REDETERMINATION OF MONOCHROMATIC ABSORPTION COEFFICIENTS' VALUES OF AMMONIA IN VISIBLE RANGE OF THE SPECTRUM FOR ATMOSPHERES OF JUPITER AND SATURN

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By improvement of the method of A.V.Morojenko, the monochromatic absorption coefficients' values of ammonia in visible range of the spectrum for atmospheres of Jupiter and Saturn have been redetermined on the base of measurements of the same parameter in the laboratory conditions.

The main gas constituents of Jupiter's and Saturn's atmospheres are hydrogen (0,86 and 0,83 correspondingly) and helium (0,13 and 0,16), and insignificant degree of methane (~ 0,07 %) and ammonia (~ 0.01 %). In comparison with absorption band of methane in the spectra of Jupiter the absorption band of ammonia possess considerably smaller intensity, but is still well-defined enough. At Saturn ammonia bands are definable on a detection limit.

In visible spectral area of Jupiter two absorption bands of ammonia with the central wavelength λ 5520 Å and λ 6475 Å are observed; the first of them is partially overlapped with a weak absorption band of methane at 5430 Å. The question on presence of ammoniac absorption in the Saturn's atmosphere remained disputable for a long time and this point is in detail discussed in V.V. Avramchuk and A.I. Karmeljuk's work [1]. By spectral observations [2,3] and also by the spectrograms obtained with 2-m SHAO NAN of Azerbaijan reflector by deceased N.B. Ibragimov in 1969-1974 [4,5] ammonia's presence in the atmosphere of Saturn had been established.

By existing estimations the relative content of ammonia in the Saturn's atmosphere is $C(NH_3)<0.0001$, whereas at Jupiter it is at least 7 times higher. It must be noted that ammonia and methane play an important role in optical and dynamical intra-atmospheric processes occurring in atmospheres of Jupiter and Saturn. In spite of the fact that in Jupiter's atmosphere ammonia's content is insignificant quantity, but it plays about the same role as water vapor plays in Earth's atmosphere, and for certain, not to a lesser degree in the atmosphere of Saturn.

Observable intensity of absorption bands of molecular gases depends on their concentration and local temperature changes created by convective streams and vortex formations. Such dynamics in atmospheres of Jupiter and Saturn influences values of relative concentration of molecular gases, including the quantity of NH_3 in the gaseous form. Due to lower temperature in Saturn's atmosphere a certain part of gaseous ammonia should freeze, having turned to crystals, forming a visible cloud layer of the planet. Therefore in the visible range of Saturn's spectrum it is possible to observe only absorption bands of ammonia NH_3 at λ 6475 Å and its intensity will be different on different points over Saturn's disk. The research carried out in this direction last years in AFI NAN PK [6,7,8,9] represent great interest and play a considerable role in understanding of real structure of atmospheres of those planets.

At studying of vertical structure of atmospheres of Giant planets a number of general character problems and also difficulties connected with choosing of models arise, which are in detail studied in A.V. Morozhenko's works [10,11,12]. Optical parameters of planets' atmospheres are determined from the analysis of the observed data (i.e., by research brightness distribution over the disks of planets in a continuous spectrum, and also molecular absorption bands) within the limits of those or other representations about vertical structure of atmosphere. Therefore, the analysis even the same observed data, under various assumptions of vertical structure of a cloud layer, leads to various values of determined parameters.

For systematic research of that point it was necessary to systematize in more details available data and to consider a number of important factors as temperature dependence of absorption coefficients of molecular gases, the account of aerosol scattering, more exact determination of relative concentration of gases and an effective optical thickness etc. For this purpose it is necessary to know exact values of monochromatic coefficients of absorption of gases k_ν under corresponding conditions, i.e. in the conditions of atmospheres of planets. For Jupiter and Saturn, first of all, it concerns methane and ammonia at equilibrium temperatures. Unfortunately, the true data of k_ν which are available for methane, is not present now for ammonia even in laboratory conditions (discrepancies of k_ν are about 10 % in the centers of absorption bands and several times differ near to a continuous spectrum) [13,14].

