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THE ROLE OF MINOR ATMOSPHERE ADMIXTURES IN THE ABSORPTION OF INFRARED RADIATION

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SUMMARY

The role of minor atmospheric gas admixtures in the absorption of infrared radiation is discussed from various points of view. The unavailability of practical methods of computations is emphasized. The transparency of minor atmospheric admixtures is plotted as a function of W/W_0 and the errors of calculation are evaluated. It is concluded that minor atmospheric components play a significant role in the attenuation of infrared radiation.

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1. The minor atmospheric components N_2O, CH_4 and CO, as well as CO_2 have an approximately constant relative concentration at various heights up to 50 km. For N_2O it constitutes ~ ~ $0.27 \cdot 10^{-6}$ g/g, for CH_4 ~ $2.4 \cdot 10^{-6}$ g/g and for CO ~ $1.1 \cdot 10^{-6}$ g/g [1]. In comparison with carbon dioxide, for which the concentration is ~ $320 \cdot 10^{-6}$ g/g, the N_2O, CH_4 and CO content in the atmosphere is negligible. Therefore for the solution of many problems of atmospheric optics the absorption of radiation by these components was generally not taken into account. However, minor admixtures must unquestionably play an essential role in absorption when radiation passes at various heights through the entire thickness of the Earth's atmosphere. An experimental solution of the stated problem in real conditions is beset with difficulty and high cost of the experiment; therefore, in the present investigation the problem is solved by means of computation.

2. At the present time there is in litereture a series of investigations of spectral absorption of minor atmospheric components [2-4,6], nonetheless, practical methods for computations are absent.

Howard et al [7] have shown by means of experimental data processing that absorption of infrared radiation in rotation-vibration H_2O bands may be represented with an error not exceeding 5% in the form of a function of two parameter ratio: the mas W of absorbing gas on the radiation's path and the spectral parameter W_0 equivalent to the mass of gas responsible for 50% of radiation absorption in the given wavelength at normal pressure. The obvious simplicity and convenience of such a presentation of functional dependence of water vapor absorption at sufficiently high precision of calculations would be desirable for the consideration of absorption by minor atmosphere components.

Laboratory data by Burch and Williams [3,4] obtained at normal pressure for all masses of absorbing gases and realized in the experiment, are presented in form of a function of ratio W/W_0 in Fig.1. Experiments [3,4] were performed with values of N_2O mass from $1 \cdot 10^{-3}$ to 10 atm·cm, CH_4 from 0.134 to 188 atm·cm and CO from $7 \cdot 10^{-2}$ to 1140 atm·cm. In real conditions, possible mass values of these components lie respectively within the limits of 0-9 atm·cm, 0-80 atm·cm and 0.35 atm·cm, i.e. the aggregate of points in Fig.1 encompasses almost all possible amounts of absorbing substance in real atmosphere. The circles in the figure refer to various portions of spectrum in the 4.5 and 14.5 mkm absorption bands of N_2O, to the points of CO bands 2.34 and 4.66 mkm: the crosses correspond to 3.31, 6.5 and 7.65 mkm absorption bands of CH_4.

As in the case of H_2O of [7], the obtained combination of points represents an entirely specific functional dependence of transmission T of minor components on the ratio W/W_0 with maximum point scattering not exceeding 8%. This dependence is described by a simple expression [8] (Fig.1, solid line):

$$T = (1 + W/W_0)^{-1} \tag{1}$$

in which the absorption coefficient is $K_\lambda = 1/W_0$.

The value of parameters W_0 for certain absorption bands of minor atmosphere admixtures, found as a result of processing the experimental data of [3,4] are compiled in Table 1.

Both expression (1) or direcly Fig.1, may be used for the estimate of transparency at passage of infrared radiation through inhomogeneous atmospheric paths by means of mass determination of the absorbing substance W at normal pressure, equivalent absorption-wise to the gas mass ω, located over the inhomogeneous path. The determination of W, equivalent absorption-wise to ω, is usually realized approximately by the effective mass method.

