

Modeling the Earth's Nightglow Intensity of the Chamberlain and Herzberg I Bands and Comparing the Calculation Results with the Experimental Data

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Received October 14, 2021; revised January 21, 2022; accepted January 27, 2022

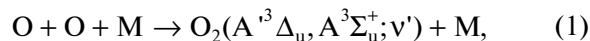
Abstract—The calculations of volume intensity profiles of the Earth's nightglow of the Chamberlain and Herzberg I bands of molecular oxygen are given. The calculations of glow intensities of the Chamberlain and Herzberg I bands are compared with the experimental data obtained from the Discovery Space Shuttle (STS-53) and from the EbertFastie spectrograph (Kitt Peak National Observatory, USA, Arizona). It is shown that the best agreement between the calculation results and experimental data is observed when correcting the quantum yields of the vibrational levels $A^3\Delta_u$ and $A^3\Sigma_u^+$ of the molecular oxygen states under triple collisions.

DOI: 10.1134/S001679322204003X

1. INTRODUCTION

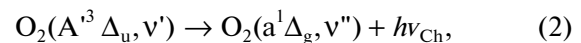
Awareness of the possibility of upper atmosphere radiation at middle and low latitudes under quiet geomagnetic conditions did not arise until the task of estimating the planet's surface illumination at nighttime was proposed. By the end of the second decade of the 20th century it became obvious that the Earth's atmosphere is undergoing processes that are indicated by the intrinsic glow of the night atmosphere under quiet geomagnetic conditions (Shefov et al., 2006).

One of the sources of nightglow is electronically excited molecular oxygen $O_2(A^3\Delta_u, A^3\Sigma_u^+)$, which is formed during triple collisions in the Earth's atmosphere with the involvement of two O atoms and a third particle:

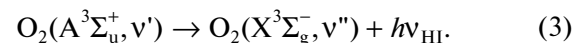


where v' is the vibrational level of the indicated state; M is the third particle in the collision. Oxygen atoms are effectively formed in the Earth's atmosphere during the daytime during the photodissociation of O_2 molecules by the solar UV radiation: $O_2 + h\nu \rightarrow O + O$. Triple collisions (1) with the formation of $O_2(A^3\Delta_u, A^3\Sigma_u^+)$ are most effective in the Earth's atmospheric layer with a thickness of ~ 10 km centered at the altitude of ~ 90 km (Shefov et al., 2006; Broadfoot and Bellaire, 1999). Further, the electronically excited oxygen molecule passes into the lower energy state, by emitting photons of light at the same time. Spontaneous

transitions from the electronically excited $A^3\Delta_u$ to the electronically excited $a^1\Delta_g$ state of the oxygen molecule lead to the glow of Chamberlain (Ch) bands:



while transitions from the electronically excited $A^3\Sigma_u^+$ state to the $X^3\Sigma_g^-$ ground state of the oxygen molecule leads to the glow of Herzberg I (HI) bands:



This work uses experimental data on the characteristic concentrations [O] in the mentioned layer based on the characteristics of the fluorescence of atomic oxygen O for different months of the year under low ($F10.7 = 75$, 1976 and 1986) and high ($F10.7 = 203$, 1980 and 1981) solar activity at mid-latitudes (55.7° N; 36.8° E, Zvenigorod Observatory of the Obukhov Institute of Atmospheric Physics (IAP) of the Russian Academy of Sciences). Regular data on the fluorescence of atomic oxygen O were obtained from a semi-empirical model that integrates several types of different mid-latitude measurements, regression relations, and theoretical calculations over several decades by the IAP staff (Shefov et al., 2006). In accordance with the main seasonal patterns of variations in the intensity of the 557.7 nm emission, the atomic oxygen layer also significantly changes the position of its maximum, depending on both the month of observations and the solar activity (Shefov et al., 2006; Perminov

et al., 1998). An increase in solar activity leads to a growth of the O concentration at the layer maximum and to a descent of its lower boundary (Semenov and Shefov, 1999).

The results obtained showed a significant change in the values of absolute concentrations of atomic oxygen at the layer maximum, the height of which also remained inconstant. The model calculation results for the 557.7 nm emission have revealed that there is a negative correlation between the height of the maximum of atomic oxygen and its concentration. Moreover, a negative correlation is clearly traced between an intensity of 557.7 nm emission and a height of the emitting layer maximum both for seasonal variations and for the dependence on solar activity (Semenov and Shefov, 1997; Shefov et al., 2000).

