident, that first an adequate method to calculate the outgoing radiation has to be found, where the influence of the individual parameters of the calculation can be verified. First we tested the mutual influence of actual transmission functions and of the Planck function in different spectral regions [9] . We found, that we had to look for a better principle for the calculation of the infrared spectrum. A new method of OPPENHEIM and BEN ARYEH [28] will be applied and extended in the present report, together with a short discussion of the well known methods.

The necessity of accurate calculations may be understood by the scientific situation in sensing a planetary atmosphere: (for simplicity reasons we first assume that any scattering or reflection from surfaces can be neglected and that local thermodynamical equilibrium is valid). The radiation which will be detected by a vertically downward viewing instrument at the top of the atmosphere depends only on absorption and emission of atmospheric gases and on the emissivity of the earth surface or of cloud layers. It originates from different atmospheric levels, according to the frequency of the electromagnetic radiation. Under model conditions each atmospheric level can be determined by a definite temperature. Consequently, if a temperature profile shall be derived, measurements have to be performed at different frequencies, or better, frequency intervals. Each frequency interval has to be broad enough to assure, that enough energy reaches the detector:sensitivity of the detectors and particularly stabilization and adjustments for the mechanical stress in a satellite are problems [5] , which grow with diminuishing spectral width. On the other hand, the width of the frequency interval influences the height-resolution of the inversion procedure, the deduction of vertical atmospheric structure from radiation measurements [6] .

A compromise has to be found between experimental possibilities and meteorological wishes.

Within the last years the experimental techniques have been improved currently as has been shown by HANEL [7] . Accordingly it must be looked for suitable theoretical procedures which can satisfy the needed meteorological accuracy.

The main theoretical problems are:

a) the calculation of the outgoing radiation
b) deduction of atmospheric parameters from the real (observed) spectrum, by using an inversion procedure.

The accuracy of a) is an essential presupposition for b). Our investigations will deal with a): the key lies in the equation of radiative transfer, by which the outgoing radiation has to be calculated:

$$F_{\Delta\nu}=\int_{\Delta\nu}\phi_\nu d\nu\int_{U}^{\infty}\varepsilon_\nu B_\nu(T_0)\cdot d\tau_\nu(T,p,u)+\int_{\Delta\nu}\phi_\nu d\nu\int_{0}^{U}B_\nu(T(z))\;d\tau_\nu(T,p,u) \tag{1}$$

$\Delta\nu$ = wave number interval, T_0= ground temperature,
ϕ_ν = filter function of the sensing instrument,
ε_ν = emissivity, $F_{\Delta\nu}$ = outgoing radiation,
T = absolute temperature, B_ν= Planck-function,
z = height, τ_ν = transmission function, U = total absorber mass, u = effective absorber mass, p = pressure.

This equation contains a somewhat problematic quantity, the transmission of the atmospheric gases. For direct integration one should know τ as analytical function of the wavenumber ν , and of the temperature T, if also T would be an analytical function of p and u. The reality does not satisfy such ideal conditions, therefore the integration must be performed numerically. Thus the problem arises to find a numerical procedure of calculation, which approximates in a good way the real atmospheric conditions and at the same time works rationally.

For the solution of this problem in the case of very broad spectral intervals, the principle of the radiation diagram of MÖLLER has been most useful [1] .

More emphasis to the spectral distribution of the outgoing radiation will be necessary for the interpretation of future radiation measurements from satellites and space probes. The test, how far averaging procedures, applied to still relatively wide spectral intervals allow to obtain sufficient information on the outgoing radiation, showed unsatisfactory results [9] . There an empirical principle was used, which had proved useful in calculations of the downward directed radiation [10] . It now proved, that for the outgoing radiation such calculations can give only a very rough picture and that it is impossible to discuss them quantitatively. - Finally special band model calculations lead to good results, as will be shown here.

A second question would be, how detailed the subdivision of the vertical temperature profile T (p,u) must be, particularly when discontinuities are present. This question has been attacked by ZIRKIND [11] .

Thirdly, the emissivity of cloud surfaces and of the soil is still unknown for a wide range of conditions in the nature. From theoretical investigations of HARVARD [12] we will derive clouds emissivities and check their influence on the outgoing radiation.

For orientation purposes the empirical procedure is applied to the region of the Nimbus I high resolution infrared radiometer (HRIR) to get an idea, whether the absorption in this channel may be neglected with the determination of cloud surface temperatures. Also the long wave length wing of the 6.3 micron H_2O band has been checked: it was to test, whether the region between 7.25 to 7.75 microns would be suitable for the determination of the relative humidity in the troposphere, as there are bands of CH_4 and N_2O additionally to that of H_2O.

For general investigations of the necessary accuracy conditions in overlapping cases and inversion problems the special band model version of transmission calculations of OPPENHEIM and BEN ARYEH has been prepared for actual problems and applied to simplified conditions in the atmosphere. The method is based on adequate laboratory transmission measurements of the atmospheric gases. It includes the possibility to determine easily the influence of changes in the meteorological parameters (mixing ratios, temperatures, emissivities) on the infrared radiation which is to be seen by a satellite in interesting spectral intervals. This will be shown for the 4.3 micron region where the bands of N_2O, CO and CO_2 are overlapping, and which is interesting for soundings in the Mars atmosphere. Similar calculations could be performed for other IR-bands, as the 1595 H_2O, 3020 CH_4, 2563/2461 N_2O, 1306/1550 CH_4 band, as is shown by adequate representation of some of the basic data.

II. CALCULATION OF THE OUTGOING RADIATION USING TRANSMISSION SPECTRA

a) Principle

For the purpose of numerical integration on the IBM 7090 the equation (1) is approximately by

$$(2)\quad F_{\Delta\nu} = \phi_{\Delta\nu}\Big[\varepsilon_{\Delta\nu}\cdot\overset{*}{\tilde{\tau}}_{\Delta\nu}(T_o,p_o,U)\cdot B_{\Delta\nu\, z_n} + \sum_{i=1}^{n} B_{\Delta\nu,\, z_n}\cdot\Delta\overset{*}{\tilde{\tau}}_{\Delta\nu}(T_i,p_i,u)\Big]$$

i = 1,...,n = number of atmospheric layers,
* indicates that j gases have to be regarded, whose transmissions are multiplied with each other: $\overset{*}{\tilde{\tau}}_{\Delta\nu} = \prod_{j} \tau_{i,\Delta\nu}$)
subscripts $\Delta\nu$ or Δz indicate, that the quantity is the arithmetic average over the interval $\Delta\nu$ or Δz.

It is $u = \sum_{1}^{i} \Delta u_i$.

The vertical inhomogenity of the atmosphere is considered by using a weighted pressure according to CURTIS-GODSON [17], 18 and a weighted temperature after BOLLE [10]:

$$p_i = \frac{\sum_{1}^{i} p_{\Delta z_i} \Delta u_i}{\sum_{1}^{i} \Delta u_i} \, , \quad T_i = \frac{\sum_{1}^{i} T_{\Delta z_i} \cdot \Delta u_i}{\sum_{1}^{i} \Delta u_i} \tag{3), (4}$$

The transmissions, entering equation (2), are derived in the following sections b) and c). In Figure 2 we show the vertical distribution of the transmission of single atmospheric minor constituents and their combinations in the long wavelength wing of the 6.3 micron H_2O-band. For the NIMBUS I HRIR channel we have derived $\phi_{\Delta\nu}$ from the filter function Fig. 2, see also ref. [19]. We derived $\phi_{\Delta\nu} = 0.4$ as average value of the filter function.

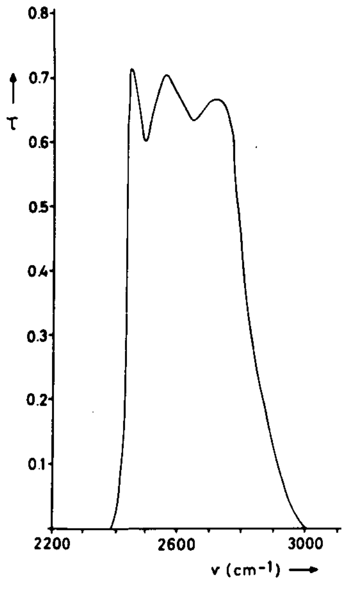

Fig. 2 Filter function of the Nimbus I, High Resolution Infrared Radiometer (HRIR).

b) Empirical transmission formulas:

HOWARD,BURCH,SINGLETON,FRANCE and WILLIAMS, in the following abbreviated as HBW, have given extensive material on the transmission of atmospheric minor constituents [14], but at relatively low resolution (20 cm^{-1}). For most of the bands they have derived empirical functions A_{band} for the integrated absorption, which have the form:

$$A_{band}=(1-\tau_{band})=c\cdot[u\cdot p^{a}] \quad \text{or} \quad A_{band}=(1-\tau_{band})=C+D\cdot\log(u\cdot p^{a})$$

where a,b,c,C,D are empirical constants.

The empirical formulas are valid only for limited values of mass and pressure. They are often not sufficient for the conditions of the earth atmosphere. If extrapolations become necessary the results need to be regarded extremely critically. Often calculations must not be performed for the whole region of the band of an atmospheric gas, but only for part of the band. To take care of this case, we replace

$$A_{band}=(1-\tau_{band}) \quad \text{by} \quad A_{part}=K\,(1-\tau_{band})$$

where K gives the percentual amount of that part of the integrated absorption (of the whole band) which lies in the regarded spectral interval - if only one gas is considered.

The average transmission over a spectral interval is then:

$$\tau_{\Delta\nu}=1-\frac{K}{\Delta\nu}\cdot A_{band} \tag{4}$$

We have applied this formula. Its explicit representations for calculations in this paper are taken from [14] where we introduced our values of K and $\Delta\nu$.

For the wave-number interval

$\Delta\nu$ = 7,25 - 7,75 microns (= 1290 - 1379 cm^{-1}): CH_4-absorption, a part of the 1306 CH_4 band, it is:

$$\tau_{\Delta\nu,\ell} = 1 - 6{,}86.10^{-3}.\ \left[7{,}3\ (u_i \cdot p_i^{0{,}6})^{0{,}45}\right]$$

regions of validity : $20 < A_{band} < 130\ [cm^{-1}]$

$10 < p < 760\ [mm\ Hg]$.

For the wave-number interval

$\Delta\nu = 2380 - 3000\ cm^{-1}$ (Nimbus HRIR-region):CH_4 - absorption, a part of the 3020-CH_4-band, it is:

$$\tau_{\Delta\nu,\ell} = 1 - 7{,}09.10^{-4}.\ \left[15{,}5\ (u_i \cdot p_i^{0{,}4})^{0{,}55}\right]$$

regions of validity: $15 < A_{band} < 250\ [cm^{-1}]$

$10 < p < 760\ [mm\ Hg]$.

c) <u>Transmissions from spectra or tables</u>

In some cases, formulas for the integrated absorptions were not available. HBW and also GOODY and WORMELL [20] have given diagrams, where A_{band} is represented as function of pressure and absorber mass. We have digitised those diagrams and interpolated to get values of A_{band} for atmospheric conditions. This has been done in the following cases:

$\Delta\nu = 1290 - 1379\ [cm^{-1}]$: region of N_2O absorption, a part of 1167 N_2O-band, it is:

$$\tau_{\Delta\nu} = 1 - (0.162.10^{V_i}\ .0.0681)$$

V_i is obtained from the spectra of Goody and Wormell, by linear interpolation in logarithmic coordinates in the digitised spectra (table VI in the appendix), by the formula

$$V_i = \frac{\log u_i - \log u_b}{\log u_{b+1} - \log u_b}\ (y_{a,b+1} - y_{a,b}) + \left(\frac{\log p_i - \log p_a}{\log p_{a+1} - \log p_a}\right)\ (y_{a+1,b+1} -$$

$$y_{a,b+1} - y_{a+1,b} + y_{a,b}) + \left(\frac{\log_{pi} \quad - \log p_a}{\log p_{a+1} - \log p_a}\right. \cdot (y_{a+1,b} - y_{a,b}) + y_{a,b} \qquad (5)$$

a and b are running indices on the p and u - ordinates.
y are step-values in the interpolation in the y-field, where
$y = {}^{10}\log A_{band}$.

A similar procedure has been applied to the N_2O-absorption between $\Delta\nu = 2380 - 3000$ [cm^{-1}], where we have the 2563-N_2O band (gas 1) and the 2426 N_2O band (gas 2): hereby spectra of reference [14] have been digitised (table VII, VIII in the appendix): $\tau_{\Delta\nu}$ is obtained by

$$\tau_{\Delta\nu,\,l} = (1 - V_{i,1}) (1 - V_{i,2}) \text{ , where}$$

$V_{i,gas}$ is obtained by interpolation with formula (5), only here the meaning of y is changed to $y = A_{band}$.

For H_2O and CO_2-transmission the Plass-tables [30] have been used; there the transmission is given as function of p, m, T. At a fixed temperature interpolation for $\tau_{\Delta\nu}$ is performed also by formula (5), the meaning of y is now: $y = \tau_{\Delta\nu}$. To get the values for the $\tau_{\Delta\nu}$-field of the interpolation scheme the values of the Plass-tables between 2380 to 3000 [cm^{-1}] and 1290 to 1379 [cm^{-1}] have been summed up and mean values have been formed at the table-conditions (see appendix, table IX, X, XI).

The Plass-tables are given for three different temperatures. When the interpolation in the (p, u)-schemes (each of them built up at one of the three temperatures) has been executed, linear interpolation for τ_i (u_i, p_i) between these schemes, now with respect to the temperature can be done, so that now
$\tau_i = \tau_i (u_i, p_i, T_i)$.

III. METHOD OF BAND MODELS TO CALCULATE OUTGOING RADIATION

The equation of radiative transfer (1), (2) will be solved in this method for relatively narrow spectral intervals, as the transmission for such intervals can be calculated by means of band models. Already PLASS [48] mentioned that empirical expressions are not sufficient to provide reliable predictions of the absorption for values of path lengths and pressure as they are found in the atmosphere: they have limited regions of validity. If these cannot be observed, serious errors can occur, we have demonstrated this in table I of ref. [9]. Besides, when going to other planetary atmospheres, other sets of conditions would become necessary, and the amount of necessary data would arise tremendously, especially for measurements with high spectral resolution. It is evident, that model representations of the absorption bands have to be found, which gave a reasonably simple (computing time!) but satisfactory means for representation and prediction of transmission data.

a) Principle of transmissivity calculations by band models.

Several band models are already known and from time to time new ones are invented, to approximate the distribution of position, intensity and shapes of the lines in a distinct band optimally. But this should only be done, if the actual quantities and their behaviour under different parameter conditions are known with sufficient accuracy, which mostly is not the case, and such calculations will be valid only for a limited range of conditions; for extremely different experimental conditions different band models may be applicable, as different transitions between the energy levels of the molecule will become efficient.