3. We shall estimate the error in computation introduced as a consequence of the approximation method by taking account of atmosphere inhomogeneity. If W is found as $\omega(P/P_0)^n$, then, as a rule, when converting the transmission at normal pressure P_0 to the case

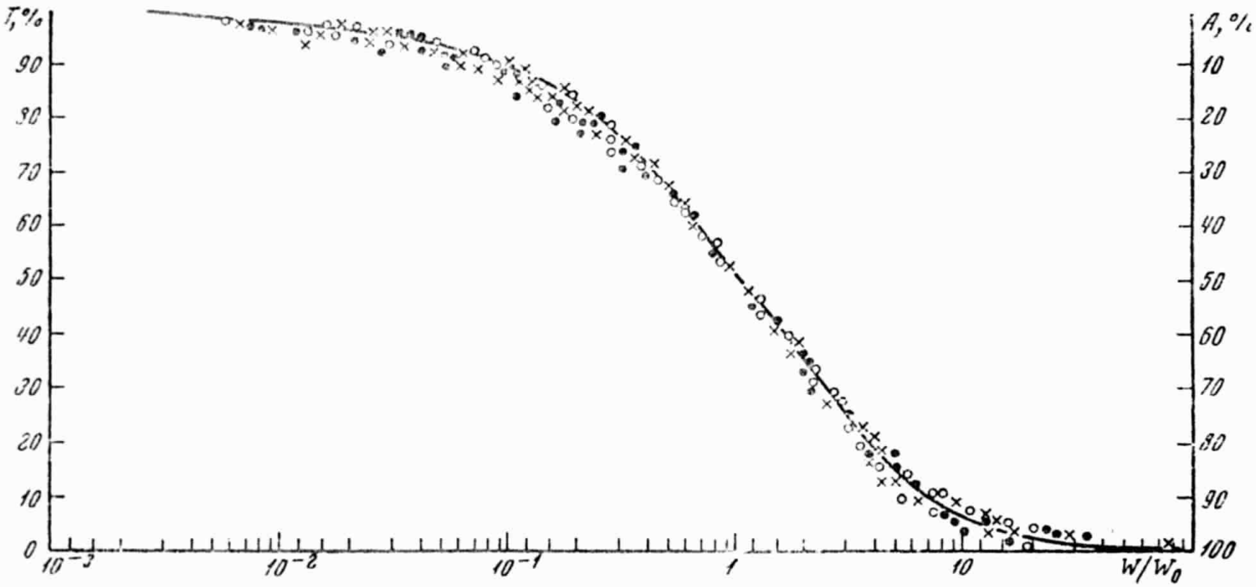

Fig.1

Transmission function of minor atmosphere admixtures.

of pressure P for each concrete gas, a single invariable adjustment parameter n is used in the assumption of its weak dependence on the wavelength, pressure and the absorbing mass.

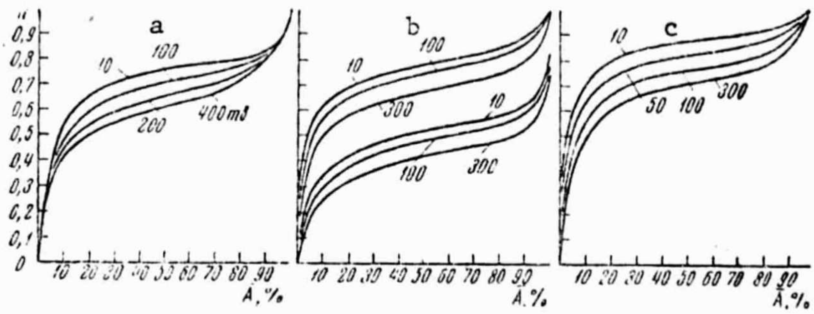

Fig.2

Dependence $n = f(\bar{A})$ for different absorption bands of minor components:
a) 4.5 and 14.5 mkm N_2O bands,
b) 3.31 and 7.65 mkm CH_4 bands,
c) 4.66 mkm CO band.