As a result of a change in profiles of the atomic oxygen concentration, the inevitable changes occur in profiles of the formation rate of the electronically-excited molecular oxygen O_2^* in the Earth's atmosphere due to process (1) and the glow intensity of various bands of molecular oxygen. Therefore, the glow intensities of the Chamberlain and Herzberg I bands depend both on the season and on the solar activity.

In this paper, the processes of excitation and quenching of electronically excited molecular oxygen in the Earth's atmosphere at the nightglow heights are considered. It should be noted in this case that the Herzberg I bands have a wide spectrum in the Earth's nightglow, in contrast to the Chamberlain bands, which are present in a smaller spectral range.

The purpose of this work was to compare the results of theoretical calculations of the glow intensities of the Chamberlain and Herzberg I bands with experimental data on the nightglow of molecular oxygen O_2^* in the Earth's atmosphere. Particular attention is paid to the peculiarities of the formation of different vibrational levels v' of the electronically excited states $A^3\Delta_u$ and $A^3\Sigma_u^+$ of the oxygen molecule as a result of triple collisions (1).

2. THE EARTH'S NIGHTGLOW

Figure 1 shows several spontaneous radiative transitions from different vibrational levels of the $A^3\Delta_u$ state to different vibrational levels of the state $a^1\Delta_g$, at which the emission of the brightest Chamberlain bands occurs. Several spontaneous radiative transitions from different vibrational levels of the $A^3\Sigma_u^+$ state to various vibrational levels of the $X^3\Sigma_g^-$ state are also given, at which the Herzberg I bands are emitted.

All the mentioned states are below the O_2 molecule dissociation energy of $\sim 41300 \text{ cm}^{-1}$ ($8065 \text{ cm}^{-1} = 1 \text{ eV}$). The wavelength λ of the Chamberlain and Herzberg I bands can be calculated using the formulas

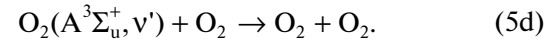
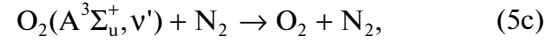
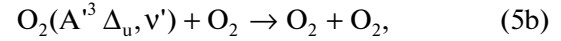
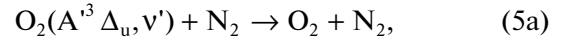
$$\lambda_{\text{Ch}} = 1/(E_{A'(v')} - E_{a(v'')}), \quad (4a)$$

where $E_{A'(v')}$ (cm^{-1}) is the energy of the vibrational level v' of the $A^3\Delta_u$ state and $E_{a(v'')}$ (cm^{-1}) is the energy of the vibrational level v'' of the $a^1\Delta_g$ state,

$$\lambda_{\text{HI}} = 1/(E_{A(v')} - E_{X(v'')}), \quad (4b)$$

where $E_{A(v')}$ (cm^{-1}) is the energy of the vibrational level v' of the $A^3\Sigma_u^+$ state and $E_{X(v'')}$ (cm^{-1}) is the energy of the vibrational level v'' of the $X^3\Sigma_g^-$ state.

Since the transitions between the considered states are dipole-forbidden the characteristic radiative times of the $A^3\Delta_u$ and $A^3\Sigma_u^+$ states are on the order of 1 and 0.1 s, respectively (Bates, 1989). Therefore, when calculating the concentrations of electronically excited oxygen, it is necessary to take the quenching of $O_2(A^3\Delta_u)$ and $O_2(A^3\Sigma_u^+)$ molecules into account not only during radiative transitions (2) and (3), but also during collisions with nitrogen N_2 and oxygen O_2 molecules (Kirillov, 2012):



Since the N_2 concentrations at altitudes of 90–100 km exceed 10^{13} cm^{-3} , while the quenching constants of the $A^3\Delta_u$ and $A^3\Sigma_u^+$ states exceed $\sim 10^{-12} \text{ cm}^3 \text{ s}^{-1}$ (Kirillov, 2010, 2014), the collisional lifetimes of the considered vibrational levels of these states are either comparable or much smaller than radiative ones of the Chamberlain and Herzberg I bands at nightglow altitudes. This means that the kinetics of Herzberg states within the considered range of atmospheric altitudes is largely determined by collisional processes.