Instead of special models, a set of general models should be developed. The difference between the present models is supposed to be small compared with the error inherent in the basic data.

Generally ought to be said, that theoretical transmission calculations should always be checked by laboratory measurements for the same conditions: the conditions are the same, if not only p, T, u are equal, but also the spectral resolution of the source spectrum, the spectrum, which is transmitted through the medium. Therefore the band model parameters must be adequate to the spectral resolution of the "source" in the spectrograph, which is the radiation incident on the absorption cell. Therefore theoretically derived parameters (section b.)) must not only be averaged over the spectral interval by an adequate weighting, but also a split function must be superimposed to them. If the band model parameters have been derived directly from experiments, (section c.)), no slit function must be superimposed for comparisons with the measurements from which they have been derived.

The application of band model calculations to the real atmosphere contains the assumption, that the band model parameters represent the source spectrum of the atmosphere. (For further discussions see section c.).

Two general models are the Elsasser model and the statistical model. The mean absorptance A over the frequency interval for which the model is valid, is

$$A_{\Delta\nu}(\beta, y) = \sinh\beta \int_0^y \exp(-t \cosh\beta)\; I_0 (i.t) \,.\, dt \tag{6}$$

for the Elsasser model with Lorentz line shape, and

$$A_{\Delta\nu} = 1 - \exp\left[-\beta.x.e^{-x}.\, (I_0 (x) + I_1 (x))\right] \tag{7}$$

for the statistical model,

where $= \frac{2\pi\alpha}{d}$, $y = \frac{S.u}{\sinh\beta}$, $x = \frac{S^o . p . L}{2\pi\alpha \, .p_e}$

α = half width (cm^{-1}) for Lorentz shape
d = mean line spacing (cm^{-1})
S = integrated intensity of a line ($cm^{-2}.atm^{-1}$)
I_o, I_1 are modified Bessel functions (with real argument)
u = optical path of the absorber (atm-cm)
p_e = equivalent pressure (effective broadening pressure)
p' = partial pressure of the absorbing gas (atm)
p_t = total pressure of the gas mixture
B = self broadening coefficient
u = p'.L, $p_e = p_t + (B - 1).p'$

For calculations with these models one needs to know average values of d, S , α, over the regarded frequency interval. Usually this is not the case. Either one has to provide these values by calculations [21] , [22], [23] , [24] , [25] , [26] , see section b), or one uses combinations from the ($U = \frac{2\pi\alpha^o}{d}$, $V = \frac{S^o}{2\pi\alpha^o}$), which can easily be derived from measurements. [27] , [28] , [29] , see section c).

b) Band model parameters obtained by means of quantum theoretical relations.

This is usually a big task, already for one absorption band (see e.g. [22]): for instance the calculation of the line intensity of one individual rotational line is:

$$S_i (m) = \frac{8\pi^3 \; \omega_i(m) \; Ng''}{3 \; h.c.Q_v \; .Q_r''} \begin{pmatrix} R \; l'' \rightarrow l' \\ m'' \rightarrow m' \end{pmatrix}^2 . \beta_i^2 \; . \exp\,(-hc\,\omega''/kT) .$$

$$. [1 - \exp\,(- hc \, \omega_i(m)/ \; kT)]$$

where S_i = local rotational line intensity

N = total number of molecules per unit volume per unit pressure

g'' = degeneracy of the lower state

h = Planck's constant

k = Boltzman's constant

c = velocity of light

T = absolute temperature

β_i = dipole matrix element for the vibrational transition

Q_v = vibrational partition function

Q_r = rotational partition function

ω'' = energy of the lower state ($\omega'' = \omega_r'' + \omega_v''$ where subscripts r and v refer to rotation and vibration respectively)

R = the rotational matrix element

m = ordinal number

l = quantum number of the angular momentum associated with the doubly degenerate vibration v_2

In these calculations a set of individually measured spectroscopic constants has to be known. The total integrated intensity of the whole regarded band must be known from measurements and also the half width which is a function of pressure and temperature. For the latter function assumptions have to be used. All quantum-mechanical transitions of the band have to be regarded by such calculations. Once this has been done one has to find a good procedure or a weighting aspect to from adequate average values so that finally a band model can be applied. Such methods of construction of a model for an absorption band have been used by several authors, ref. [13], [21] to [26]. Interesting for us are especially the calculations of [26], [13]. The authors there replace the real spectrum in 5 cm^{-1} intervals by one hypothetical line.

There it is not discussed how far this assumption will influence the final result. However, the recalculations of the measured spectra seem to deviate: see for instance ref. [13], there fig. 4:
in the wings there are evidently errors from 5 to 40 percent. It seems, that it is very difficult, to find good values of the parameters for this principle.

For the interpretation of recorded atmospheric spectra a slit function must be superimposed to the calculated results, as well as for the comparison with laboratory spectra.

c) Band model parameters derived from experiments.

Here band model parameters are directly derived from measurements by a principle which has been given by OPPENHEIM and BEN ARYEH [28] . This is done by applying a fit procedure to laboratory measurements. Then one may enter immediately the band model formulas. Oppenheim and Ben Aryeh have demonstrated this by means of the HBW [14] measurements. As these have in average a spectral resolution of about 20 cm^{-1}, the derived parameters must be regarded as local mean values, averaged over 20 cm^{-1} intervals and deformed by the slit function. (This should not be mixed with the fact, that one may derive the parameters every 5 cm^{-1} or still closer together - if the spectra are good enough).

The derived parameters are defined as $U = \frac{2\pi\alpha_L^o}{d}$, $V = \frac{S^o}{2\pi\alpha_L^o}$. If one has average values of the line spacing d, which are averaged over the same spectral interval, one may also derive the average values of S and α . If this is not the case, S and α will define lines, which have to be regarded as somewhat hypothetical ones, even if their total number in the spectral interval in question would be correct. It should be expected, that there would be an optimal relation between slit width and line spacing to get an optimal picture of the actual spectrum, that means, an optimal band model. But this relation will of course be different for the individual bands. The atmospheric actual spectrum deviates from an average band model spectrum, and the superposition of the slit function to an average spectrum could be regarded as part of the averaging process itself. The effect of the slit function in the parameters will be negligible for the actual case, if the recalculations for the laboratory conditions show sufficient agreement with the experiments. It is the question, how far averaging effects within the band model principle will influence the amount of the outgoing radiation which is an average value over the regarded spectral interval. These problems will diminuish, if the laboratory instrument has the same spectral resolution as the satellite instrument, as long as the source spectrum of the laboratory experiment is regarded as a sufficient representation of the actual atmospheric source spectrum, and as long as the character of the slit function is the same for both instruments.

We shall apply the Oppenheim-Ben Aryeh principle in our investigations on the outgoing radiation. Therefore we have to develop it in more detail and extend it for our purpose. We present it as follows:

In the non-overlapping case the mean absorptance of an Elsasser band (which is the mean absorptance of one line in this band) can be represented by a Ladenburg-Reiche Curve of growth for a line with Lorentz-shape:

$$A = ß \cdot f(x) = ß \cdot x \cdot e^{-x} \cdot [\, I_0(x) + I_1(x) \,] \tag{8}$$

for definitions see section a.).

OPPENHEIM and BEN ARYEH show, that by restricting to absorptions $A < 0.2$, the non-overlapping case is included and therefore a curve of growth can be constructed from such measurements. The curve of growth has two asymptotes (figure 3), the formulas of which are in the first approximation:

$$W = S^o \cdot L_e \cdot p_e \qquad \text{linear region,}$$

$$W = 2\, p_e\, (S^o \cdot \alpha_L^o \cdot L_e)^{1/2} \text{square root region,}$$

where

α_L^o = half width for Lorentz shape
W = equivalent width of a line.

We derive for the point s of intersection of the asymptotes the band model parameters U, V.

It can be shown that no assumption of the line spacing is necessary. $A_{\Delta\nu}$ is, according to the spectral resolution of the laboratory measurements a mean value of the absorptance in the center of an interval of the width of 5 cm^{-1}. Thus, U, V have to be regarded as mean values for 5 cm^{-1} intervals. It is not necessary, to decide, how many lines would be within $\Delta\nu$. $A_{\Delta\nu}$ gives simply the mean absorptance over $\Delta\nu$.

The statistical model equation (7) may generally be written in terms of the equivalent width of a single line:

$$A = 1 - \exp\left(\frac{-\overline{W}}{d} \right)$$

Introducing the transmission τ, and assuming a Dirac probability function for the distribution of intensities, (all lines euqal), we obtain

$$-\ln\tau = \beta \cdot f(x) \tag{9}$$

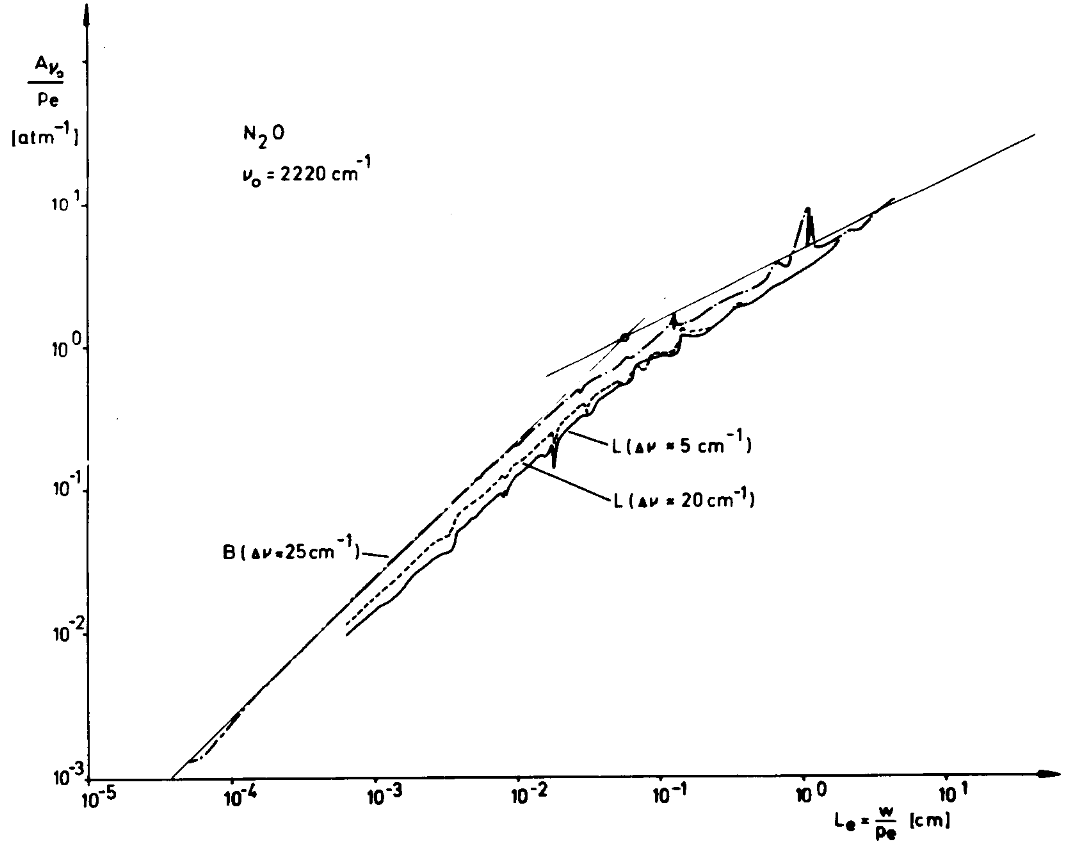

Fig. 3 Pressure independent version of the Ladenburg Reiche Curve of growth. Comparison of BURCH'S measurements (curve B) with LEUPOLT'S measurements (curve L) at the wavenumber $\nu = 2220\ cm^{-1}$ for N_2O.

$\Delta\nu$ = spectral resolution, p_e = equivalent pressure, A = absorptance, averaged over $\Delta\nu$, w = absorber mass. The asymptotes are the lines according to the OPPENHEIM - BEN ARYEH technique.

The curves are plotted by means of an electronic computer which could not make single points. Therefore the identations are caused by the scattering of the measured values.

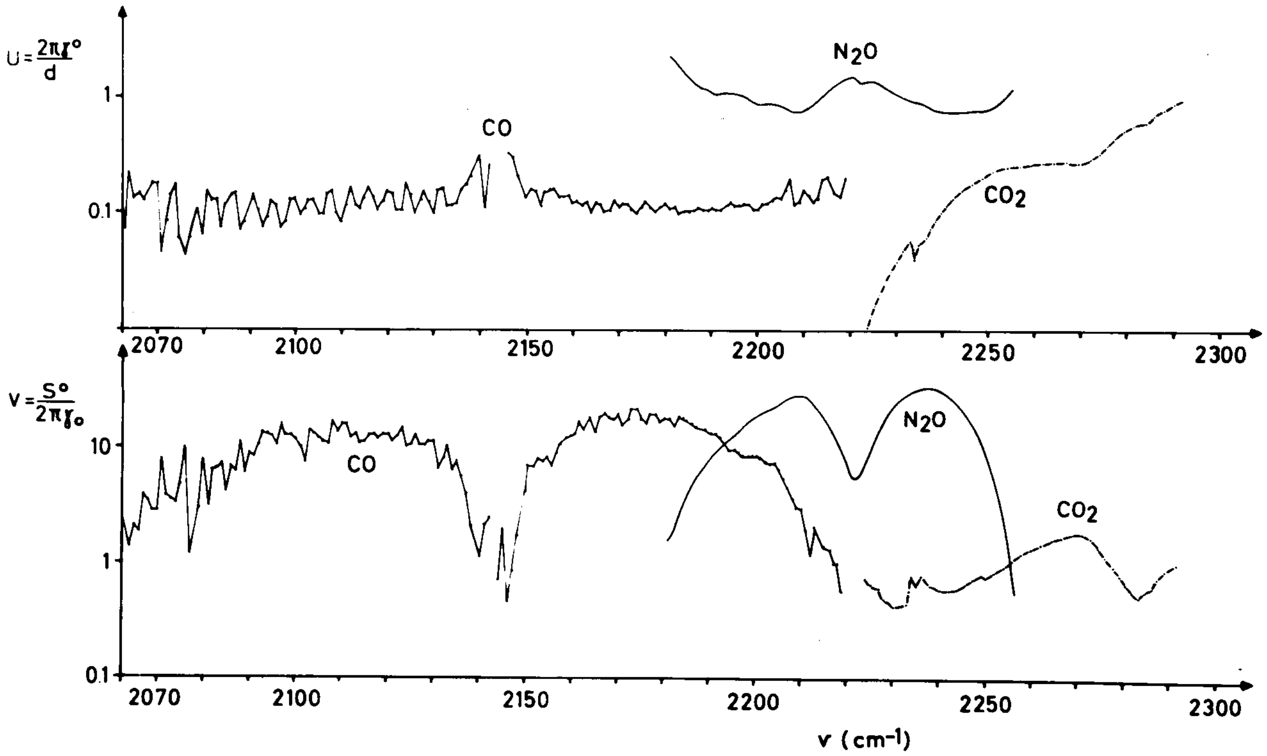

Fig. 4

Band model parameters U, V, obtained from the direct fit applied to LEUPOLT'S data.