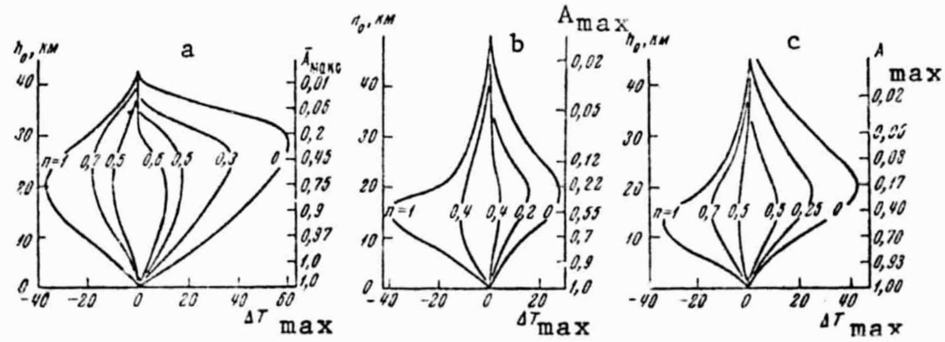

Fig.3

Errors in computations of inhomogeneous path's transparency conditioned by the use of different indexes n:
a) 4.5 mkm N_2O band
b) 3.31 mkm CH_4 band
c) 4.66 mkm CO band

The dependences of n on ω and P at the centers of N_2O, CH_4 and CO absorption bands may, however, be obtained as a result of processing the experimental data of [3,4], provided conditions $A_1(W,P_0)$ are observed. Inasmuch as in the given frequency ω and P determine the mean value of the absorption $\bar{A}$, whose accuracy of

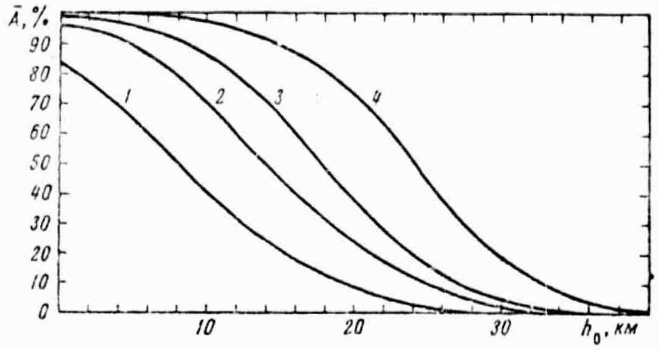

Fig.4
Dependence $\bar{A} = \phi(h_0)$ for different absorption bands of minor admixtures

computation must be determined, it is practical to investigate the dependence of n directly on $\bar{A}$ for various P. The results of computations $n = f(\bar{A})$ are presented in Fig.2. In computations the values of ω varied within the same limits as in the construction of Fig.1, while the quantity P varied from 10 to 300-400 mb. The dependence of n on higher pressures is not of interest, since the ratio P/P_0 approaches the unity as the value of P approaches P_0. The obtained curves show that a relatively weak departure of n from ω (by no more than a factor of two) is observed at the centers of minor components' bands only in the region $\bar{A}$ variation from 10 to 90%. The fluctuations of pressure from 10 to 400 mb lead respectively to the variation of n by 1.3 - 1.5 times.

Thus strictly speaking, when taking into account the inhomogeneities of the atmosphere by the method of effective mass, the value of n can not be assumed as invariable. However, considering the relatively weak variation of n in the median region of values $\bar{A}$, and the increase in the influence on W as P increases, it is possible to select at the centers of N_2O, CH_4 and CO bands for a limited region of values $\bar{A}$ a concrete invariable value of n.