The concentrations of excited oxygen $O_2(A^3\Delta_u)$ and $O_2(A^3\Sigma_u^+)$ are calculated at the Earth's upper atmosphere altitudes for vibrational levels $v' = 3-8$ of both states for October 1976 and 1986, at the low solar activity, $F_{10.7} = 75$ (Antonenko and Kirillov, 2021). In calculations of concentrations of electronically excited oxygen $O_2(A^3\Delta_u)$ and $O_2(A^3\Sigma_u^+)$, the following formulas will be used:

$$[O_2(A^3\Delta_u, v')] = q_v^A \alpha_A k_1 [O]^2 \times ([N_2] + [O_2]) / (A_{v'}^A + k_{5a}[N_2] + k_{5b}[O_2]), \quad (6a)$$

$$[O_2(A^3\Sigma_u^+, n')] = q_v^A \alpha_A k_1 [O]^2 \times ([N_2] + [O_2]) / (A_{v'}^A + k_{5c}[N_2] + k_{5d}[O_2]), \quad (6b)$$

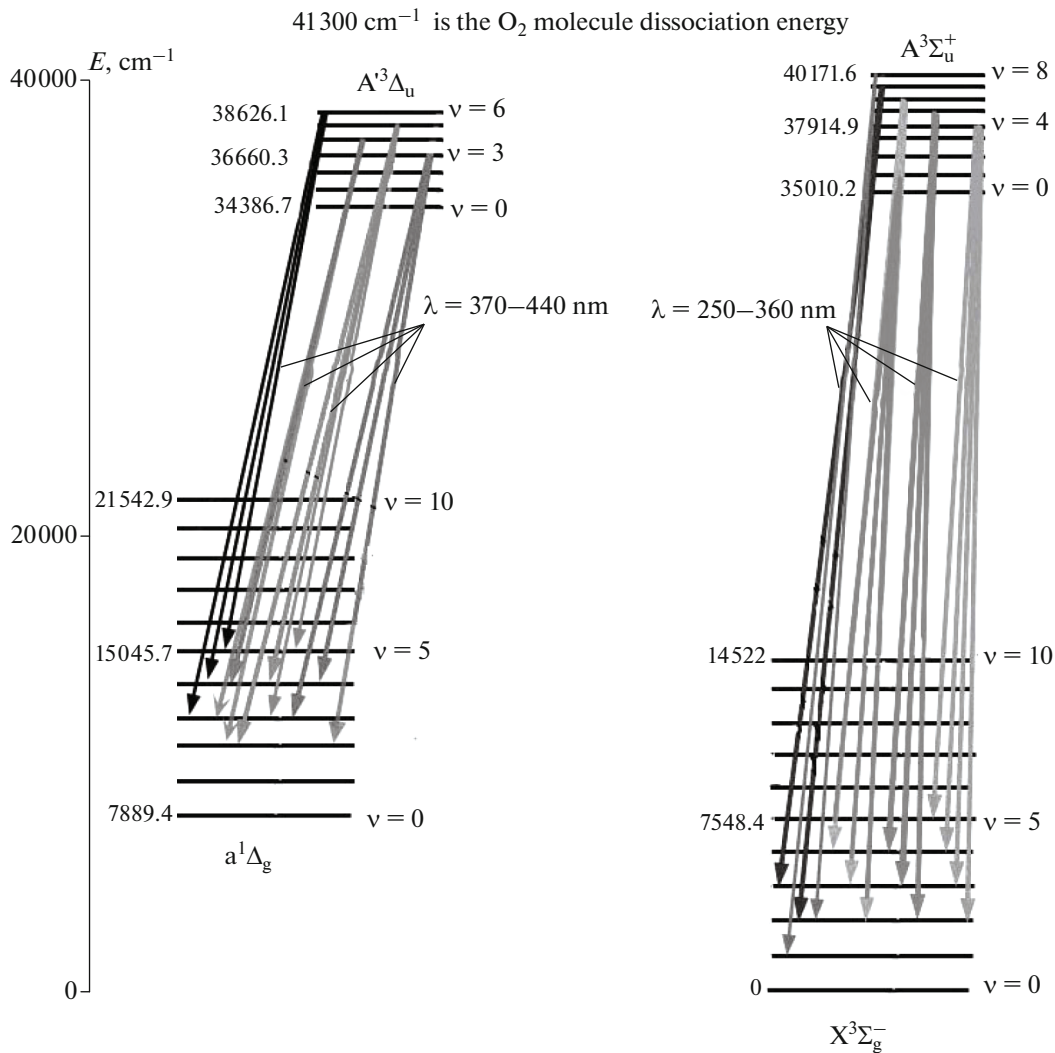


Fig. 1. Electronic transitions inside the O₂ molecule.