The goal of the present work is determination of monochromatic coefficients from ammonia's absorption bands in visible range spectra of Jupiter and Saturn in the thermal conditions of atmospheres of these planets by observed and laboratory spectral data for these bands.

DATA AND THE METHOD DESCRIPTION

As it is known, in real planetary atmospheres vertical profile of temperature $T(h)$ is rather complex [15]; various absorption bands and even separate parts of the contour of the same band are formed at various intervals of temperature. Therefore, amendments to values $k_\nu (T_0)$ will be different for various parts of absorption bands. For more precise determination of monochromatic absorption coefficient's values, obtained in laboratory conditions [16] in ammonia's absorption bands λ 5520 Å and λ 6475 Å, we have offered a simple way which is based on the analysis of an observed spectrum of planets and a laboratory spectrum of the given band of molecular gas [17]. Thereby the method of deviation of vertical structure of a cloud layer from the condition of homogeneity [11, 12, 14, 18] has been used. The essence of the method of deviation of vertical structure of a cloud layer from homogeneity condition consists in construction of graphical dependence of $ln\ (Nl/\tau_s)$ on $ln\ (Nl)$ through contours of various absorption bands of molecular gases; Nl is quantity of gas in the sight beam m•amagat, and τ_s is the scattering component of effective optical depth τ_{eff} formed by the radiation diffuse-reflected from a homogeneous semi-infinite layer, which values are determined by data albedo of single scattering in a molecular absorption band ω_ν and in a continuous spectrum ω_c:

$$\frac{Nl}{\tau_s} = \frac{\omega_\nu^{-1} - \omega_c^{-1}}{k_\nu} = \frac{\bar{n}}{\bar{\sigma}_s}, \qquad Nl = \left(Nl\big/\tau_s\right)\tau_{eff}\,\omega_\nu \tag{1}$$

Here k_ν is monochromatic coefficient of absorption of ammonia, and $\bar{n}$ and $\bar{\sigma}_s$ are volume concentrations of gas and volume coefficient of scattering of medium, which values are averaged over all optical way. Spectral values of ω are defined from comparison of values of observable reflective abilities with calculated for model optical homogeneous semi-infinite layer. The calculation method of τ_{eff} differs from calculations of works [10,11,19] and is described as follows.

A.V.Morozhenko calculated τ_{eff} according to formula [19, formula 6]:

$$\tau_{eff} = \left[(1-\omega)(3-x_1)\right]^{-1/2} + \frac{5}{5-x_2}\left[\mu_0 - q(\infty)\right] + O\left[(1-\omega)^{1/2}\right], \tag{2}$$

where x_1 and x_2 are coefficients of the expansion of scattering indicatrix in a Legendre polynomial series, $q(\infty)$=0.710446… is Hopfa's constant, $arccos\ \mu_0$ is angle of incidence to outer normal. He underlined that at determining effective optical depth according to [10, 11, 20], analytical expressions τ_{eff} are more or less proved only in case of small true absorption, the condition $1 - \omega << 1$ which practically is never fulfilled. He noted that the values of effective optical depth calculated in such a way have big errors which can reach up to 100 % [20]. Therefore, it is necessary to remember that their application rather restricted, and more often it is reduced to an establishment of qualitative or relative regularities. Eh.G.Yanovitskij [21] thinks that such point of view is wrong, and puts forward a new, more correct way for calculation of the effective optical thickness. We used his approach in calculations of the parameter and we consider that it has positively affected accuracy of our calculations.

The essence of the new concept of Eh.G. Yanovitskij [21] on determination of an effective optical thickness of an atmosphere layer which forms an observable spectrum of a planet consists in the following. As it is known, in a real case the spectrum is observed with a relative error ε, and the valid information on optical properties of medium will be born only by those photons which have mainly scattered only in a corresponding surface layer of the atmosphere. Because changes of optical properties of atmosphere in rather deep layers of medium can be fixed only at corresponding accuracy of their observation.