We shall now determine the greatest absolute errors ΔT_{max} in the computation of minor atmosphere component's transparency when using various constant values of n. The greatest errors will take place at passage of the infrared radiation through the entire atmospheric thickness at the altitude h_0 above the Earth's surface. as in such cases, the maximum possible values of ω and $\bar{A}_{max}$ are realized. The results of computations of ΔT_{max} as a function of h_0 are presented in Fig.3 from which it may be seen that with the unfounded selection of the value of n, the transmission of minor components may be either underrated to ΔT_{max} = 35-40%, or overrated to ΔT_{max} = 30-60%. When selecting the values of n, taking into account the dependence $n = f(\bar{A})$, the additional error in the transparency over inhomogeneous paths introduced by the use of the appro-

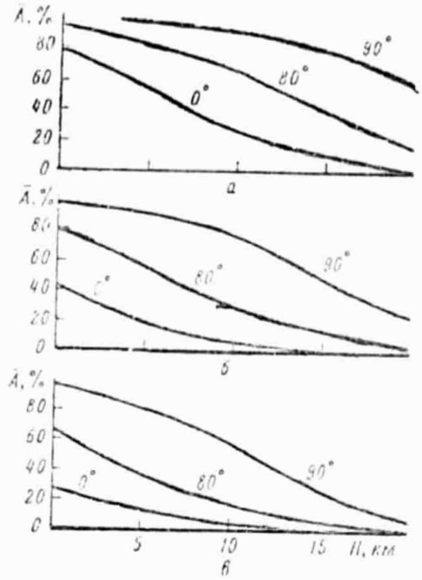

Fig.5
Variability of angular absorption of minor gas components at various levels in the atmosphere:
a) 4.5 mkm N_2O band, b) 3.31 mkm CH_4 band,
c) 4.66 mkm CO band.

ximate method, will not exceed + 10%.

In this case it turns out that for the center of the 4.5 mkm N_2O band one may assume the value n = 0.6, for 14.5 mkm N_2O band, the value n = 0.5 for the centers of the 3.31 mkm and 7.65 mkm CH_4 bands, respectively the values n = 0.3-0.4, n = 0.6-0.7 and for the center of the 4.66 mkm CO band a value n = 0.5-0.6.

4. In conclusion we shall compute the transparency of N_2O, CH_4 and CO for various geometries of infrared radiation passage in the atmosphere.

The results of computations of absorption of radiation $\bar{A}$ traversing the entire atmosphere thickness at altitudes h_0 above the Earth's surface respectively for the centers of the bands: 14.5 mkm N_2O (curve 1), 3.31 mkm CH_4 and 4.66 mkm CO (curve 2), 7.65 mkm CH_4 (curve 3) and 4.5 mkm N_2O (curve 4) are presented in Fig.4.*

Computations of $\bar{A} = \phi(h_0)$ show that at transmission of infrared radiation near the Earth's surface ($h_0 = 0$) both the weak (curves 1,2) and the strong absorption bands (curves 3,4) of minor atmosphere admixtures practically lead to total absorption of passing

* Taking account of Earth's curvature and of infrared ray refraction [5].

radiation. A strong absorption, up to 40-98%, is retained as h_0 increases up to 10 km. A sufficiently high transparency in the absorption region of minor components (above 80%) begins only with the values h_0 > 30 km in the strong ones.

The results of computations of angular variability of minor gas components' absorption at various levels H in the atmosphere are presented in Fig.5. These computations are also evidence of substantial contribution of minor components to the weakening of infrared radiation, particularly for observation of zenithal angles Z, close to 90°.