where $\alpha_{A'}$ and α_A are the quantum yields of the $A'^3\Delta_u$ and $A^3\Sigma_u^+$ states in triple collisions (1), while $q_{v'}^{A'}$ and $q_{v'}^A$ are the quantum yields of the vibrational levels v' of these states, respectively; k_1 is the recombination rate constant in triple collisions (1), k_{5a} , k_{5b} , k_{5c} , and k_{5d} are the rate constants of reactions (5a)–(5d); and $A_{v'}^{A'}$ and $A_{v'}^A$ are the sums of the Einstein coefficients for all spontaneous radiative transitions from the vibrational levels v' of the $A'^3\Delta_u$ and $A^3\Sigma_u^+$ states; moreover, for the $A'^3\Delta_u$ state it is also necessary to take spontaneous transitions to the ground state $X^3\Sigma_g^-$ at which the emission of Herzberg III bands occurs into account (Bates, 1989).

The recombination rate constant k_1 (cm⁶ s⁻¹) was used as a calculated value depending on the atmo-

spheric temperature within the considered altitude interval according to Shefov et al. (2006); the constants of quenching of the electronically excited oxygen in double collisions of the molecular oxygen with particles of atmospheric components k_{5a} (cm³ s⁻¹), k_{5b} (cm³ s⁻¹), k_{5c} (cm³ s⁻¹), and k_{5d} (cm³ s⁻¹) were taken into account according to Kirillov (2010, 2014); the quantum yields $\alpha_{A'}$ and α_A , according to Krasnopolsky (2011); the Einstein coefficients for all spontaneous transitions were taken according to Bates (1989).

The analytical formula for calculating quantum yields $q_{v'}^{A'}$ and $q_{v'}^A$ was presented in (Kirillov, 2012):

$$q_{v'} \sim \exp[-(E_{A',A(v')} - E_0)^2 / \beta^2], \quad (7)$$

where $E_0 = 40000$ cm⁻¹, $\beta = 1500$ cm⁻¹ are parameters determined using the least squares method by com-

paring the calculated vibrational populations of the $A^3\Delta_u$ and $A^3\Sigma_u^+$ states with the results of ground-based observations. Equation (7) was used to calculate the values of $q_{v'}^{A'}$ and $q_{v'}^A$; in this case the values of quantum yields were normalized in such a way so that a sum for each electronically excited state was equal to unity.

3. THE RESULTS OF MODELING THE GLOW INTENSITIES OF THE CHAMBERLAIN AND HERZBERG I BANDS

According to Eqs. (6a) and (6b), the profiles of altitude distribution of concentrations of the electronically excited molecular oxygen O_2^* were calculated for the $A^3\Delta_u$ and $A^3\Sigma_u^+$ states in the Earth's upper atmosphere. When calculating the concentrations of electronically excited oxygen, the altitude temperature profiles were used which were compiled on the basis of long-term (1960–2000) measurements of temperature profiles at altitudes of 30–110 km (Semenov et al., 2004). The method that has been developed by these authors for calculating the altitude temperature profiles and the total atmospheric concentration makes it possible to determine the temperature and density of the atmosphere at middle latitudes for given heliogeophysical conditions (altitude, solar activity level, and year).

The values of the volume emission intensities of the bands corresponding to transitions (2) and (3) were calculated by the formula

$$i_{v',v''}(\text{cm}^{-3} \text{ s}^{-1}) = [O_2^*]A_{v',v''}, \quad (8)$$

where $[O_2^*]$ (cm^{-3}) is the calculated concentration of electronically excited oxygen O_2^* depending on the altitude h (Antonenko and Kirillov, 2021) and $A_{v',v''}$ (s^{-1}) is the Einstein coefficient that corresponds to the spontaneous radiative transition from the vibrational level v' of the upper state to the vibrational level v'' of the lower state in (2) and (3) (Bates, 1989).