Similarity of equations (8), (9) show that there is now a single procedure for representing the mean absorptance of a band as a function of band parameters. Equation (9) bases on the assumption of the special distribution of the line intensities in the band. But as this distribution has no influence on the asymptotes [32], it does not influence the coordinates of their point of intersection, that means it does not influence the values of the parameters U, V themselves.

So we conclude, that the values of the parameters are independent of the model*. We derived the parameters directly from the curve of growth and not from its **asymptotes**: Very often the curve of growth is not long enough to show a distinct linear and sqare root region. Then it is not possible to construct the asymptotes and derive parameters. An example for pressure reduced curves of growth is given in fig. 5. For discussion see section VI b.).

Having derived the spectral distribution of the parameters (fig. 4) we recalculate the absorption for conditions of the measurements by means of the two band model formulas (6), (7). In the computer program we approximate these by series representations: SEITZ and LUNDHOLM [33] have given an adequate expression for the Elsasser model; for the statistical model with lines of equal intensity it can be easily derived, and will be given elsewhere.

Sometimes it is sufficient to use the strong-line approximation for the statistical band:

$$\tau = \exp - (u_i \cdot p_{\Delta z_i} \cdot Z)^{1/2} \tag{13}$$

where we now combine the band parameters Z from U and V:

$$Z = \frac{2}{\pi} U^2 \cdot V \tag{14}$$

---

* and of the distribution function of the line intensities

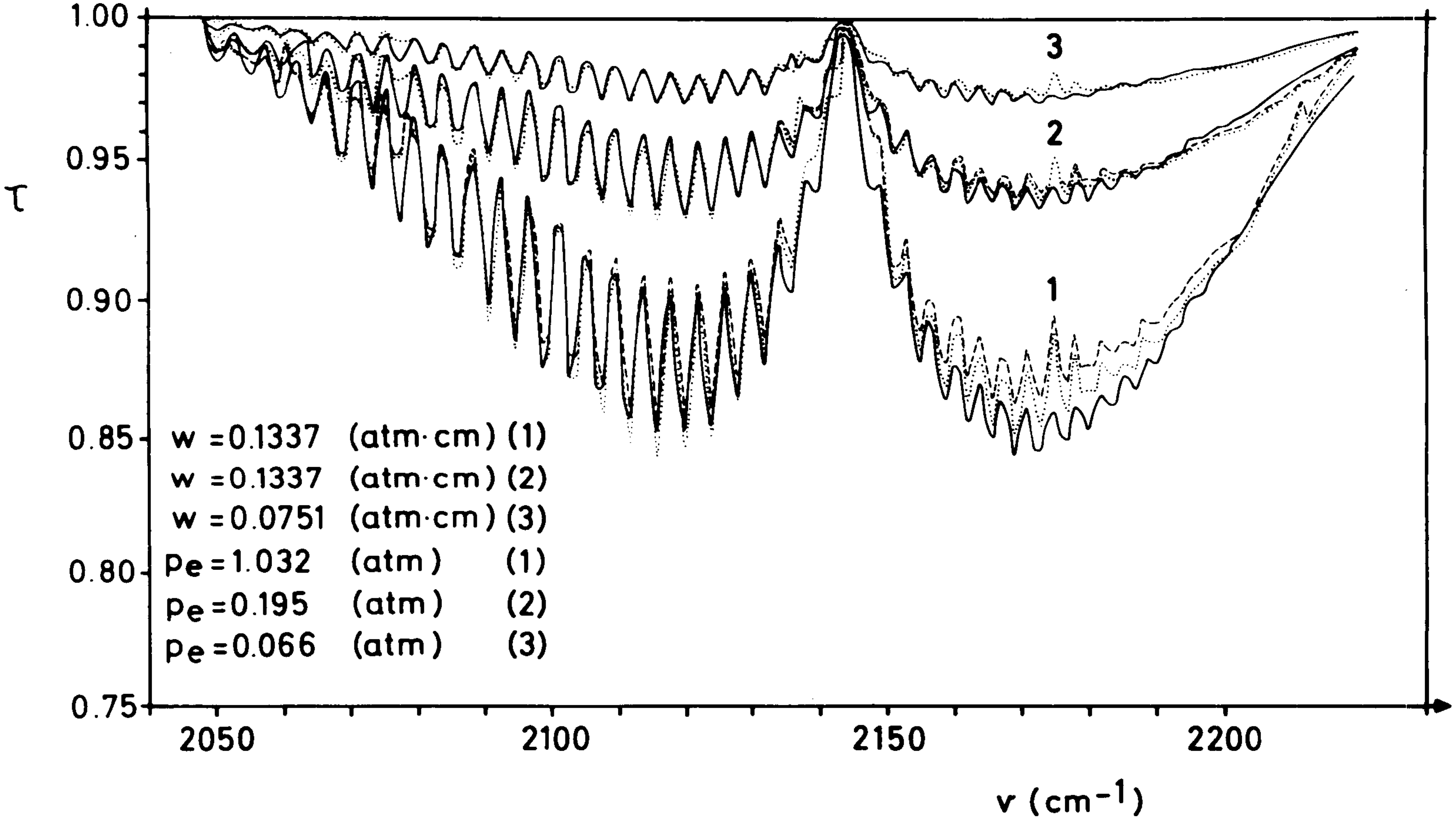

Fig. 5

Measured CO spectra compared with band model calculation ------= Elsasser model, -·-·-= statistical model with lines of equal intensity, ——= measured spectrum, w = absorber mass, p_e = equivalent pressure, τ = Transmission.

From the recalculations of the measured laboratory spectra we can decide which band model is more adequate (fig. 5), and how far band model calculation is suitable over homogeneous paths.

Formulas (10) to (14) are used then for the calculations under atmospheric conditions.

d) Mixed line shapes.

In the following we shall outline the possibility of an extension of our band model calculations to conditions where mixed line shapes - the Voigt profile - ought to be used: in the earth atmosphere Doppler broadening becomes remarkable at pressures lower than 10^{-2} atm. Our band model parameters U, V have been derived from measurements at relatively high pressures under laboratory conditions. To make our band model-calculations applicable also to conditions where mixed line shapes have to be used, the solution of PLASS-FIVEL 34 can be introduced. From the findings of these authors we know, that, if the weak line approximation is valid, the line shapes have no influence on the equivalent width: we now find

$$W = S \cdot u = u \cdot d \cdot V \cdot U$$

the equivalent width of a weak line, and

$$A = 1 - e^{-U.V.u} \,. \tag{15}$$

the absorptance for both band models in the weak line approximation.

If the strong line approximation can be applied, the Voigt profile (mixed line shape) can be considered according to PENNER [36] :

$$W_m = 2\ (S.\alpha_L.u)^{1/2} \cdot \left[1 + \frac{3}{16} a^{-2}x^{-1} + \frac{45}{512} a^{-4}x^{-2} - \frac{3}{32} a^{-2}x^{-2} + - \dots\right]$$

(16) $$W_m = d.(u \frac{2}{\pi}.p.V.U^2)^{1/2} \cdot \left[1 + \frac{3}{16} a^{-2}x^{-1} + \frac{45}{512} a^{-4}x^{-2} - + \dots\right]$$

where

(17) $$a = \frac{\alpha_L}{\alpha_D} \cdot (\ln 2)^{1/2}, \qquad \alpha_D = \frac{(2\ k\ T.\ln\ 2)^{1/2}}{(mc^2)^{1/2}} .$$

ν_0 = wave number in the center of the interval,
c = velocity of light
k = Boltzmann-constant
T = absolute temperature
subscripts L, D refer to Lorentz or Doppler-line shape.

W_m = equivalent width of a line with mixed shape.

It is

(18) $$x = \frac{S^0 \cdot u}{2\ \pi \alpha^0} = V \cdot u$$

$$\alpha_L^0 = \frac{d}{2\pi} \cdot U$$

$$a = \frac{d \cdot U \cdot (mc^2)^{1/2}}{2\pi\ (\ 2kT)^{1/2} . \nu_0} = U \cdot N , \quad \text{where}$$

$$N = \frac{d \cdot U \cdot (mc^2)^{1/2}}{2\pi\ (\ 2kT)^{1/2} . \nu_0}$$

To perform these calculations, the average line spacing d must be known - for instance from spectroscopic measurements - or a hypothetical line must be introduced: the mean absorptance over the wave number interval is represented in this case by the hypothetical line, whose width is d.

The absorptance for the strong-line approximation of statistical modelis now from (13), (16) in terms of U,V:

$$(19)\quad A_{\Delta\nu} = 1 - \exp\left(p_{\Delta z_i} \cdot u_i \cdot \frac{2}{\pi} \cdot U^2.V\right)^{1/2} . \left[1 + \frac{3}{16} U^{-2}.V^{-1}.N^{-2}. .u^{-1} + \frac{45}{512} U^{-4}\, V^{-2}\, N^{-4}\, u^{-2} - + \ldots\right]$$

and can be calculated only by using the parameters U, V which have been derived for Lorentz-shape, and by the Doppler half width (relations (17), (18)).*

The general case to calculate transmission with mixed line shapes by the band model formulas directly will be developed elsewhere [16] . These developments could not yet be introduced into our numerical calculations, and shall be regarded as proposed extension.

e) Radiative transfer over inhomogeneous paths in an atmosphere.

We presume that Beer's law is valid for the transmission of monochromatic radiation through an optical path (deviations of Beer's law have been found by TOURIN and BABROV for high temperatures, where the absorption coefficient depends on the mixing ratio). In the"monochromatic" case - if the width of is sufficient narrow - one may apply the condition law

$$(20)\qquad \tau_\nu\left(\int du\right) = \exp\left(-\int k_\nu(p,T).du\ (p,T)\right)$$

---

[*] similar considerations may be made in the case of the strong line approximation for the Elsasser model.

where k_ν= monochromatic absorption coefficient. This equation allows to calculate "exactly" that means the atmosphere can be divided into layers which are sufficiently narrow, so that they may be regarded as homogeneous. The integration of the equation of radiative transfer (1) can be done in this case directly by using equation (2) without additional assumptions. But in band model calculations we have not to deal with "monochromatic" transmissions but with mean values which are averaged over the region of one line at least. So we cannot use equation (2) but we have to work with

$$\tau_{\Delta\nu} = \tau_{\Delta\nu}(S_{\Delta\nu}, \alpha_{\Delta\nu})$$

instead of $\tau_\nu = \tau_\nu(k_\nu)$. That means: in the monochromatic case we have only to superimpose values of k at different pressures and temperatures, while in the $\Delta\nu$-case we have to superimpose line profiles of different width, as for instance $\alpha_L = \alpha_L(p,T)$. In homogeneous paths the transmission of a line is representable by Lorentz Doppler or Voigt profiles. The question is now, which is the actual atmospheric profile, which results from a superposition of profiles with different width and shapes-depending on the height of the layers - in the real atmosphere. This way van de Hulst [37] has formulated the "problem of calculations over inhomogeneous paths". It has been discussed by GOODY (1964) [19] : As it is known, the Voigt profile results from the convolution of a Lorentz and a Doppler profile (see UNSÖLD [38]), that means, that the multiplication of their Fourier-transforms gives the Fourier transform of the Voigt profile:

$$f(t) = S.u.\exp\left(-\alpha_L.t - \frac{1}{4}\alpha_D^2.t^2\right) \tag{21}$$

where

$f\ (t) = S.u.\exp\ (-\alpha_L .t)$ = Fouriertransform of Lorentz-profile

$f\ (t) = S.u.\exp\ (-\frac{1}{4}\alpha_D^2 .t^2)$ = Fouriertransform of Doppler-profile

The Fourier transform of the actual atmospheric profile, that means, when atmospheric parameters are varying along the optical path, is obtained only by replacing u by an integration then (21) becomes

$$f\ (t) = \int S.\exp\ (-\alpha_L .t - \frac{1}{4}\alpha_D^2 . t^2)\ du \tag{22}$$

This integral may be simulated by the Fourier transform of a Voigt profile

$$f\ (t) = \tilde{S}.\tilde{u}.\exp\ (-\alpha_L .t - \frac{1}{4}\bar{\alpha}_D^2 . t^2) \tag{23}$$

where $\tilde{S}$, $\tilde{u}$ could be called reduced values for an inhomogeneous layer. Comparisons of powers of t from (22) and (23) lead to the Curtis-Godson-approximation or to approximations of other degree and give also a possibility to determine contributions from Lorentz and Doppler profile independently.

The VAN DE HULST technique is the means by which the transformation of line profiles by any atmospheric conditions can be regarded, only by the assumption of dividing the atmosphere into a set of homogeneous paths (numerical integration). The technique would be applicable to our formulations of the problems by using U, V parameters. But it was not to our →

knowledge, while the present calculations were performed, and therefore we only applied the Curtis-Godson approximation, which is an approximation of the VAN DE HULST technique:

(24) $$\tilde{\alpha} = \frac{\int \alpha \cdot dm}{\int dm}$$

is reduced value of the half width, which may be used for inhomogeneous layers of the atmosphere.
With the condition

$$\frac{\alpha}{\alpha_0} = \frac{p}{p_0}$$

equation (24) becomes

(25) $$p_{reduced} = \frac{\int p dm}{\int dm}$$

which is used in the form of equation (3) for numerical calculations. Thus calculations or laboratory measurements of transmission over homogeneous paths become applicable to inhomogeneous paths.

The CURTIS-GODSON approximation might be not always sufficient: VIGROUX and MAYOT [39] have compared laboratory measurements of A_0 at m_0, p_0 with calculations over inhomogeneous paths which give the same value of A_0 for the same total mass p_0. They found that for such calculations a $p_{reduced}$ would be necessary, which deviates remarkably from p_0. However, this has been done for O_3 (9.6 μ band), which has a non uniform distribution in the atmosphere. It would be necessary to check the influence of this approximation on our results, which will be reported here. This could not yet be done.

f) Temperature dependence:

In the search for good spectral regions for inversion experiments the temperature dependence of both, the Planck-function B and the individual transmission functions τ_ν play an essential role, as the integral $\int B_\nu(T)\cdot d\tau(T,p,m)$ has to become inverted, to get information on the vertical distribution of temperatures. Here we will not discuss suitable approximations of the Planck-radiance which are different according to the regarded spectral region, as such approximations can be found. Really unknown are in most cases the temperature dependences of the transmission functions. For the method reported in section a) one needs to know, how the intensity of each line varies with the temperature. It is possible to calculate this for individual lines in the vibration rotation band (see GRAY, SELVIDGE [21]), if the integrated absorptance of the band is known together with a set of spectroscopic constants which must be calculated; especially tabulations of vibrational and rotational partition functions at the interesting temperatures must be available. For the method of section b) it would be necessary to take spectra at a set of different temperatures and derive then the parameters U, V as described and build tables for U and V and interpolate for the actual temperatures.