TABLE I

Value of parameter W_0 for certain absorption bands of minor atmospheric admixtures

ν, см⁻¹	N_2O	ν, см⁻¹	CH_4	ν, см⁻¹	CH_4
500	$9,4\cdot10^4$	1040	$9.4\cdot10^4$	1500	$4,8\cdot10^2$
510	$6,2\cdot10^4$	1060	$1,6\cdot10^4$	1520	$1,4\cdot10^3$
520	$2,5\cdot10^4$	1080	$9,5\cdot10^3$	1540	$9,5\cdot10^1$
530	$3,7\cdot10^3$	1100	$4.7\cdot10^3$	1550	$3,1\cdot10^1$
540	$8.7\cdot10^1$	1120	$1.9\cdot10^3$	1560	$1,8\cdot10^2$
550	$2,7\cdot10^1$	1140	$9.5\cdot10^2$	1580	$1.4\cdot10^3$
560	$1.2\cdot10^1$	1160	$4.1\cdot10^2$	1600	$6,3\cdot10^2$
570	$5,8\cdot10^0$	1180	$2.4\cdot10^2$	1620	$4,7\cdot10^2$
580	$3.5\cdot10^0$	1200	$8.4\cdot10^1$	1640	$4,7\cdot10^2$
585	$5,4\cdot10^0$	1220	$2.2\cdot10^1$	1660	$8,0\cdot10^2$
590	$1,2\cdot10^0$	1230	$9.6\cdot10^0$	1670	$6,3\cdot10^2$
595	$3.7\cdot10^0$	1235	$1.0\cdot10^1$	1680	$8,0\cdot10^2$
600	$3,7\cdot10^0$	1250	$3.0\cdot10^0$	1700	$2,5\cdot10^3$
610	$6,6\cdot10^0$	1260	$4.1\cdot10^0$	1710	$2,4\cdot10^3$
620	$1.5\cdot10^1$	1270	$1.8\cdot10^0$	1720	$5.0\cdot10^3$
630	$7,0\cdot10^1$	1280	$2.7\cdot10^0$	1740	$6,2\cdot10^4$
640	$3,7\cdot10^2$	1300	$2.1\cdot10^0$	1760	$9,4\cdot10^4$
650	$4.7\cdot10^3$	1310	$3.7\cdot10^{-1}$		
660	$3,7\cdot10^3$	1320	$9,0\cdot10^0$		
670	$1.6\cdot10^3$	1340	$2,1\cdot10^0$		
680	$8,7\cdot10^2$	1350	$1.5\cdot10^0$		
690	$5,8\cdot10^2$	1360	$1.7\cdot10^0$		
692	$1,1\cdot10^2$	1380	$1.1\cdot10^1$		
695	$5,8\cdot10^2$	1400	$9.5\cdot10^1$		
710	$5,8\cdot10^2$	1420	$1,5\cdot10^2$		
720	$1.3\cdot10^3$	1440	$1,6\cdot10^2$		
730	$9,4\cdot10^3$	1460	$1,8\cdot10^2$		
740	$6,2\cdot10^4$	1480	$2,6\cdot10^2$		

Table continued........

T A B L E I (continuation)