Therefore, the author of work [21] preferred to determine an effective optical thickness τ_0^e of a surface layer of semi-infinite atmosphere, where formation of an observable spectrum of a planet at frequency ν has occurred, at the given accuracy of observation from the following equation:

$$\frac{\rho_\infty(\mu,\mu_0,\varphi-\varphi_0) - \rho(\mu,\mu_0,\varphi-\varphi_0,\tau_0^e)}{\rho_\infty(\mu,\mu_0,\varphi-\varphi_0)} = \varepsilon \tag{3}$$

$\rho(\mu,\ \mu_0,\ \varphi\text{-}\varphi_0,\ \tau_0^e)$ is reflection coefficient of a surface layer of atmosphere of the optical thickness τ_0^e, "cut off" from all semi-infinite atmosphere. Such estimation is necessary at carrying out of interpretation of any spectral and photometric observation of planets. We used results of the calculations [21], allowing to estimate τ_0^e at the given ε for the elementary model of flat homogeneous semi-infinite atmosphere though the equation (2) concerns any non-uniform model of atmosphere too.

The essence of our method of determination of monochromatic coefficient of absorption k_ν in the conditions of atmosphere of planets can be described shortly as follows. As the form of the graphic dependence of $ln\ (Nl/\tau_s)$ from $ln\ (Nl)$ does not depend on the form of scattering indicatrix [10,11], we can plot graphs by the contours of gas absorption band for observed spectra of a planet and for laboratory measurements on the same gas absorption band. For a given wavelength set of the laboratory spectra NH_3 corresponding values of $ln\ (Nl)$ and β_ν (where, $\beta_\nu = \omega_\nu^{-1} - \omega_c^{-1}$) have being selected. Then $ln\ (Nl/\tau_s)$ is calculating from the same dependence plotted for observed spectra of a planet. Therefore $\beta_\nu\big/\kappa_\nu$ are calculated for a planet and then κ'_ν are determined in the atmosphere conditions of a planet.

Thus, values of κ'_ν for the specified absorption bands in the thermal conditions of the planets have been determined from the laboratory spectra and measurements of monochromatic absorption coefficients of for bands NH_3 λ 6475 Å and λ 5520 Å at a room temperature, and also on observable spectra of Jupiter and Saturn,

RESULTS OF CALCULATIONS

NH_3 λ 6475 Å. According to observation for equatorial area of Jupiter [22, 23] and Saturn [24, 29], to laboratory measurements [16], and also by results of calculations [21, 26] in a case $g = 0.5$ for the absorption band of NH_3 λ 6475Å dependences of $ln\,(Nl/\tau_s)$ from $ln\,(Nl)$ for those planets have been separately plotted. After plotting dependences $ln(Nl/\tau_s)=f(ln(Nl))$ with step $\Delta\lambda$=5Å values of monochromatic coefficients of absorption NH_3 λ 6475 Å (Table 1, a fig. 1) have been calculated.

Table1.

Spectral values of k_v (m•amagat)$^{-1}$ for absorption bands NH_3 λ 6475Å and λ 5520Å