However, in the 4.5 micron region, the temperature dependence of the Planck-function is very high, see table I:

Table I

T [°K]	$a_\nu(\nu = 4\mu)$	$a_\nu(\nu = 5\mu)$
180-190	19,4	15
270-280	13,0	10
310-320	11,4	9

where $$B_\nu \sim T^{\alpha_\nu}$$

and it is supposed that it is much stronger than the temperature dependence of the transmission functions. So we did not introduce any temperature dependence of transmission functions as we apply the method to the 4.5 micron region.

IV. DIRECT METHOD TO CALCULATE THE OUTGOING RADIATION

The equation of radiative transfer (1), (2) has to be integrated "monochromatically" over the paths in the atmosphere: the width $\Delta\nu$ must be sufficient narrow, so that equation (20) can be applied.

The absorption coefficient is [36]:

$$k_{\nu,a} = \frac{k_o a}{\pi} \int_{-\infty}^{+\infty} \frac{\exp(-y^2)}{a^2 - (\omega - y)^2} \, dy \tag{26}$$

when both, the Doppler effect and Lorentz collision damping contribute to the one width (Voigt profile). It is

$$a = \frac{\alpha_L}{\alpha_D} (\ln 2)^{1/2}, \quad \omega = \frac{\nu - \nu_o}{\alpha_D} (\ln 2)^{1/2}, \quad k_o = \frac{S}{\alpha_D} \left(\frac{\ln^2}{\pi} \right)^{1/2}$$

$$y = \left(\frac{mc^2}{2\,k\,T}\right)^{1/2} \frac{1}{\nu_o} (\nu' - \nu_o), \qquad \nu' = \nu_o \left(1 - \frac{v_x}{c}\right),$$

v_x = velocity of the molecules, for further definitions see section III c).

It seems not easy to integrate for the range of a and ω which would apply to a planetary atmosphere [35] . Recent tabulations of the integral (26) exist from Ch. Young for selected values of ω and a.

The advantage of the direct method is, that one avoids difficulties with inhomogeneous path calculations (see section d)). The disadvantage: If there is to introduce any correction to the obtained transmission by changing a basic parameter, for instance the mixing ratio or temperature distribution or slit function, one has to start from the very beginning. This task is tremendeous for lower resolution (5 cm^{-1}) and not at least adequate for inversion procedures. The method is really clumsy. Besides very often the basic data are not known accurately enough [45] . This is another important disadvantage.

V. MODEL CONDITIONS

a) Radiance from soil and clouds.

Investigations on the derivation of emissivities from NIMBUS - I - HRIR measurements have becoming undertaken by BÜTTNER and co-workers [40] . Radiance spectra of clouds have been measured by BLAU, ESPINOLA and co-workers [41] . But these measurements were taken only between 2.4 to 3.8,and 2.2 to 2.4, and 2.7 to 2.9, and 1.2 to 2.4 microns. MARLATT [42] and SALOMONSON [43] have derived from radiation temperature measurements, taken by airplane, the emissivity and reflectivity of soil (Prawnee National Grassland) and over clouds. The spectral intervals were 0.2 to 4.0 and 0.55 to 0.85 microns, and 8 to 12 microns. Their measurements have been applied by R. E. SAMUELSON [44] in comparisons with interpretations of NIMBUS -I- HRIR satellite measurements.

There were some slight differences between emissivities after MARLATT and those after SAMUELSON. It will be investigated in this paper, whether atmospheric absorption might account for such discrepancies.

HAVARD [12] has performed theoretical calculations on albedo = a and transmission = τ of clouds with different particle size for varying cloud thickness l and water content w. From these theoretical results we have now derived emissivities (which are given in table II) by the relation $\varepsilon = 1 - a - \tau$. For the present claculations between 3.4 to 4.2 microns we shall use some of those values:

Thick cloud ($w.l = m \geqslant 6.25\ gr/m^2$) : $\varepsilon = 0.8167$
Middle cloud ($w.l = m = 1,50\ gr/m^2$) : $\varepsilon = 0.7631$
where droplet radius r = 6 microns and HAVARD'S wavelength $\lambda = 3.6$ microns.

b) Vertical structure and mixing ratios.

All calculations have been performed on the basis of the US-Standard-Atmosphere 1962 [44] . We have divided the atmosphere into 50 layers. The numerical values of this division are given in table XII in the appendix, together with the water vapor distribution and total amount.

We have adopted uniform mixing ratios for the gases N_2O, CO_2, CO, CH_4. As it is still uncertain which are the most probable values, we have checked the influence of the amount of gases on the outgoing radiation (see results section VI). Table III gives a range of probable mixing ratios, and the resulting total amounts of gases between 0 and 31 km. The mass of each absorbing gas between two atmospheric levels is calculated by ⟶

Table II

Emissivity of Clouds

r = droplet radius [microns]. λ = wavelength (micron)
w = water content of the cloud [g / cm^3], l = cloud thickness [m]
ε = emissivity. a = albedo

	$r = 6$ $\lambda = 3,6$ $w = 0,1$		$r = 6$ $\lambda = 3,6$ $w = 0,25$		$r = 3$ $\lambda = 3,6$ $w = 0,1$		$r = 3$ $\lambda = 3,6$ $w = 0,25$		$r = 6$ $\lambda = 4,6$ $w = 0,1$	
l	ε	a	ε	a	ε	a	ε	a	ε	a
10	0,124	0,816	0,280	0,606	0,149	0,650	0,321	0,366	0,095	0,817
20	0,232	0,669	0,471	0,372	0,271	0,441	0,492	0,148	0,241	0,612
30	0,324	0,549	0,597	0,229	0,366	0,304	0,572	0,061	0,257	0,556
40	0,404	0,452	0,679	0,142	0,438	0,212	0,606	0,025	0,323	0,462
50	0,471	0,372	0,731	0,088	0,492	0,148	0,621	0,010	0,381	0,385
100	0,679	0,142	0,809	0,008	0,606	0,025	0,630	0,001	0,573	0,157
150	0,763	0,054	0,816	0,001	0,627	0,004	0,631	0,000	0,659	0,064
200	0,789	0,028	0,817	0,000	0,630	0,001	0,631	0,000	0,696	0,026
250	0,809	0,008	0,817	0,000	0,631	0,000	0,631	0,000	0,711	0,011
300	0,814	0,003	0,817	0,000	0,631	0,000	0,631	0,000	0,717	0,004
350	0,816	0,001	0,817	0,000	0,631	0,000	0,631	0,000	0,720	0,002
400	0,816	0,000	0,817	0,000	0,631	0,000	0,631	0,000	0,721	0,001
450	0,817	0,000	0,817	0,000	0,631	0,000	0,631	0,000	0,721	0,000
500	0,817	0,000	0,817	0,000	0,631	0,000	0,631	0,000	0,722	0,000

Table II continued

Emissivity of Clouds

r = droplet radius [microns], λ = wavelength (micron)
w = water content of the cloud, [g / cm^3], l = cloud thickness [m]
ε = emissivity, a = albedo

	$r = 6$ $\lambda = 4{,}6$ $w = 0{,}25$		$r = 6$ $\lambda = 7{,}0$ $w = 0{,}1$		$r = 6$ $\lambda = 7{,}0$ $w = 0{,}25$		$r = 6$ $\lambda = 8{,}5$ $w = 0{,}1$		$r = 6$ $\lambda = 8{,}5$ $w = 0{,}25$	
l	ε	a	ε	a	ε	a	ε	a	ε	a
10	0,220	0,611	0,152	0,773	0,334	0,530	0,147	0,799	0,325	0,573
20	0,381	0,384	0,279	0,600	0,539	0,286	0,271	0,640	0,533	0,323
30	0,495	0,244	0,384	0,468	0,658	0,155	0,375	0,513	0,660	0,193
40	0,573	0,156	0,470	0,366	0,726	0,084	0,461	0,413	0,737	0,112
50	0,625	0,100	0,539	0,286	0,763	0,046	0,533	0,332	0,783	0,065
100	0,703	0,018	0,726	0,084	0,807	0,002	0,737	0,112	0,843	0,004
150	0,720	0,001	0,784	0,025	0,809	0,000	0,810	0,038	0,847	0,000
200	0,722	0,000	0,801	0,007	0,809	0,000	0,834	0,013	0,847	0,000
250	0,722	0,000	0,807	0,002	0,809	0,000	0,843	0,004	0,847	0,000
300	0,722	0,000	0,808	0,001	0,809	0,000	0,846	0,002	0,847	0,000
350	0,722	0,000	0,809	0,000	0,809	0,000	0,847	0,001	0,847	0,000
400	0,722	0,000	0,809	0,000	0,809	0,000	0,847	0,000	0,847	0,000
450	0,722	0,000	0,809	0,000	0,809	0,000	0,847	0,000	0,847	0,000
500	0,722	0,000	0,809	0,000	0,809	0,000	0,847	0,000	0,847	0,000

Table III

Mixing Ratios [cm^3/m^3] and Total Amount [atm - cm] of Minor Constituents in the Earth Atmosphere between 1013 to 10 Millibars.

	CO_2	CO	N_2O	CH_4
Mixing Ratios				
a) US-Standard-Atmosphere 1962	314	0,2	0,5	2,0
b) Tannhäuser, Raschke [9]	313	0,2	0,3	1,4
c) Gray, Mc Clatchey [26]	-	-	-	-
Total Amount				
a) US-Standard Atmosphere 1962	246,7	0,158	0,393	1,58
b) Tannhäuser, Raschke [9]	246,2	0,158	0,236	1,11
c) Gray, Mc Clatchey [26]	256	-	0,22	-

$dm_{i,g} = \rho_{i,g} \cdot dz$ definition of the mass of a layer

$dz = \frac{dp}{g \cdot \rho_{i,L}}$ barometric formula

$\frac{\rho_{i,g}}{\rho_{i,L}} = c_v \circ \frac{M_g}{M_L}$ definition of volume-mixing-ratio between two levels

usually the mass per surface (dm_g) in gr/cm^2 is given by the height in cm of a column over this surface; for this purpose $dm_{i,g}$ has to be divided by the density of the gas at normal conditions:

$dm_{i,g}$ $[gr/cm^2]$ $du_{i,g} = \frac{dm_{i,g}}{\rho_{o,g}}$ [cm = atm - cm]

then one obtains, by using $\rho_g = \frac{M_g}{22,4}$

$$du_{i,g} = \frac{c_i \circ 22,4 \cdot dp}{g \cdot 28,966} \quad [\text{atm - cm}]$$

z = height, p = pressure, ρ = density, c_v = volume-mixing-ratio,
M = molecular weight, 28,966 = molecularweight of dry air,
g = gravity acceleration = 981 (cm/sec^2), 22,4 volume of one mol.
u and m are absorber masses,
subscribt i counts the atmospheric levels
subscribt g says "gas"
subscribt l says "air"
subscribt o says at normal conditions.

VI. DISCUSSIONS AND RESULTS

a) Derived from the empirical method (II).

For the NIMBUS-I-HRIR region we have calculated the equivalent temperatures of the outgoing radiation for clouds of different height and emissivity. The results are given in table IV. The influence of the single atmospheric minor constituents is given as well as the influence of combinations of these constituents, which are CH_4, CO_2, N_2O. If they would be neglected, an error would occur, which ranges from 4.5 to 0.2 degree Kelvin, depending on cloud height and emissivity and the regarded gases. So we may conclude, that the discrepancies between MARLATT's and SAMUELSON's [44] findings in the determination of cloud top temperatures can be caused by the neglected influence of the atmospheric minor constitutents. As mentioned in section V a, SAMUELSON has compared cloud top temperatures derived from NIMBUS-I-HRIR measurements with aircraft measurements of MARLATT, without considering atmospheric absorption. Our table IV could be used as guide for corrections for atmospheric absorption in actual cases.

In our calculations the filter function of the HRIR instrument has been included (see section II a). No calculations have been done without water vapor influence on the outgoing radiation. However, from 500 millibars upwards, the transmission of water vapor is higher than 0.988, so water vapor may be neglected if clouds are higher than 500 millibars. But using an emissivity of $\varepsilon = 0.76$, the gases CO_2, CH_4, N_2O have still an influence of about 1.6 $^{\circ}K$.

The influence of minor constituents in the 7.25 to 7.75 micron hypothetical channel are given in table V. If N_2O and CH_4 would be neglected against H_2O an error of about 9 degrees

Table IV.

Influence of Atmospheric Minor Constituents on the Outgoing Radiation (Equivalent Temperature) Between 3.4 to 4.2 Microns.

h [km] = height of the emitting level, T [°K] =equivalent temperature,

ε = emissivity of the emitting level. The regarded gases are given in brackets following T. In the brackets following to Δ T those gases are given which are responsible for the temperature difference Δ T. Example: $\Delta T\ (CO_2,\ CH_4) = T\ (H_2O,\ CO_2,\ CH_4) - T\ (H_2O)$

	h	$T\ (H_2O)$	$T\begin{Bmatrix}H_2O\\CO_2\end{Bmatrix}$	$T\begin{Bmatrix}H_2O\\CO_2\\CH_4\end{Bmatrix}$	$T\begin{Bmatrix}H_2O\\CO_2\\CH_4\\N_2O\end{Bmatrix}$	$\Delta T(CO_2)$	$\Delta T\begin{Bmatrix}CO_2\\CH_4\end{Bmatrix}$	$\Delta T\begin{Bmatrix}CO_2\\CH_4\\N_2O\end{Bmatrix}$
ε = 1,0	0,00	268,1	266,4	265,6	263,6	1,7	2,5	4,5
	1,05	262,6	261,1	260,4	258,7	1,5	2,2	3,9
	2,65	253,8	252,6	252,1	250,7	1,2	1,7	3,1
	5,15	239,7	238,9	238,6	237,7	0,8	1,1	2,0
	8,50	220,3	220,0	219,9	219,5	0,3	0,4	0,8
ε = 0,8167	0,00	264,6	263,0	262,4	260,5	1,6	2,2	4,1
	1,05	259,1	257,7	257,1	255,6	1,4	2,0	3,5
	2,65	250,4	249,4	248,9	247,7	1,0	1,5	2,7
	5,15	236,6	236,0	235,6	234,9	0,6	1,0	1,7
	8,50	217,8	217,5	217,4	217,1	0,3	0,4	0,7
ε = 0,7631	0,00	263,4	262,0	261,3	259,6	1,4	2,1	3,8
	1,05	257,9	256,7	256,1	254,6	1,2	1,8	3,3
	2,65	249,3	248,3	247,8	246,7	1,0	1,5	2,6
	5,15	235,6	235,0	234,7	234,0	0,6	0,9	1,6
	8,50	216,9	216,7	216,5	216,3	0,2	0,4	0,6