Figure 2 shows the calculated altitude distributions of the volume emission intensities of the bands associated with spontaneous transitions $A^3\Delta_u$ ($v' = 6$) \rightarrow $a^1\Delta_g$ ($v'' = 3$) (Figs. 2a, 2c) and $A^3\Sigma_u^+$ ($v' = 6$) \rightarrow $X^3\Sigma_g^-$ ($v'' = 3$) (Figs. 2b, 2d), for conditions of low ($F10.7 = 75$, 1976 and 1986) (Figs. 2a, 2b) and high ($F10.7 = 203$, 1980 and 1981) (Figs. 2c, 2d) solar activity at the middle latitudes of the Earth. The numerals stand for the months of the year: 1 for January, 2 for April, 3 for July, and 4 for October. The calculations used data on the atomic oxygen concentrations for the middle months of each season. Along horizontal axes, the values of the volume emission intensity i ($\text{cm}^{-3} \text{ s}^{-1}$) are given; along the vertical axes, altitudes in km are laid.

Figures 3a and 3b show fragments of the average nightglow spectrum in the ranges of 370–440 nm and 250–360 nm, respectively, measured by the spectrograph at the Discovery Space Shuttle (STS-53) in an interval from 115 to 900 nm over its 12-day mission in January 1995 (low solar activity conditions) (Broadfoot and Bellaire, 1999). The vertical axes show the intensities in Rayleigh/angstrom ($R/\text{\AA}$) ($1 R = 10^6$ photons/ $\text{cm}^2 \text{ s}$), while the horizontal axes show the wavelengths in angstroms ($\lambda(\text{\AA})$). The two numerals above the glow peaks denote vibrational levels ($v'-v''$) at radiative transitions (2) and (3).

The calculated values of emission intensity I ($\text{cm}^{-2} \text{ s}^{-1}$) (histograms) for various Chamberlain and Herzberg I bands caused by radiative transitions (2), (3) and presented in Fig. 1 were obtained for October 1976 and 1986 (conditions of low solar activity $F10.7 = 75$) within the same wavelength range. The calculation results are shown in Figs. 3c and 3d; in this case, when recalculating the volume emission rate $i_{v',v''}$ into the emission intensity $I_{v',v''}$, the optically thin layer approximation is used, i.e., the absorption of photons inside the layer is neglected.

As the calculations have shown, a discrepancy between the calculated values of the emission intensity and the experimental values is observed for the third and fourth vibrational levels in the case of Chamberlain bands and for the third and fourth vibrational levels for the Herzberg bands. This discrepancy may be explained either by underestimated values of the quantum yields $q_{v'}$ for these vibrational levels, or by overestimated values of the constants of quenching processes (5a)–(5d) during a collision with N_2 and O_2 molecules.

In (Kirillov, 2010, 2014), the calculated constants for the processes of quenching the electronic excitation of Herzberg states showed good agreement with the results of laboratory measurements. For the quantum yields $q_{v'}^{A'}$ and $q_{v'}^A$, in their evaluation in (Kirillov, 2012) the analytic formula (7) was initially used, which might give an error for vibrational levels for small values. Therefore, in these calculations, we vary the values of quantum yields (Table 1) by increasing their values by approximately one-third for the third and fourth vibrational levels of the $A^3\Sigma_u^+$ state (Antonenko and Kirillov, 2021). For the $A^3\Delta_u$ state, the values of the normalizing coefficients of quantum yields for different vibrational levels are increased for the third level by 5 times and for the fourth level by 1.5 times. Accordingly, the values of the normalizing coefficients of quantum yields for other vibrational levels were reduced; this is also shown in Table 1. When using the modified quantum yields $q_{v'}^A$, better agreement was achieved between the calculated intensities of the emission bands of the excited oxygen O_2^* ($A^3\Sigma_u^+$, $v' = 3$ –8) and the spectra obtained from the Shuttle