NH_3 λ 6475 Å					**Jupiter** **NH_3 λ 5520Å**		
			Present work				
λ (Å)	[12]	[17]	**Jupiter**	**Saturn**	**λ (Å)**	[12]	Present work
	ln k_v	ln k_v	ln k_v	ln k_v		ln k_v	ln k_v
6360	-9,90	-10.24	-9,98	-10.08	5455	-	-
6370	-9.43	-9.65	-9,47	-9.58	5460	-12.206	-11.549
6380	-8.80	-8.94	-8,83	-8.93	5465	-10.82	-10.213
6390	-8.42	-8.39	-8,35	-8.52	5470	-10.26	-9.633
6395	-8.29	-	-8,18	-8.36	5475	-9.433	-8.821
6400	-8,15	-8.15	-8,03	-8.19	5480	-8.65	-8.082
6405	-7.96	-	-7,80	-7.97	5485	--8.079	-7.481
6410	-7.60	-7.50	-7,44	-7.61	5490	-7.506	-6.884
6415	-7.24	-	-7,08	-7.24	5495	-9.511	-6.547
6420	-6.91	-6.73	-6,67	-6.88	5500	-7.378	-6.739
6425	-6.61	-	-6,27	-6.48	5505	-7.924	-7.352
6430	-6.10	-5.68	-5,6	-5.84	5510	-8.217	-7.688
6435	-5.57	-	-4.93	-5.19	5515	-7.601	-7.033
6440	-5.31	-4.58	-4,51	-4.79	5520	-7.264	-6.656
6445	-5.32	-4.42	-4,34	-4.64	5525	-7.378	-6.839
6450	-5.61	-4.76	-4,69	-5.00	5530	-7.601	-7.095
6455	-6.08	-	-5,17	-5.48	5535	-7.824	-7.330
6460	-6.64	-6.28	-6,12	-6.37	5540	-7958	-7.479
6465	-6.57	-	-6.12	-6.36	5545	-8.063	-7.607
6470	-5.81	-4.93	-4.86	-5.17	5550	-8.200	-7.786
6475	-5.25	-4.25	-429	-4.58	5555	-8.390	-8.002
6480	-5.49	-4.82	-4.65	-4.93	5560	-8.651	-8.276
6485	-5.76	-	-4.98	-5.27	5565	-8.963	-8.607
6490	-5.91	-5.20	-5.13	-5.42	5570	-9.210	-8.870
6495	-6.03	-	-5.37	-5.64	5575	-9.498	-9.163
6500	-6.17	-5.58	-5.51	-5.78	5580	-9.904	-9.578
6505	-6.27	-	-5.71	-5.96	5585	-10.260	-9.971
6510	-6.27	-5.86	-5.80	-6.06	5590	-10.724	-10.482
6515	-6.59	-	-6.13	-6.36	5595	-11.331	-11.14
6520	-6.71	-6.18	-6.22	-6.46	5600	-11.736	-11.504
6525	-6.96	-	-6.53	-6.76			
6530	-7.13	-6.67	-7.03	-7.00			
6535	-7.26	-	-6.93	-7.14			
6540	-7.29	-7.05	-7.00	-7.20			
6545	-7.60	-	-7.42	-7.50			
6550	-7.96	-7.67	-7.67	-7.87			
6555	-8.18	-	-7.94	-8.13			
6560	-8.42	-8.15	-8.16	-8.36			
6565	-8.62	-	-8.37	-8.57			
6570	-9.56	-8.70	-8.36	-9.50			
6575	-10.23	-9.07	-9.85	-10.08			
6580	-12.21	-9.22	-9.67	-12.17			

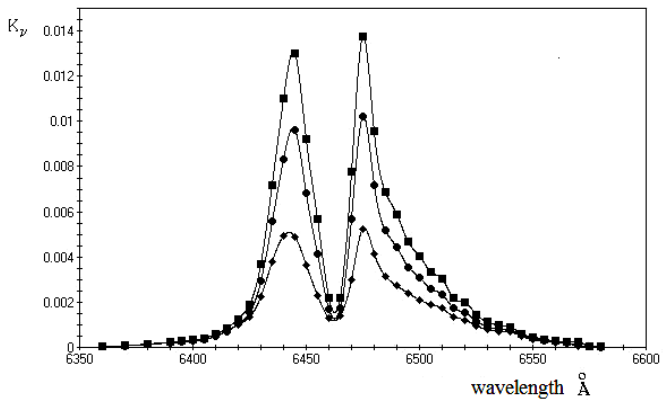

Fig. 1. Comparison of profiles of monochromatic coefficient of absorption k_ν for NH_3 λ 6475Å band; small squares correspond to the conditions of Jupiter's atmosphere, circles – to the conditions of Saturn's atmosphere, rhombuses – to the data of work [16] at room temperature.