Table V

Influence of Atmospheric Minor Constituents on the Outgoing Radiation Between 7.25 to 7.75 Microns in Terms of the Equivalent temperature T [°K]

The regarded gases are given in brackets following the equivalent temperatures T. In the brackets following Δ T those gases are given, which are responsible for the temperature difference Δ T. Mixing ratios from table III have been used. Case I Table III, b)
Case II Table III,a)

		case I	case II
(1)	T (H_2O)	269,8	269,8
(2)	T (H_2O, N_2O)	267,7	267,0
(3)	T (H_2O, CH_4)	264,1	262,5
(4)	T (H_2O, N_2O, CH_4)	262,6	261,0
Δ T (N_2O)	= (1) - (2)	2,1	2,8
Δ T (N_2O)	= (4) - (3)	1,5	1,5
Δ T (CH_4)	= (1) - (3)	5,7	7,3
Δ T (CH_4)	= (2) - (4)	5,1	6,0
Δ T (CH_4,N_2O)	= (1) - (4)	7,2	8,8

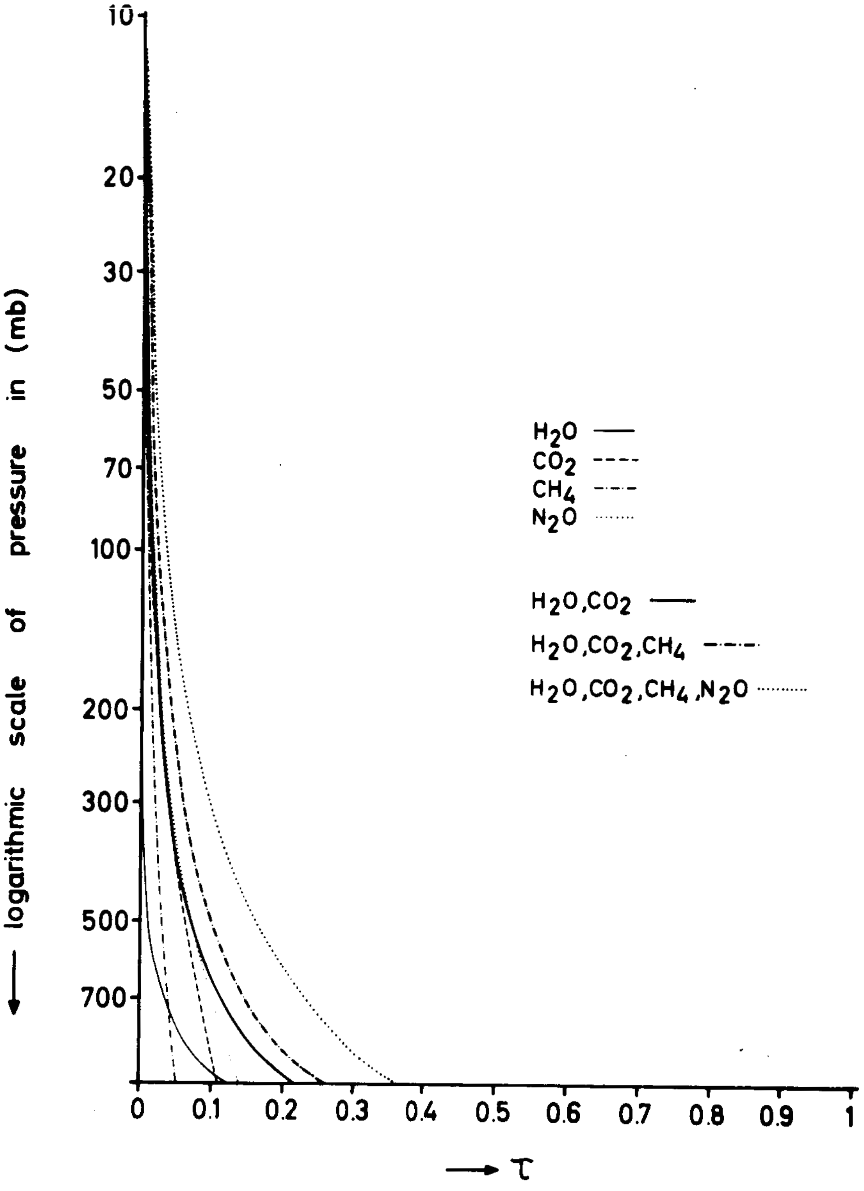

Fig. 6

Transmission of layers with growing thickness, starting from 10 mb pressure level to the earth surface. The influence of different gases is given. Spectral region: 7.25 - 7.75 microns.

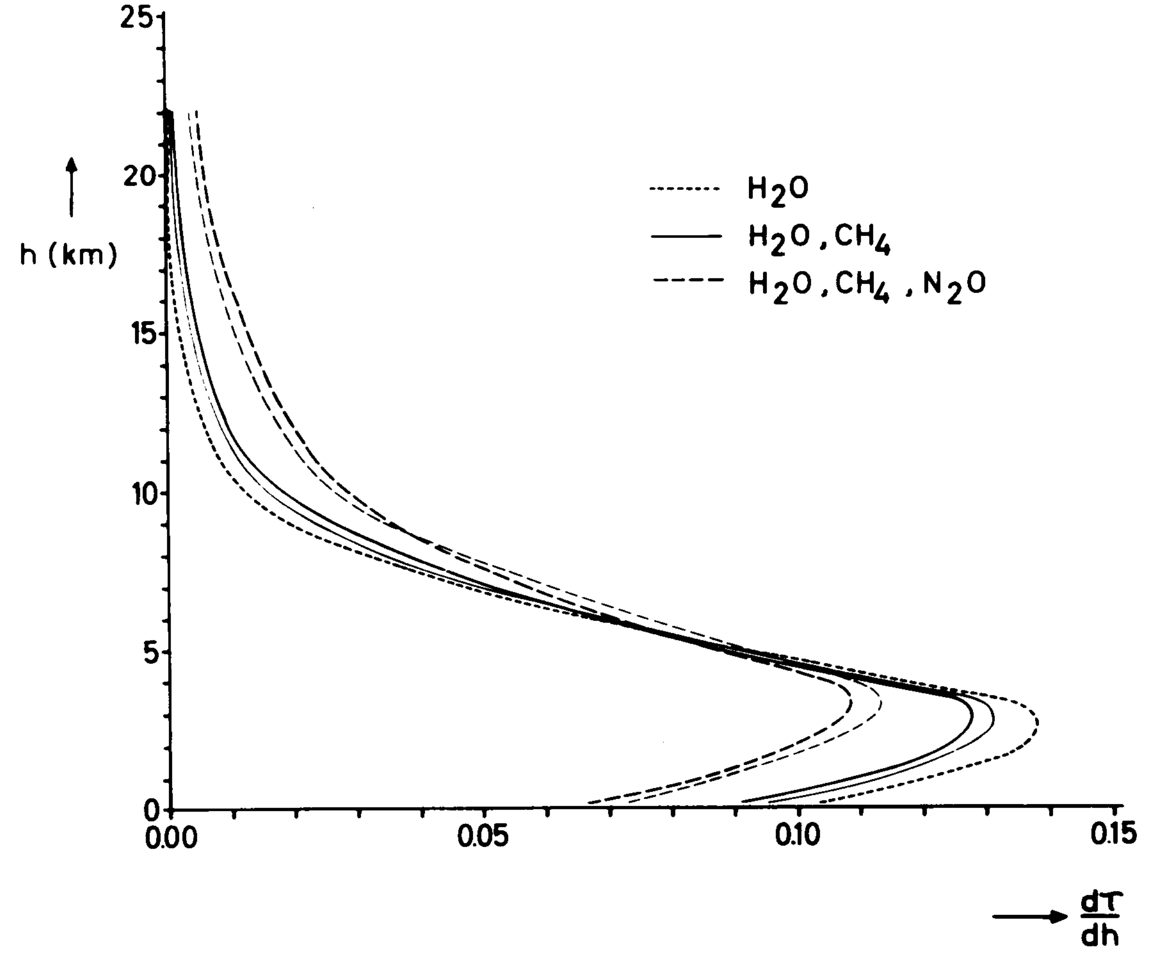

Fig. 7

Weighting functions between 7.25 to 7.75 microns (wing of the 6.3 micron H_2O-band), calculated for different mixing ratios,

thin lines : mixing ratios according to table III, b)
thick lines : mixing ratios according to table III, a)

Kelvin could occur. That means, that measurements from this channel must be corrected if they should be used for determinations of the relative humidity of the troposphere.

The influence of CH_4 and N_2O on the vertical distribution of transmissions weighting functions is given in fig. 6 and 7. If these gases are neglected against H_2O, the maximum is shifted about 1 km downwards.

The results of the empirical method can only be regarded as very rough illustration for the conditions to be expected, as the author has shown formerly [9] .

b) Derived from band model calculations.

In fig. 1 we have compared our results with those from GRAY and McCLATCHEY [26] for the spectral region between 2190 to 2290 cm^{-1}. Here the bands of the gases CO_2, N_2O and CO are considered in the calculation. In this comparison we have used the same atmospheric models and the same mixing ratios as these authors. Though their curve ("GRAY ") of the outgoing radiation has the same general course like ours (curve 1), it is evident, that there exists still a relative high difference in the absolute values to be expected: the differences are at several frequencies higher than 8 degrees in terms of equivalent temperatures. Possible reasons for such discrepancies are:

1) different band model principle (see section III), that means differently derived band model parameters. For further investigations we suggest to make comparisons between their and our parameters, which would be possible by adequate formulations.

How seriously erroneous transmission functions can influence the outgoing radiation, can be seen from the example in figure 8, and will be discussed in more detail elsewhere [16] .

2) We have divided the atmosphere into 50 layers, while GRAY, McCLATCHEY used only 7 layers.

3) Inadequate consideration of the slit function (see section III).

While the influence of point 2) could easily be looked over, 1) shows, that transmission functions need to be handled with utmost care and that they contain still problems which must be investigated; consequences for the height of the maxima of weighting functions, which are important for inversion problems,will be discussed elsewhere [16] .

We expect, that the influence of point 3) will be very important, too: GRAY, McCLATCHEY have superimposed a slit-function to their calculations (curve S in figure 1). It is somewhat surprising, that their curve without slit-function shows less spectral structure than our corresponding curve 1, which already contains the slit-influence. We expect, that our solution of the ~~s~~plit-problem - which uses parameters from laboratory experiments with the same slit function as the satellite instrument, - is advantageous. This can be concluded from our recalculations of laboratory spectra which we approximate quite well, see fig. 7 for CO and ref. [16] for CO_2 and N_2O.

Additionally we have to point out, that there exist still uncertainties in the mixing ratio of the minor constituents. Values of these mixing ratios, which are in the expected range, are given in table II. The influence of these values is of the

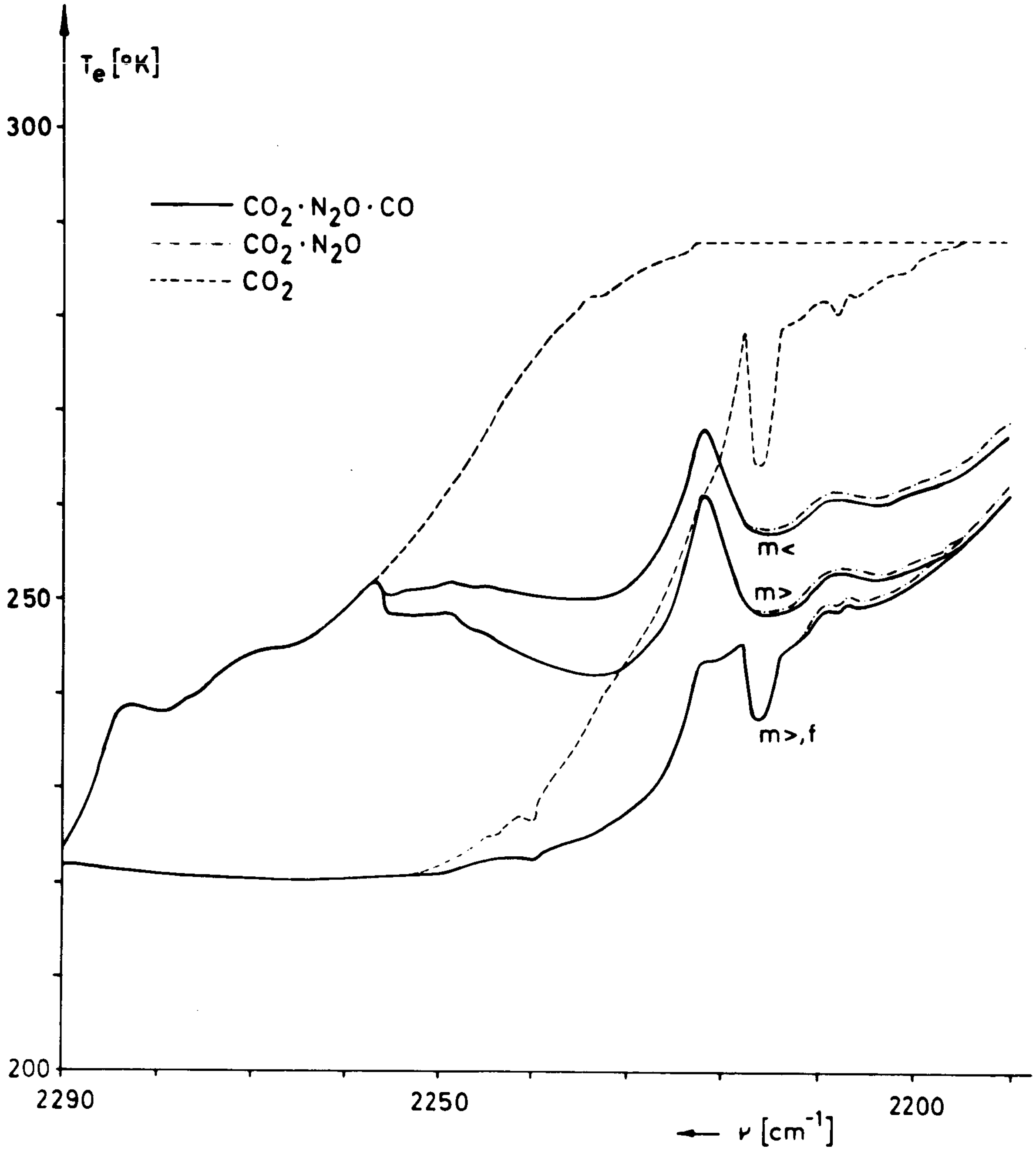

Fig. 8

Outgoing radiation at 10 mb (in terms of the equivalent temperature T_e) as function of the wave number ν. The influence of different mixing ratios and of the transmission function is shown.

m < : mixing ratios from table III b
m > : mixing ratios from table III a (smaller than from table III b),
m >, f " " " " and erroneous transmission parameters.

same order of magnitude as the one between different ways of calculation or of erroneous absorption coefficients, as may be seen from fig. 1 and fig. 8. A good illustration for this fact is given in fig. 9, where the vertical distribution of the transmission of the atmosphere for different conditions of some parameters is presented. At the wavenumber $\nu_0 = 2240\ \mathrm{cm}^{-1}$ the gas N_2O alone gives the same distribution as N_2O and CO_2 together, if another N_2O mixing ratio is adopted.