ν, $см^{-1}$	N_2O	CH_4	CO	ν, $см^{-1}$	N_2O	CH_4	CO
1950			$7,6\cdot10^{3}$	2210	$4,1\cdot10^{-2}$	$2,2\cdot10^{4}$	$9,2\cdot10^{0}$
1960			$6,1\cdot10^{3}$	2220	$4,1\cdot10^{-2}$	$2,1\cdot10^{4}$	$2,5\cdot10^{1}$
1970			$4.6\cdot10^{3}$	2224	$5,7\cdot10^{-2}$	—	—
1980			$3,0\cdot10^{3}$	2230	$4,9\cdot10^{-2}$	$2,0\cdot10^{4}$	$7,0\cdot10^{1}$
1990			$1,4\cdot10^{3}$	2240	$2,5\cdot10^{-2}$	$1,9\cdot10^{4}$	$2,0\cdot10^{2}$
2000			$7,6\cdot10^{2}$	2250	$4,3\cdot10^{-2}$	$1,7\cdot10^{4}$	$4,6\cdot10^{2}$
2010			$3,8\cdot10^{2}$	2260	$2,0\cdot10^{-1}$	$1.6\cdot10^{4}$	$2,3\cdot10^{3}$
2020			$2,0\cdot10^{2}$	2270	$2,3\cdot10^{0}$	$1,4\cdot10^{4}$	$7,6\cdot10^{3}$
2030			$1,1\cdot10^{2}$	2280	$2,5\cdot10^{1}$	$1,2\cdot10^{4}$	
2040			$6,5\cdot10^{1}$	2290	$3,8\cdot10^{2}$	$1,1\cdot10^{4}$	
2050			$3,4\cdot10^{1}$	2300	$1,9\cdot10^{3}$	$9,5\cdot10^{3}$	
2060			$1,6\cdot10^{1}$	2320		$7,9\cdot10^{3}$	
2070			$7,6\cdot10^{0}$	2340		$6,3\cdot10^{3}$	
2080			$4,6\cdot10^{0}$	2360		$5,0\cdot10^{3}$	
2090			$3,1\cdot10^{0}$	2380		$3,8\cdot10^{3}$	
2100	$1,4\cdot10^{3}$	$6,3\cdot10^{4}$	$1,8\cdot10^{0}$	2400		$2,7\cdot10^{3}$	
2110	$9,7\cdot10^{2}$	$5,5\cdot10^{4}$	$1,5\cdot10^{0}$	2420		$1,6\cdot10^{3}$	
2120	$5,8\cdot10^{2}$	$4,7\cdot10^{4}$	$1,5\cdot10^{0}$	2440		$1,3\cdot10^{3}$	
2130	$2,9\cdot10^{2}$	$4,2\cdot10^{4}$	$2,4\cdot10^{0}$	2460		$1,1\cdot10^{3}$	
2140	$8,3\cdot10^{1}$	$3,8\cdot10^{4}$	$4,1\cdot10^{0}$	2480		$9,0\cdot10^{2}$	
2150	$2,1\cdot10^{1}$	$3,4\cdot10^{4}$	$2,4\cdot10^{0}$	2500		$7,0\cdot10^{2}$	
2160	$6,5\cdot10^{0}$	$3,1\cdot10^{4}$	$1,1\cdot10^{0}$	2520		$6,0\cdot10^{2}$	
2170	$1,9\cdot10^{0}$	$2,9\cdot10^{4}$	$1,06\cdot10^{0}$	2540		$5,1\cdot10^{2}$	
2180	$3,7\cdot10^{-1}$	$2,7\cdot10^{0}$	$1,4\cdot10^{0}$	2560		$4,0\cdot10^{2}$	
2190	$1,5\cdot10^{-1}$	$2,5\cdot10^{4}$	$2,4\cdot10^{0}$	2580		$3,0\cdot10^{2}$	
2200	$6,2\cdot10^{-2}$	$2,3\cdot10^{4}$	$4,8\cdot10^{0}$	2600		$2,8\cdot10^{2}$	
				2620		$1,9\cdot10^{2}$	