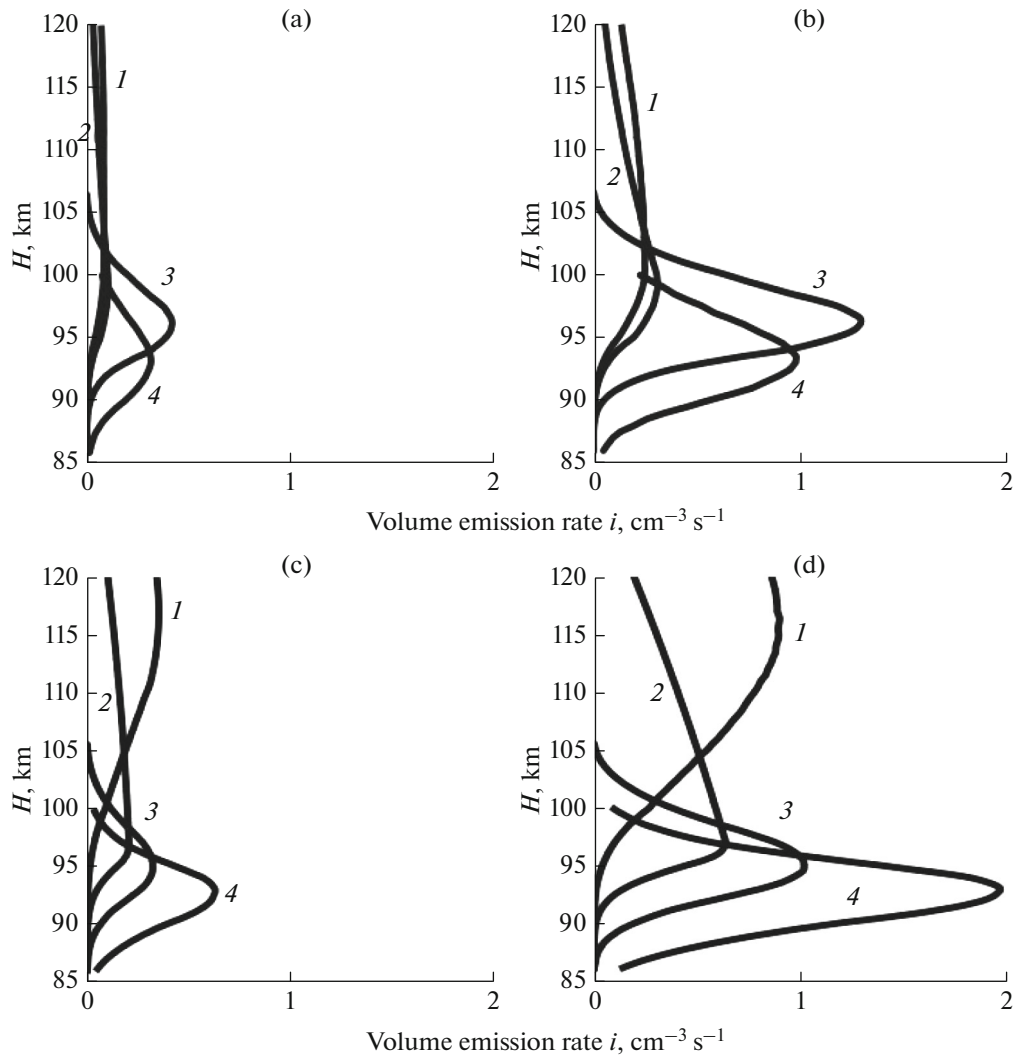


Fig. 2. The calculated altitude distributions of the volume emission rate $i_{v'v''}$ ($\text{cm}^{-3} \text{s}^{-1}$) of the (a, c) Chamberlain bands and (b, d) Herzberg I bands at the middle latitudes of the Earth for different months of the year: January (1), April (2), July (3), October (4).

(Broadfoot and Bellaire, 1999), that is, the experimental data on the nightglow within a range of 250–360 nm, which is clearly seen in Fig. 3d.

For the $\text{O}_2(\text{A}^3\Delta_u, v' = 3-6)$ state, it is much more difficult to compare the theoretically calculated values of band intensities with the experimental data, since the Chamberlain band glow intensities are much lower and the experimental errors are higher. Figure 3c shows the results of calculations of the glow intensities of 10 Chamberlain bands. For the band emitted during the spontaneous transition (2) with $v'-v'' = 6-4$, during the calculation with the Einstein coefficient according to Bates (1989), the obtained glow intensity values are significantly lower than in the spectrum received from an aircraft (Broadfoot and Bellaire, 1999). Therefore, in the present work, the Einstein coefficient for this transition was increased by a factor of five. After using the modified value of the Einstein

coefficient, it became possible to obtain a glow peak in the region of 400 nm, as was observed in (Broadfoot and Bellaire, 1999).