An example for the influence of bad absorption functions on the vertical distribution of the atmospheric transmission is shown in figure 9.

In our investigations we have used the experimental transmission spectra from A. LEUPOLT [4] . Generally they show slight deviations from those of BURCH [14] , [15] ; these differences cannot always be explained by the different spectral resolution, see for instance figure 3. We should point out, that LEUPOLT could measure with the original instruments of BURCH at the OHIO - State University, by the obligingness of Prof. J. H. SHAW. The difference of the results (see also [16]), which comes to light by our curve of growth representation, shows the difficulty to obtain "true" transmission functions. This fact influences the results from GRAY, McCLATCHEY as well as ours; there the total band absorption, which must be taken from experiments, enters the calculation - and it should be investigated, how an error from this quantity influences the final result - and here the parameters at each wave-number could be provided with an individual error.

So far we have given examples for the 4.5 micron region. Of course, in principle the method is also applicable to other spectral regions, as for instance the NIMBUS I HRIR region and the long wave length wing of the 6.3 micron H_2O band.

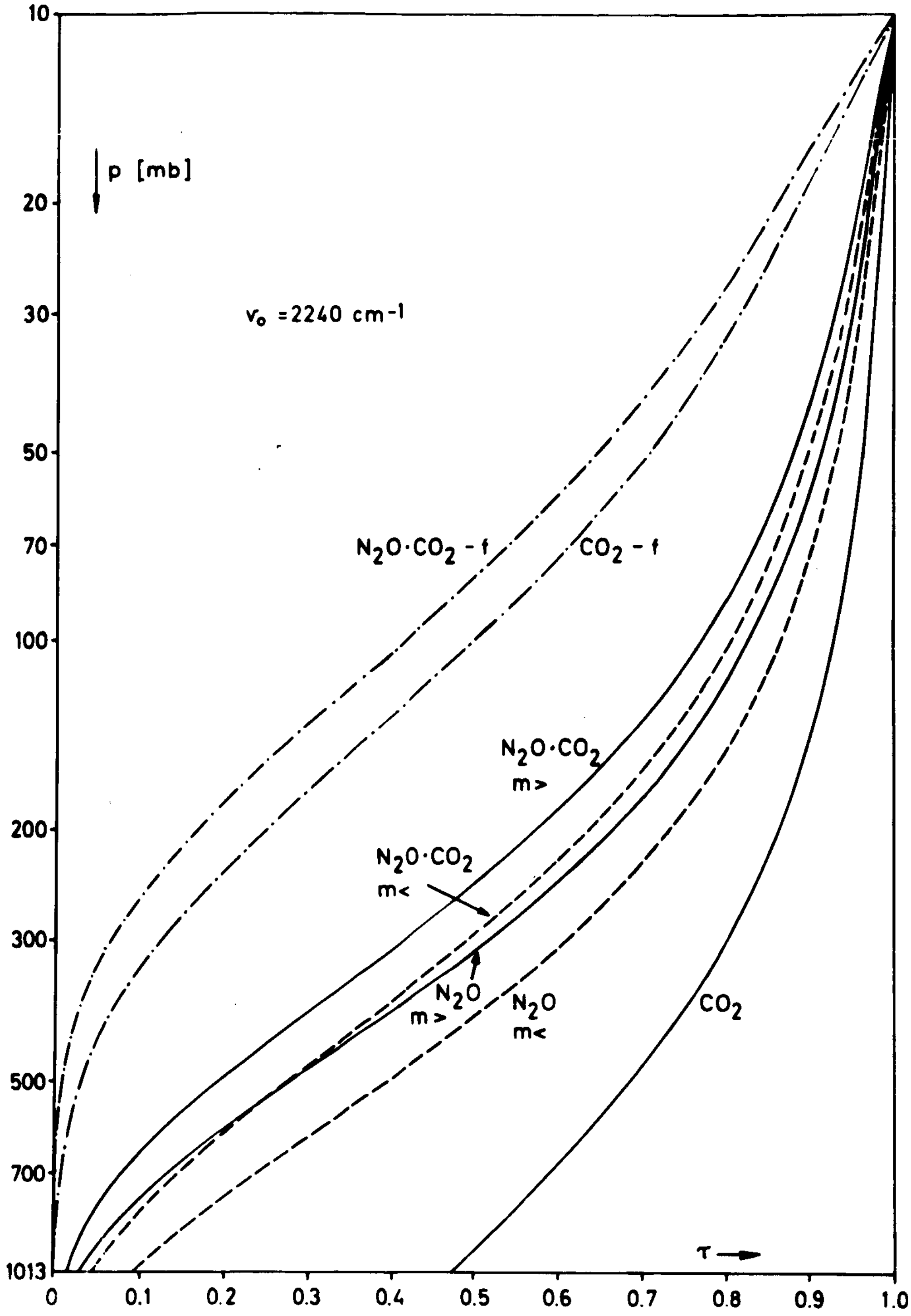

Fig. 9

Transmission of layers with growing thickness, starting from 10 mb pressure level to the earth surface, at the wave number 2240 cm^{-1}. The influence of different mixing ratios of the single gases, the overlapping effect of the bands of several gases and the effect of a wrong CO_2-transmission are shown.

m < : mixing ratios from table III b
m > : mixing ratios from table III a, (smaller than from table IIIb)
f : mixing ratios from table III a, and wrong CO_2-transmission-parameters

This may be seen from figures 10, 11, 12, 13, where we give sets of curves of growth for the 6.3 water vapor band, 3020 CH_4 band, 2563/2461 N_2O band, 1306/1550 CH_4 band. To get the necessary data, we have digitized the spectra of BURCH [14] , [15] . It can be seen, that it is nearly impossible to construct asymptotes, so that the parameters must be derived from a direct fit, as we have applied at the LEUPOLT measurements.

VII. CONCLUSIONS

Apart from the meteorological information contents and from the experimental possibilities the selection of spectral intervals for inversion experiments needs a realistic theory. The above discussed uncertainty of some parameters in atmospheric transmission calculations determines to what degree the interpretation of data of measured radiation will be realistic. It is therefore necessary to improve the accuracy of these parameters by useful coordinated experimental and theoretical investigations. This results especially from the discussion in section VI b).

VIII. ACKNOWLEDGEMENT

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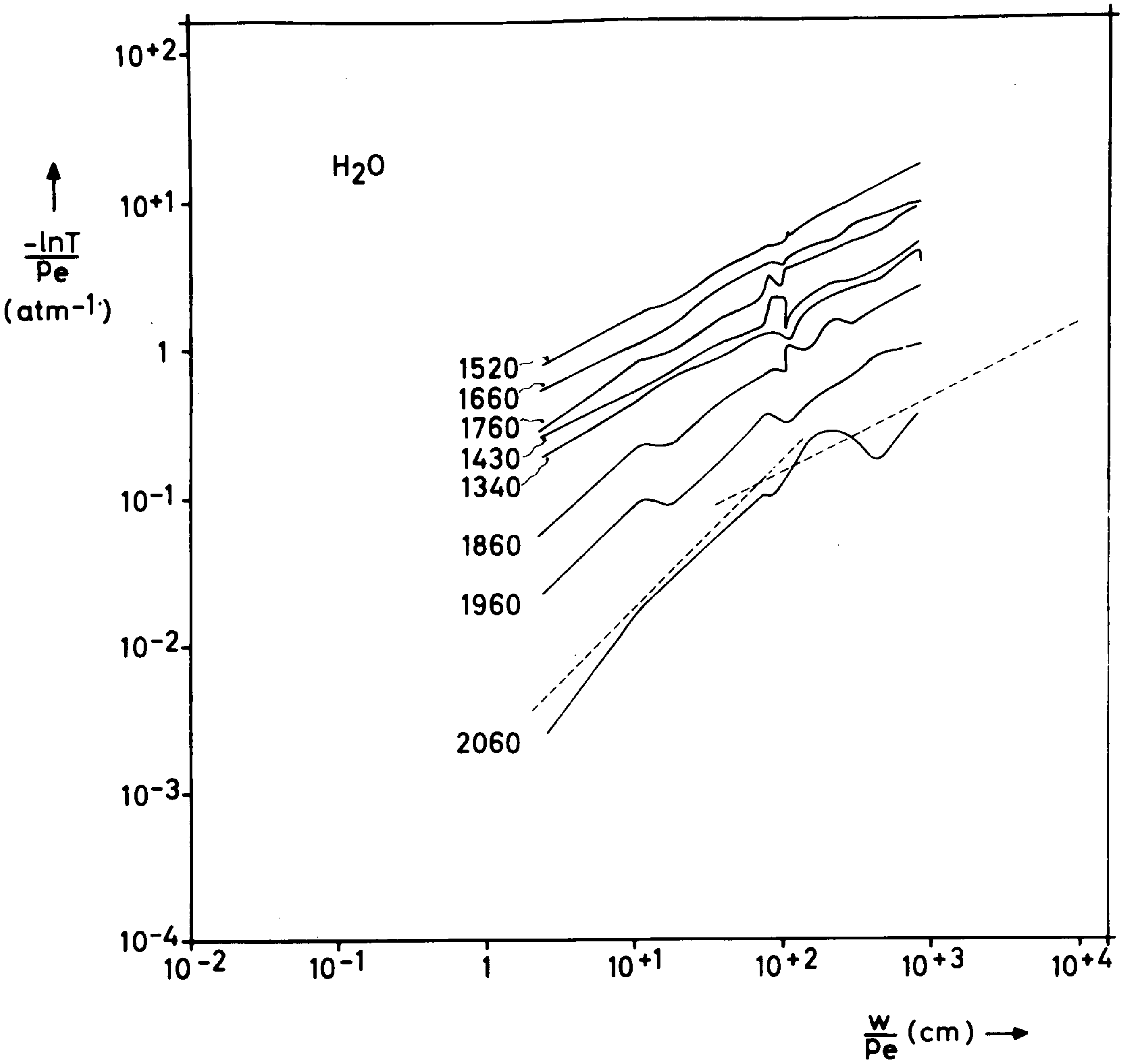

Fig. 10

Curves of growth for different wave-numbers in the 6.3 micron H_2O band, (data from BURCH'S measurements). T = transmission; ---- = attempt to draw asymptotes. The curves have been plotted by means of an electronic computer which could not make single points. Therefore the identations are caused by the scattering of the measured values.

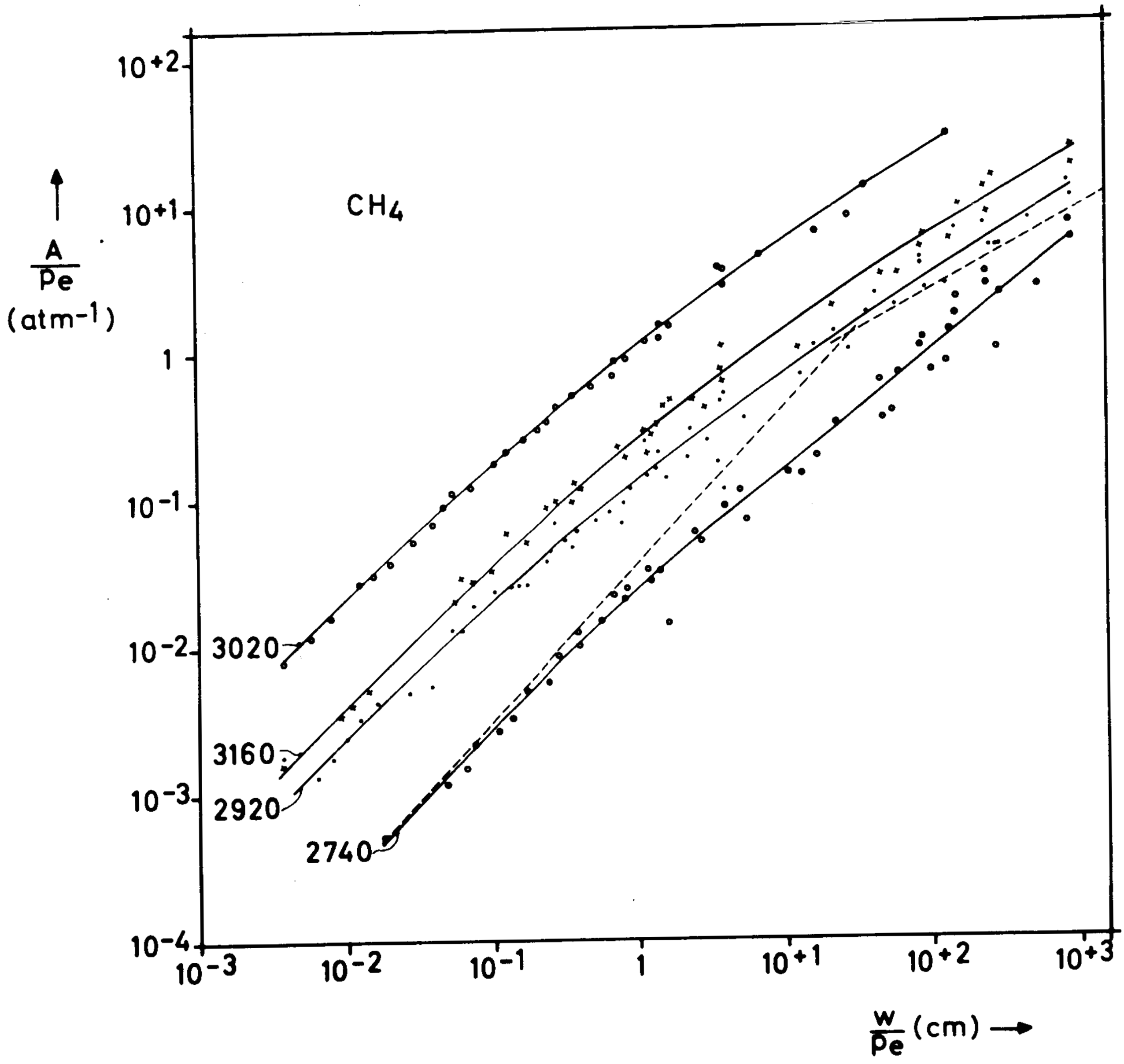

Fig. 11

Curves of growth for different wavenumbers in the 3020 CH_4 band. ---- = attempt to draw asymptotes.