ν, $см^{-1}$	CH_4	ν, $см^{-1}$	CH_4	ν, $см^{-1}$	CO
2640	$3,5\cdot10^{2}$	3240	$1,1\cdot10^{3}$	4120	$4,8\cdot10^{4}$
2660	$1,6\cdot10^{2}$	3260	$3,8\cdot10^{3}$	4130	$2,4\cdot10^{4}$
2680	$1,9\cdot10^{2}$	3280	$9,4\cdot10^{3}$	4140	$1,2\cdot10^{4}$
2700	$1,4\cdot10^{2}$	3300	$1,2\cdot10^{4}$	4150	$5,7\cdot10^{3}$
2720	$1,4\cdot10^{2}$	3320	$1,9\cdot10^{4}$	4160	$2,8\cdot10^{3}$
2740	$1,4\cdot10^{2}$	3340	$2,7\cdot10^{4}$	4170	$1,4\cdot10^{3}$
2760	$9,4\cdot10^{1}$	3360	$3,8\cdot10^{4}$	4180	$8,9\cdot10^{2}$
2780	$6,3\cdot10^{1}$	3380	$4,7\cdot10^{4}$	4190	$5,7\cdot10^{2}$
2800	$3,8\cdot10^{1}$	3400	$6,3\cdot10^{4}$	4200	$4,7\cdot10^{2}$
2820	$3,8\cdot10^{1}$			4210	$3,8\cdot10^{2}$
2840	$2,3\cdot10^{1}$			4220	$3,2\cdot10^{2}$
2860	$3,8\cdot10^{1}$			4230	$2,8\cdot10^{2}$
2880	$1,7\cdot10^{1}$			4240	$3,2\cdot10^{2}$
2900	$1,3\cdot10^{1}$			4250	$5,7\cdot10^{2}$
2920	$1,0\cdot10^{1}$			4255	$7,1\cdot10^{2}$
2940	$8,8\cdot10^{0}$			4260	$5,2\cdot10^{2}$
2960	$6,9\cdot10^{0}$			4270	$2,4\cdot10^{2}$
2980	$6,7\cdot10^{0}$			4280	$1,7\cdot10^{2}$
3000	$7,6\cdot10^{0}$			4290	$1,7\cdot10^{2}$
3020	$3,8\cdot10^{0}$			4300	$1,9\cdot10^{2}$
3040	$7,0\cdot10^{0}$			4310	$3,6\cdot10^{2}$
3060	$1,0\cdot10^{1}$			4320	$8,9\cdot10^{2}$
3080	$7,6\cdot10^{0}$			4330	$1,9\cdot10^{3}$
3100	$6,3\cdot10^{0}$			4340	$4,1\cdot10^{3}$
3120	$7,6\cdot10^{0}$			4350	$1,4\cdot10^{4}$
3140	$1,1\cdot10^{1}$			4360	$2,4\cdot10^{4}$
3160	$1,9\cdot10^{1}$			4370	$4,8\cdot10^{4}$
3180	$3,8\cdot10^{1}$				
3200	$9,5\cdot10^{1}$				
3220	$4,7\cdot10^{1}$				

CONCLUSIONS

1. The interpretation of transparency of minor atmosphere admixtures in the form of function of W/W_0 shows a sufficiently specific dependence with maximum scattering of points not exceeding 8%, which could be described by an analytical expression.

2. Taking into account the atmospheric inhomogeneties by the method of effective mass, the unfounded selection of indexes $\underline{n}$ may lead at the computation of transparency T to substantial errors.

3. If the average absorption of radiation $\overline{A}$ at the center of the N_2O, CH_4 and CO bands varies from 10 to 90%, it is possible to select the value of $\underline{n}$ in such a manner, that the possible maximum absolute error in the computations of transmission will not exceed ±14% of the aggregate error of functional representation of transparency in the form $T = F(W/W_0)$ (±4%) and the error resulting in the neglect of the variability of $\underline{n}$ from ω and P (±10%).

4. The accounting of the variability of $\underline{n}$ from ω and P according to the dependence $n = f(\overline{A})$ underrates the maximum error in transparency computations of minor components to ±5-7%.

5. The computation of transparency of different air masses at the centers of the N_2O, CH_4 and CO absorption bands attests to the significant role of minor atmospheric components in the weakening of infrared radiation.

* * * * THE END * * * *

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R E F E R E N C E S

1. J.N. HOWARD, J.S. GARING, The Transmission of the Atmosphere in the Infrared. Rev. Infrared Phys., 2, No.2, 1962
2. P.M. GOODY, Atmosphere Radiatiation. "MIR", 1966.
3. D.E. BURCH, D. WILLIAMS, Total Absorrtance of Carbon Monoxide and Methane in the Infrared. Appl. Opt., 1, No.5. 1962

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