The agreement of the theoretically calculated intensities of the Chamberlain and Herzberg I bands with the experimental data indicates that the experimentally obtained data on the glow of molecular bands can be used to estimate the rates of formation and quenching of various vibrational levels of electronically excited states in various collisional processes. In this case, the best agreement between the results of calculations and experimental data was obtained due to the correction of quantum yields $q_{v'}^{\text{A}'}$ and $q_{v'}^{\text{A}}$, which were approximated in (Kirillov, 2012) by analytic formula (7).

Similarly, Fig. 4a shows the nightglow spectrum within the wavelength range of 370–440 nm, which was measured by the EbertFastie spectrograph (Kitt

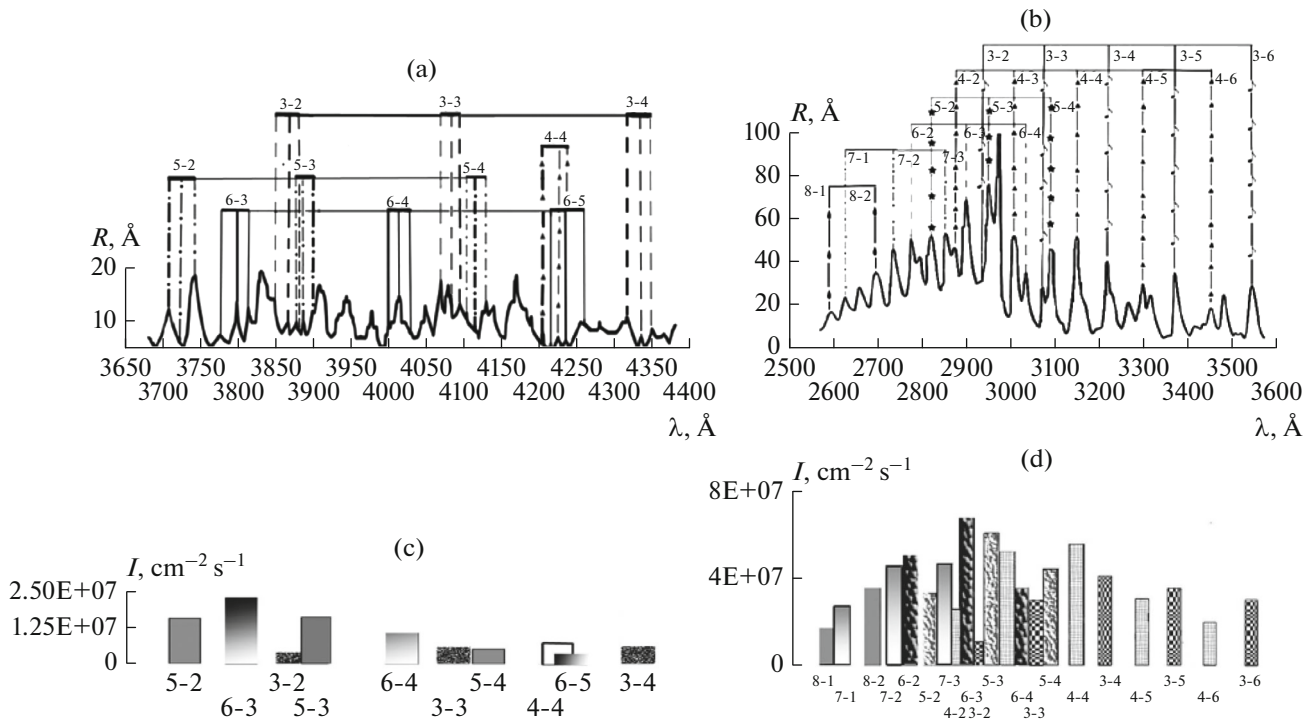


Fig. 3. (a) A fragment of the averaged nightglow spectrum in the range of 370–440 nm, measured by a spectrograph from the Space Shuttle (Broadfoot and Bellaire, 1999): The ordinates are the intensities ($R/\text{Å}$), the abscissas are the wavelengths λ (Å), numerals above peaks indicate ($v'-v''$) at radiative transitions (2). (b) A fragment of the averaged nightglow spectrum in the range