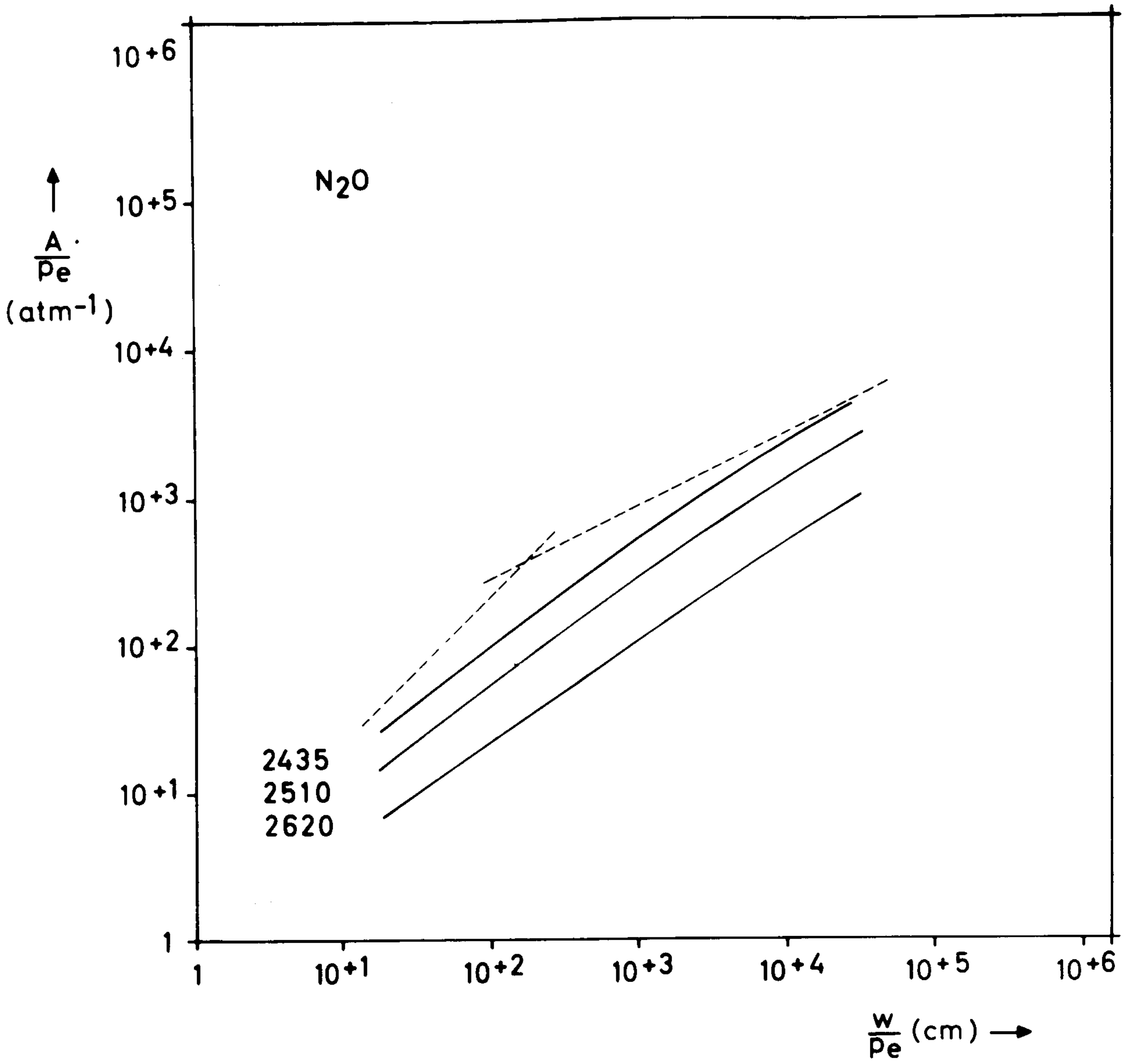

Fig. 12

Curves of growth for some wave-numbers in the 2563/2461 N_2O - bands. ---- = attempt to draw asymptotes.

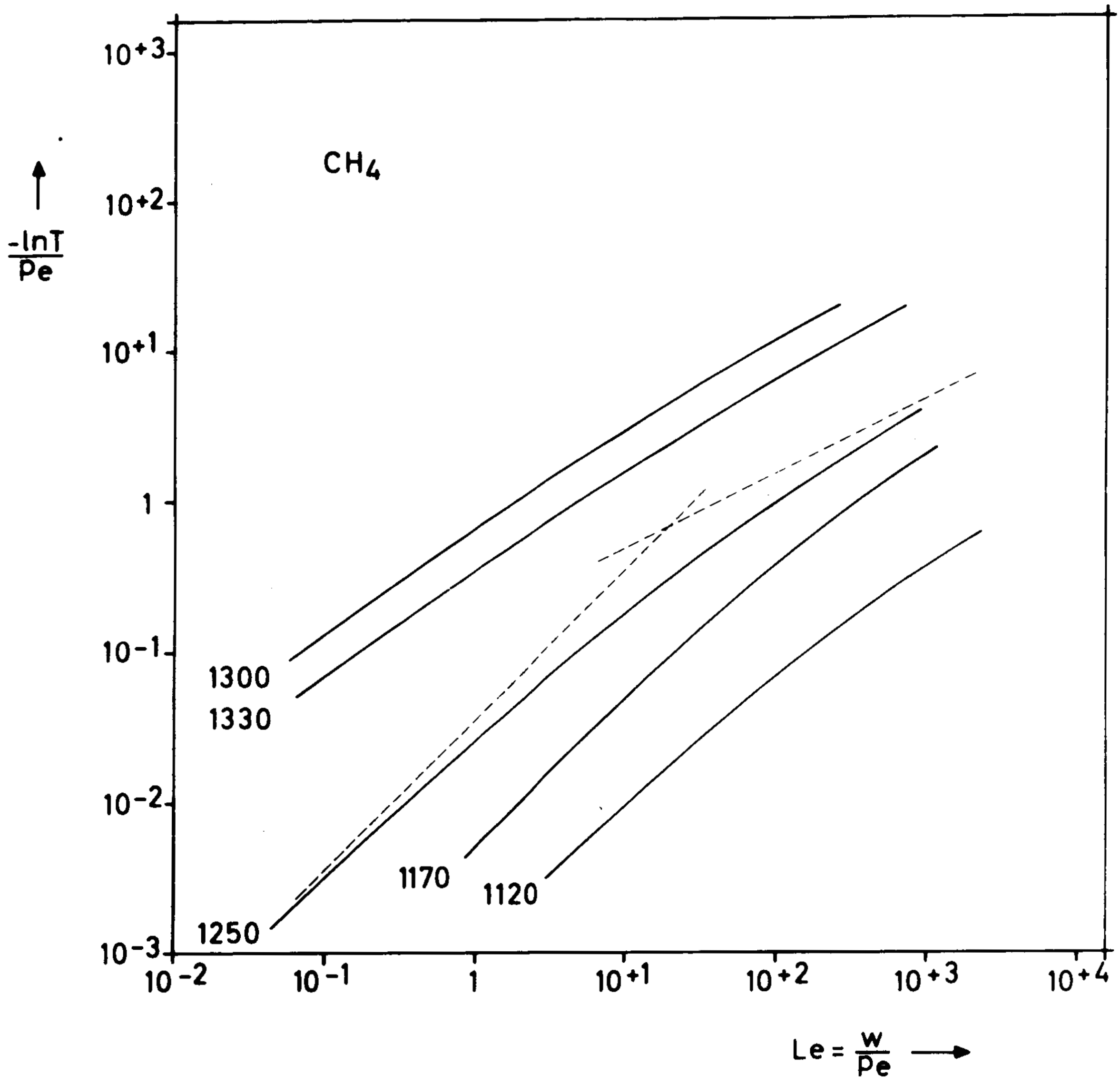

Fig. 13

Curves of growth for some wave-numbers in the 1306/1550 CH_4 - bands. ----- = attempt to draw asymptotes.

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APPENDIX

Table VI.

Integrated Absorptance of 7.8 Micron N_2O-Band at Room-Temperature after GOODY and WORMELL

p [Torr] = pressure, u [atm-cm] = absorber mass, V_i [flash-numbers] = recording of integrated band absorption.

The table values are: $V_i = {}^{10}\log A_i$

u \ p	10,000	15,849	25,119	39,810	63,096	100,000	158,490	251,190	398,100	630,960
3.1900	+0,02	+0,08	+0,17	+0,23	+0,29	+0,34	+0,38	+0,42	+0,46	+0,47
2.0121	-0,07	-0,01	+0,08	+0,25	+0,22	+0,27	+0,32	+0,38	+0,42	+0,43
1.26997	-0,17	-0,10	-0,02	+0,06	+0,12	+0,20	+0,26	+0,32	+0,35	+0,38
0.80131	-0,26	-0,18	-0,11	-0,04	+0,04	+0,11	+0,17	+0,24	+0,29	+0,33
0.50556	-0,38	-0,30	-0,22	-0,15	-0,06	+0,01	+0,08	+0,15	+0,22	+0,26
0.31900	-0,48	-0,39	-0,32	-0,24	-0,17	-0,09	-0,03	+0,05	+0,11	+0,16
0.20121	-0,58	-0,51	-0,43	-0,36	-0,28	-0,20	-0,14	-0,07	0,00	+0,05
0.126997	-0,69	-0,62	-0,54	-0,47	-0,39	-0,32	-0,25	-0,19	-0,14	-0,11
0.080131	-0,81	-0,74	-0,67	-0,60	-0,52	-0,45	-0,38	-0,32	-0,28	-0,23
0.050556	-0,92	-0,86	-0,78	-0,71	-0,64	-0,53	-0,51	-0,46	-0,43	-0,40
0.031900	-1,05	-0,98	-0,91	-0,84	-0,77	-0,72	-0,67	-0,62	-0,58	-0,56
0.020121	-1,16	-1,10	-1,03	-0,98	-0,92	-0,87	-0,82	-0,77	-0,76	-0,75
0.0126997	-1,27	-1,22	-1,16	-1,10	-1,06	-1,01	-0,98	-0,95	-0,93	-0,93
0.0080131	-1,38	-1,33	-1,28	-1,24	-1,20	-1,17	-1,16	-1,14	-1,12	-1,13
0.0050556	-1,49	-1,44	-1,40	-1,37	-1,35	-1,33	-1,33	-1,32	-1,31	-1,31
0.0031900	-1,60	-1,56	-1,52	-1,51	-1,50	-1,49	-1,49	-1,48	-1,48	-1,49

Table VII

Integrated Absorptance of 2563 cm^{-1} N_2O - Band at Room Temperature after Reference [14]

p [mm Hg] = pressure, u [atm - cm] = absorber mass, A_{band} [cm^{-1}] = integrated absorptance

p \ u	0,004	0,0045	0,005	0,0055	0,006	0,0065	0,007	0,0075	0,008	0,0085	0,009	0,0095	0,010	0,012
10	0,110	0,125	0,140	0,150	0,165	0,175	0,185	0,190	0,200	0,215	0,225	0,240	0,250	0,280
40	0,130	0,150	0,160	0,180	0,195	0,210	0,220	0,230	0,250	0,265	0,280	0,300	0,310	0,370
100	0,138	0,158	0,170	0,190	0,210	0,220	0,235	0,250	0,270	0,290	0,300	0,320	0,340	0,400
250	0,140	0,160	0,180	0,200	0,220	0,230	0,250	0,265	0,290	0,300	0,320	0,345	0,360	0,440
760	0,145	0,170	0,190	0,210	0,230	0,250	0,270	0,290	0,305	0,335	0,350	0,385	0,400	0,490

p \ u	0,014	0,016	0,018	0,020	0,025	0,030	0,035	0,040	0,045	0,050	0,055	0,060	0,065	0,070
10	0,320	0,350	0,400	0,435	0,510	0,600	0,690	0,750	0,800	0,850	0,950	1,000	1,050	1,100
40	0,430	0,480	0,550	0,600	0,710	0,850	0,970	1,050	1,100	1,200	1,300	1,400	1,500	1,150
100	0,470	0,530	0,600	0,700	0,840	1,000	1,100	1,200	1,360	1,500	1,600	1,800	1,900	2,000
250	0,500	0,600	0,670	0,750	0,950	1,200	1,400	1,500	1,600	1,800	1,900	2,100	2,250	2,400
760	0,570	0,640	0,750	0,850	1,100	1,250	1,600	1,700	1,800	2,100	2,300	2,500	2,700	2,900

p \ u	0,075	0,080	0,085	0,090	0,095	0,100	0,120	0,140	0,160	0,180	0,200	0,250	0,300	0,350
10	1,150	1,200	1,270	1,350	1,400	1,450	1,650	1,800	2,000	2,200	2,300	2,650	3,000	3,400
40	1,700	1,800	1,870	2,000	2,050	2,200	2,400	2,700	3,000	3,350	3,500	4,000	4,600	5,000
100	2,100	2,300	2,400	2,500	2,600	2,700	3,150	3,500	4,000	4,400	4,700	5,500	6,400	7,000
250	2,500	2,700	2,900	3,000	3,200	3,300	3,900	4,400	5,000	5,500	6,000	7,300	8,450	9,000
760	3,200	3,400	3,600	3,900	4,000	4,300	5,000	5,700	6,500	7,250	8,000	9,500	11,500	12,500

Table VII continued

Integrated Absorptance of 2563 cm^{-1} N_2O - Band at Room Temperature after Reference [14]

p [mm Hg] = pressure, u [atm - cm] = absorber mass, A_{band} [cm^{-1}] = integrated absorptance

p \ u	0,40	0,45	0,50	0,55	0,60	0,65	0,70	0,75	0,80	0,85	0,90	0,95	1,00
10	3,75	4,00	4,20	4,50	4,80	4,90	5,00	5,40	5,50	5,80	6,00	6,20	6,40
40	5,50	5,90	6,20	6,50	7,00	7,20	7,50	7,80	8,00	8,30	8,50	8,70	9,00
100	7,50	8,20	8,60	9,25	10,00	10,10	11,00	11,50	11,90	12,10	12,70	13,00	13,20
250	10,00	11,00	12,00	12,90	13,70	14,00	14,80	15,20	16,00	16,20	17,00	17,50	18,00
760	14,00	15,00	16,00	17,00	18,00	19,00	20,00	21,00	22,00	22,50	23,50	24,00	25,00

p \ u	1,20	1,40	1,60	1,80	2,00	1,50	3,00
10	7,00	7,50	8,00	8,60	9,25	10,80	12,00
40	10,00	11,00	12,00	12,90	13,50	15,50	17,00
100	14,80	16,00	17,00	18,00	19,00	21,50	24,00
250	19,80	21,00	23,00	25,00	26,50	29,80	32,00
760	27,00	30,00	32,00	34,50	36,00	40,00	44,00