Recalculation of values k_ν in a thermal mode for atmospheres of Jupiter and Saturn was conducted by a "fitting" of the laboratory data of the planetary atmosphere. At first, for values k_ν, of course, the laboratory data [16] were adopted. Results of the calculation show that in the conditions of atmospheres of Jupiter and Saturn in far wings of the absorption band NH_3 λ 6475 Å the values of k_ν are comparable with laboratory measurements, but in the central region of this band the deviation increases even to ~2.8 times (Fig. 2).

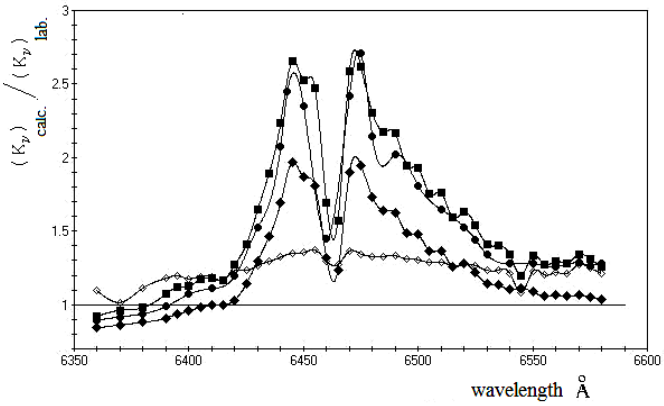

Fig.2. Circles denote the dependence of ratio of the calculated monochromatic coefficients to the laboratory measurement values of Jupiter [17] for absorption band NH_3 λ 6475 Å on wavelength. Squares denote the dependence of ratio of the calculated monochromatic coefficients to the laboratory measurement values of Jupiter for absorption band NH_3 λ 6475 Å with step 5 Å; the same dependence is denoted by dark rhombuses for Saturn. The ratio of the calculated monochromatic absorption coefficients of Jupiter to Saturn is denoted by light rhombuses.

The spectral dependence of the ratio of the calculated values monochromatic absorption coefficients to the laboratory measurement ones has a complex character and reminds the curve of absorption band at NH_3 λ 6475 Å for both planets. From figure 2 it is clear that the curve describing the ratio of the calculated monochromatic absorption coefficients of Jupiter to Saturn's ones go with features of the absorption curve of NH_3 λ 6475 Å.

NH3 λ 5520 Å. Analogical calculations were carried out for Jupiter in a weak absorption band of NH_3 λ 5520 Å. According to observations of Voodman J.H for equatorial area of Jupiter [28], to laboratory measurements [16], and also by results of calculations [21, 26] in a case g = 0.5 for the absorption band of NH_3 λ 5520 Å dependences of $ln\ (Nl/\tau_s)$ from $ln\ (Nl)$ for this planet have been plotted. After plotting dependences $ln\ (Nl/\tau_s) = f\ (ln\ (Nl))$ with step $\Delta\lambda$ =5Å values of monochromatic coefficients of absorption NH_3 λ 5520 Å have been calculated (Table 1, Fig. 3.).

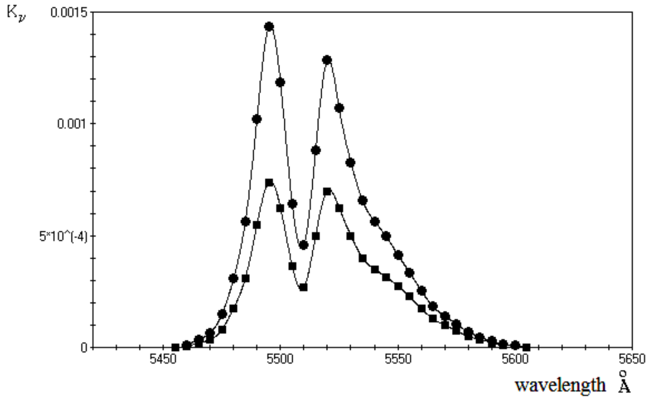

Fig.3. Comparison of contours of monochromatic coefficients k_ν of absorption bands NH_3 λ 5520 Å; circles – in the conditions of Jupiter's atmosphere, squares – from the data of [16] at a room temperature.