Table VIII

Integrated Absorptance of 2461 cm^{-1} N_2O - Band at Room Temperature, after Reference [14]

p [mmHg] = equivalent pressure, u [atm - cm] = absorber mass, A_{band} [cm^{-1}] = integrated absorptance

p \ u	0,004	0,0045	0,005	0,0055	0,006	0,0065	0,007	0,0075	0,008	0,0085	0,009	0,0095	0,010
10	0,046	0,0510	0,058	0,0640	0,070	0,0750	0,077	0,0820	0,085	0,0900	0,095	0,1000	0,105
40	0,046	0,0510	0,058	0,0640	0,070	0,0750	0,077	0,0820	0,085	0,0900	0,095	0,1000	0,105
100	0,046	0,0510	0,058	0,0640	0,070	0,0750	0,078	0,0840	0,088	0,0930	0,098	0,1050	0,110
250	0,046	0,0510	0,058	0,0640	0,070	0,0750	0,078	0,0840	0,088	0,0930	0,098	0,1050	0,110
760	0,046	0,0510	0,058	0,0640	0,070	0,0750	0,080	0,0860	0,090	0,0950	0,100	0,1100	0,115

p \ u	0,012	0,0140	0,016	0,0180	0,020	0,0250	0,030	0,0350	0,040	0,0450	0,050	0,0550	0,060
10	0,120	0,1400	0,160	0,1750	0,190	0,2250	0,270	0,3100	0,350	0,4000	0,420	0,4500	0,500
40	0,125	0,1400	0,160	0,1750	0,195	0,2300	0,280	0,3200	0,370	0,4100	0,430	0,4600	0,510
100	0,130	0,1500	0,170	0,1800	0,210	0,2500	0,300	0,3500	0,400	0,4400	0,500	0,5400	0,590
250	0,130	0,1500	0,170	0,1950	0,210	0,2600	0,310	0,3700	0,420	0,4700	0,530	0,5700	0,620
760	0,132	0,1600	0,180	0,2050	0,220	0,2850	0,330	0,4000	0,450	0,5000	0,560	0,6000	0,650

p \ u	0,065	0,0700	0,075	0,0800	0,085	0,0900	0,095	0,1000	0,120	0,1400	0,160	0,1800	0,200
10	0,550	0,5600	0,600	0,6200	0,650	0,6800	0,700	0,7400	0,850	0,9500	1,020	1,1200	1,230
40	0,560	0,5700	0,610	0,6300	0,670	0,7000	0,750	0,7800	0,900	1,0200	1,140	1,3000	1,400
100	0,610	0,6700	0,720	0,7600	0,810	0,8500	0,900	0,9200	1,070	1,2300	1,400	1,5200	1,680
250	0,670	0,7300	0,800	0,8500	0,880	0,9500	1,000	1,0200	1,220	1,4200	1,600	1,8000	2,000
760	0,720	0,8000	0,850	0,9000	0,950	1,0000	1,050	1,1000	1,330	1,6000	1,800	2,0000	2,200

Table VIII continued

Integrated Absorptance of 2461 cm^{-1} N_2O Band at Room Temperature, after Reference [14]

p [mm Hg] = equivalent pressure, u [atm - cm] = absorber mass, A_{band} [cm^{-1}] = integrated absorptance

u p	0,25	0,30	0,35	0,40	0,45	0,50	0,55	0,60	0,65	0,70	0,75	0,80	0,85	0,90
10	1,45	1,65	1,80	2,00	2,10	2,25	2,40	2,55	2,65	2,80	3,00	3,05	3,15	3,35
40	1,70	2,00	2,20	2,40	2,50	2,70	2,90	3,00	3,20	3,40	3,50	3,60	3,90	4,05
100	2,00	2,30	2,60	3,00	3,20	3,50	3,80	4,00	4,20	4,50	4,80	5,00	5,20	5,40
250	2,40	2,70	3,00	3,50	3,90	4,20	4,50	4,80	5,00	5,40	5,70	6,00	6,20	6,50
760	2,75	3,20	3,60	4,10	4,50	5,00	5,30	5,70	6,00	6,40	6,70	7,00	7,50	7,85

u p	0,95	1,00	1,20	1,40	1,60	1,80	2,00	2,50	3,00
10	3,45	3,50	4,00	4,35	4,70	5,10	5,50	6,20	7,00
40	4,15	4,20	4,90	5,30	5,80	6,30	6,60	7,60	8,50
100	5,50	5,70	6,50	7,30	8,00	8,60	9,20	10,50	12,00
250	6,80	7,00	8,20	9,00	10,00	11,00	12,00	14,00	16,00
760	8,20	8,50	8,80	11,00	12,00	13,20	14,50	17,00	20,00

Table IX.

Average Transmission $\tau_{\Delta\nu}$ of H_2O Between 129o - 1379 cm^{-1} Calculated from the Plass-Tables [3o]

T [°K] = temperature, u [g/cm] = absorber mass, p [atm] = pressure

T	p \ u	5	2	1	o,5	o,2	o,1	o,o5	o,o2	o,o1	o,oo5	o,oo1
3oo	1,oo	o,o35	o,1o9	o,198	o,3o8	o,494	o,619	o,727	o,834	o,891	o,934	o,983
	o,5o	o,o75	o,179	o,289	o,415	o,581	o,69o	o,779	o,865	o,911	o,944	o,984
	o,2o	o,168	o,3o9	o,429	o,547	o,687	o,772	o,84o	o,9o2	o,934	o,957	o,986
	o,1o	o,266	o,42o	o,536	o,64o	o,756	o,824	o,877	o,925	o,949	o,966	o,988
	o,o5	o,378	o,53o	o,635	o,723	o,815	o,867	o,9o7	o,943	o,962	o,974	o,99o
	o,o2	o,526	o,661	o,744	o,81o	o,875	o,911	o,937	o,961	o,973	o,982	o,993
25o	1,oo	o,o54	o,149	o,26o	o,391	o,569	o,686	o,78o	o,872	o,92o	o,953	o,988
	o,5o	o,11o	o,237	o,359	o,486	o,648	o,746	o,823	o,895	o,932	o,958	o,988
	o,2o	o,223	o,394	o,498	o,612	o,739	o,815	o,871	o,923	o,949	o,968	o,99o
	o,1o	o,331	o,488	o,599	o,696	o,798	o,856	o,9oo	o,94o	o,96o	o,974	o,992
	o,o5	o,446	o,592	o,688	o,767	o,847	o,891	o,924	o,955	o,969	o,98o	o,993
	o,o2	o,59o	o,712	o,784	o,842	o,897	o,927	o,949	o,969	o,979	o,986	o,995
2oo	1,oo	o,o74	o,197	o,327	o,471	o,651	o,761	o,843	o,915	o,95o	o,972	o,993
	o,5o	o,15o	o,3o3	o,438	o,57o	o,722	o,8o8	o,871	o,928	o,956	o,974	o,994
	o,2o	o,287	o,457	o,58o	o,687	o,797	o,859	o,9o5	o,946	o,965	o,979	o,994
	o,1o	o,4o8	o,569	o,674	o,758	o,844	o,891	o,926	o,957	o,972	o,982	o,995
	o,o5	o,526	o,668	o,751	o,817	o,882	o,917	o,943	o,967	o,978	o,986	o,996
	o,o2	o,664	o,77o	o,831	o,877	o,921	o,943	o,962	o,977	o,985	o,99o	o,997

Table X.

Average Transmission $\tau_{\Delta\nu}$ of CO_2 Between 238o - 3ooo cm^{-1} Calculated from the Plass-Tables [3o]

T [°K] = temperature, u [atm-am] = absorber mass, p [atm] = pressure

T	u p	5oo	2oo	1oo	5o	2o	1o	5	2	1	o,5	o,2
3oo	1,oo	o,823	o,871	o,9o2	o,926	o,951	o,963	o,971	o,978	o,982	o,986	o,99o
	o,5o	o,86o	o,9o1	o,926	o,945	o,962	o,971	o,976	o,982	o,985	o,989	o,991
	o,2o	o,9o1	o,933	o,95o	o,962	o,972	o,978	o,981	o,986	o,989	o,991	o,994
	o,1o	o,925	o,95o	o,962	o,97o	o,978	o,981	o,985	o,989	o,99o	o,993	o,995
	o,o5	o,945	o,962	o,971	o,976	o,981	o,985	o,988	o,991	o,993	o,995	o,997
	o,o2	o,962	o,972	o,978	o,981	o,986	o,989	o,991	o,994	o,995	o,997	o,998
25o	1,oo	o,817	o,867	o,898	o,924	o,95o	o,962	o,972	o,981	o,985	o,988	o,991
	o,5o	o,856	o,898	o,924	o,944	o,962	o,972	o,979	o,984	o,988	o,99o	o,993
	o,2o	o,898	o,931	o,95o	o,962	o,974	o,98o	o,984	o,988	o,99o	o,993	o,995
	o,1o	o,924	o,95o	o,964	o,972	o,98o	o,984	o,987	o,99o	o,992	o,994	o,996
	o,o5	o,943	o,962	o,971	o,978	o,984	o,987	o,99o	o,992	o,994	o,996	o,997
	o,o2	o,962	o,974	o,98o	o,984	o,988	o,99o	o,992	o,995	o,996	o,997	o,998
2oo	1,oo	o,81o	o,862	o,895	o,921	o,949	o,963	o,974	o,982	o,987	o,99o	o,993
	o,5o	o,85o	o,895	o,921	o,943	o,963	o,973	o,981	o,987	o,99o	o,992	o,994
	o,2o	o,895	o,929	o,949	o,964	o,977	o,983	o,987	o,991	o,993	o,995	o,997
	o,1o	o,921	o,948	o,963	o,973	o,982	o,986	o,99o	o,992	o,994	o,996	o,997
	o,o5	o,943	o,963	o,973	o,981	o,986	o,99o	o,991	o,994	o,996	o,997	o,998
	o,o2	o,962	o,976	o,983	o,986	o,99o	o,992	o,994	o,996	o,997	o,998	o,999

Table XI

Average Transmission $\tilde{\tau}_{\Delta\nu}$ of H_2O Between 2380 - 3000 [cm^{-1}] Calculated from the Plass-Tables [30]

T [^oK] = temperature, u [g/cm^2] = absorber mass, p [atm] = pressure

T	u p	5,000	2,000	1,000	0,500	0,200	0,100	0,050	0,020	0,010	0,005	0,002
300	1,00	0,762	0,865	0,914	0,946	0,971	0,980	0,989	0,994	0,997	0,998	0,999
	0,50	0,816	0,894	0,932	0,957	0,977	0,985	0,990	0,995	0,997	0,998	0,999
	0,20	0,869	0,923	0,949	0,967	0,982	0,989	0,993	0,996	0,998	0,998	1,000
	0,10	0,902	0,940	0,960	0,974	0,986	0,991	0,994	0,997	0,998	0,998	1,000
	0,05	0,928	0,955	0,969	0,980	0,989	0,993	0,996	0,998	0,998	1,000	1,000
	0,02	0,951	0,969	0,979	0,986	0,992	0,995	0,997	0,998	0,999	1,000	1,000
250	1,00	0,744	0,864	0,917	0,948	0,973	0,983	0,990	0,994	0,997	0,999	0,999
	0,50	0,815	0,896	0,933	0,958	0,977	0,986	0,991	0,995	0,997	0,999	1,000
	0,20	0,874	0,925	0,950	0,968	0,982	0,988	0,993	0,996	0,998	0,999	1,000
	0,10	0,906	0,943	0,961	0,975	0,986	0,991	0,994	0,996	0,998	0,999	1,000
	0,05	0,929	0,956	0,970	0,980	0,988	0,993	0,996	0,998	0,998	0,999	1,000
	0,02	0,948	0,971	0,980	0,986	0,992	0,995	0,997	0,998	0,999	0,999	1,000
200	1,00	0,716	0,857	0,918	0,951	0,975	0,986	0,991	0,997	0,997	0,999	1,000
	0,50	0,804	0,896	0,936	0,961	0,980	0,988	0,992	0,997	0,998	0,999	1,000
	0,20	0,877	0,929	0,954	0,971	0,985	0,990	0,994	0,997	0,998	0,999	1,000
	0,10	0,911	0,946	0,964	0,977	0,987	0,992	0,995	0,998	0,998	0,999	1,000
	0,05	0,936	0,959	0,972	0,982	0,989	0,993	0,996	0,998	0,998	0,999	1,000
	0,02	0,957	0,973	0,981	0,987	0,992	0,995	0,997	0,998	0,999	0,999	1,000

Table XII

Water Vapor Distribution and Atmospheric Model (US-Standard Atmosphere 1962)

i = index of atmospheric levels

T_i = temperature [°K]

c = mixing ratios of water vapor [mg/kg]

h = geopotential height [m]

p_i = pressure [mb]

i	h_i	T_i	p_i	c_i	i	h_i	T_i	p_i	c_i
1	+0.	288.1	1013.2	9900.0	26	5450.	252.7	508.5	667.8
2	150.	287.2	995.4	9192.0	27	5750.	250.8	488.2	575.6
3	300.	286.2	977.7	8534.6	28	6050.	248.8	468.6	496.2
4	500.	284.9	954.6	7730.5	29	6350.	246.9	449.6	427.8
5	700.	283.6	931.9	7002.1	30	6650.	244.9	431.2	368.8
6	900.	282.3	909.7	6342.5	31	7000.	242.6	410.6	310.2
7	1050.	281.3	893.3	5888.9	32	7350.	240.4	390.8	260.8
8	1250.	280.0	871.8	5334.1	33	7700.	238.1	371.7	219.4
9	1450.	278.7	850.8	4831.5	34	8100.	235.5	350.9	180.0
10	1650.	277.4	830.1	4376.3	35	8500.	232.9	331.0	147.7
11	1850.	276.1	809.9	3964.1	36	8950.	230.0	309.7	118.2
12	2050.	274.8	790.0	3590.8	37	9400.	227.0	289.6	94.6
13	2250.	273.5	770.6	3252.3	38	9850.	224.1	270.5	75.7
14	2450.	272.2	751.5	2945.9	39	10350.	220.9	250.5	59.1
15	2650.	270.9	732.8	2668.4	40	10850.	217.6	231.7	46.2
16	2850.	269.6	714.6	2416.9	41	11500.	216.6	209.2	33.5
17	3100.	268.0	692.2	2135.8	42	12100.	216.6	190.3	24.9
18	3350.	266.4	670.4	1887.2	43	12800.	216.6	170.4	17.6
19	3600.	264.7	649.2	1667.7	44	13600.	216.6	150.2	11.8
20	3850.	263.1	628.5	1473.7	45	14500.	216.6	130.3	7.6
21	4100.	261.5	608.4	1302.2	46	15500.	216.6	111.3	4.6
22	4350.	259.9	588.8	1150.7	47	16800.	216.6	90.7	2.0
23	4600.	258.2	569.7	1016.9	48	18400.	216.6	70.5	2.0
24	4850.	256.6	551.1	898 .5	49	20500.	217.1	50.6	2.0
25	5150.	254.7	529.5	774.6	50	23800.	220.4	30.2	2.0
					51	31000.	227.6	10.1	2.0

total water vapor amount: 2,03 [mg/kg]