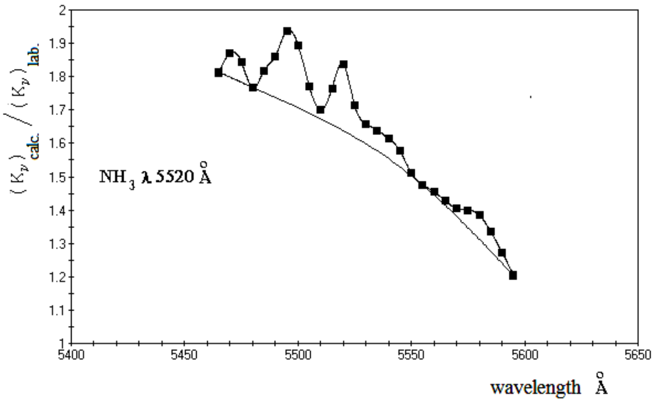

Fig.4. The ratio of the calculated monochromatic absorption band coefficients k_ν of NH_3 λ 5520 Å for Jupiter to laboratory measurement values [12] at a room temperature.

The absorption band of ammonia in the spectrum of Jupiter partially blends with a long-wave region of the absorption band of methane CH_4 λ 5430 Å. By taking into account absorption of both molecular gases in spectral region λ 5380 Å – λ 5600 Å it is possible to plot contours of curves of monochromatic coefficients passing each other for the molecular gases (fig.4). Further, it is possible to define approximately the relative contribution of each gas into the absorption spectrum by this way.

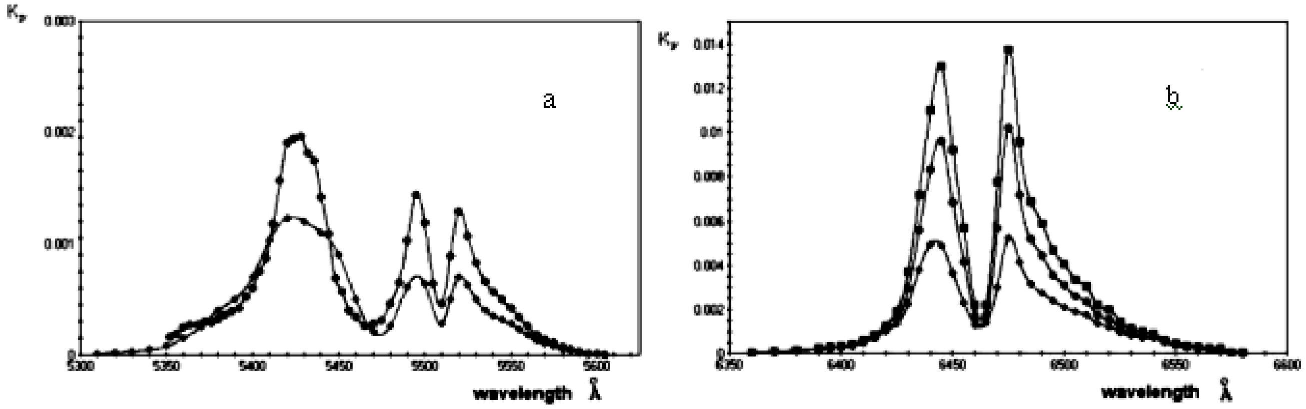

Fig.5. Dependence of a profile of monochromatic absorption coefficient on wavelength:

a) NH_3 λ 5520Å; circles correspond to the conditions of Jupiter's atmosphere, – squares to laboratory measurements date at room temperature.

b) NH_3 λ 6475Å; squares correspond to the conditions of Jupiter's atmosphere; circles correspond to the conditions of Saturn's atmosphere, rhombuses – to the laboratory measurement data at a room temperature.

From the dependences of *ln (Nl /*τ_s*)* from *ln (Nl)* for bands λ 5520 Å and λ 6475 Å are seen that, within errors of measurements for the mentioned bands of ammonia, curves of these dependences are place almost on one straight line.

Table 2.

Integral absorption coefficients S_0 of ammonia in absorption bands $6\nu_1$ (λ 5520Å) and $5\nu_1$ (λ 6475Å)

λ (Å)	Lab/measurements cm^{-1} (m·amagat)$^{-1}$	Present work	
		Jupiter	Saturn
5520	0.096 ±0.005 [16]	0.158 ± 0.03	-
6475	0.63 ±0.03 [16]	1.386 ± 0.13	1.080 ± 0.06
6475	0.66 ±0.006 [27]		

As it has already been mentioned, measurements of monochromatic absorption coefficients for ammonia were carried out at a room temperature. Therefore determination of those coefficients in the conditions of Jupiter and Saturn represents a great interest. According to laboratory measurements [16] the band $6\nu_1$ (λ 5520 Å) is weaker than the band $5\nu_1$ (λ6475 Å) approximately in 6,5 times. The calculated integral absorption coefficients for bands NH_3 λ6475 Å and λ 5520 Å in the spectrum of Jupiter differ in 8 times.

Values of the calculated integral absorption coefficient for Jupiter in 1,65 and 2,1 times differ from laboratory values for bands λ5520 Å and λ6475Å, correspondingly. Values of the calculated integral absorption coefficient for the band NH_3 λ 6475 Å in the conditions of Saturn differ from laboratory values at 1.65 times. In comparison with Jupiter temperature goes down in Saturn, owing to pressure of saturated steams sharply decreases. It can be connected with the fact that a part of ammoniac gas on Saturn has been condensed, forming a crystal cover of the planet and by that shields an internal cloud layer of the planet responsible for effective gas absorption.

It was mentioned that there is a certain discrepancy in determinations of k_ν in laboratory conditions, and also the used observed data is not deprived absolute and relative errors. Our calculations show that curves of dependences ln*(Nl/*τ_s*)* from *ln(Nl)* for two different absorption bands of ammonia λ 5520 Å and λ 6475 Å are not displaced, but lie on the one straight line. If these graphic dependences do not coincide on one straight line then it should point on non-accuracy in measurement of the monochromatic absorption coefficients.

Taking into account a total absence of values of monochromatic absorption coefficients for ammonia at different temperatures, even in laboratory conditions having of their values for a thermal mode of Jupiter and Saturn, without data on equilibrium temperature and pressure, can be considered as an important step in the description of real structure of atmospheres of these planets. To receive more exact values of monochromatic absorption coefficient for ammonia, it is necessary to carry out special spectro-photometric measurements with the spectral resolution not worse 2 Å. This will improve calculation results and will lower relative errors. Certainly, the offered method of determination of monochromatic absorption coefficients can be applied for blending band of methane NH_3 λ 7870 Å and that is a theme of a separate studying.

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ПЕРЕОПРЕДЕЛЕНИЕ ЗНАЧЕНИЙ МОНОХРОМАТИЧЕСКИХ КОЭФФИЦИЕНТОВ ПОГЛОЩЕНИЯ АММИАКА В ВИДИМОЙ ОБЛАСТИ СПЕКТРА В УСЛОВИЯХ АТМОСФЕР ЮПИТЕРА И САТУРНА

Усовершенствованием метода А.В.Мороженко, монохроматические коэффициенты поглощения аммиака были переопределены в условиях Юпитера на основе измерений соответствующего параметра по спектрам, полученным в лабораторных условиях.

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YUPİTER VƏ SATURN ATMOSFERLƏRİ ŞƏRAİTİNDƏ GÖRÜNƏN OBLASTDA AMONYAK QAZININ MONOXROMATİK UDULMA ƏMSALI QİYMƏTLƏRİNİN YENİDƏN TƏYİNİ

A.V. Morojenko tərəfindən verilmiş üsula düzəliş edilərək, Yupiterin spektrində müşahidə olunan amonyak qazının uyğun udma zolaqlarının laboratoriyada təyin edilmiş monoxromatik udulma əmsallarının qiymətlərinə əsasən, onların planet atmosferi şəraitində qiymətləri yenidən hesablanmışdır.

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