of 250–360 nm, measured by a spectrograph from the Space Shuttle (Broadfoot and Bellaire, 1999): Ordinates present the intensities ($R/\text{Å}$), abscissas present the wavelengths λ (Å), numerals above the peaks indicate ($v'-v''$) for radiative transitions (3). (c) Calculated values of the emission intensity for various Chamberlain bands taking into account the modified quantum yields $q_v^{\text{Å}}$. (d) Calculated values of the emission intensity for various Herzberg I bands with allowance for the modified quantum yields $q_v^{\text{Å}}$.

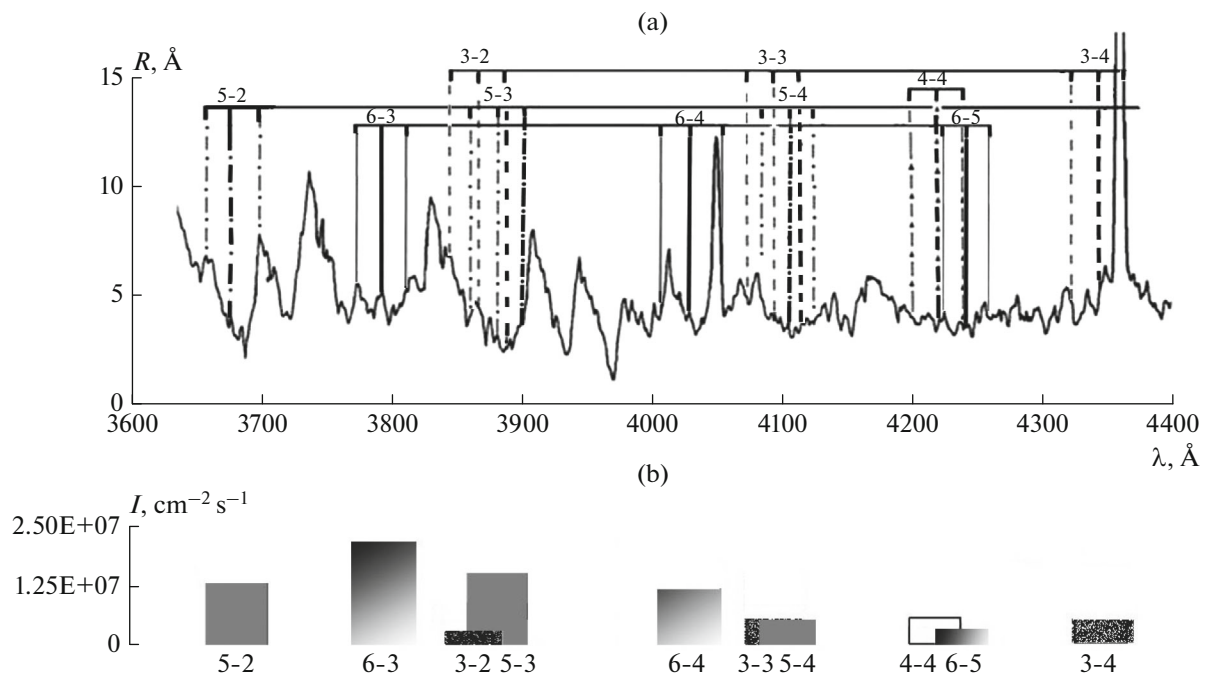


Fig. 4. (a) A fragment of the averaged nightglow spectrum in the wavelength range of 370–440 nm, measured by the EbertFastie spectrograph (Kitt Peak Observatory) at an altitude of 2080 m (Broadfoot and Kendall, 1968). The intensities ($R/\text{Å}$) are on the ordinate axis. The wavelengths λ (Å) are on the abscissa. Numerals above the peaks are ($v'-v''$) for radiative transitions (2). (b) Calculated values of the emission intensity for various Chamberlain bands taking into account the modified quantum yields $q_v^{\text{Å}}$.

Table 1. The quantum yields $q_{v'}$ of the vibrational level v' according to (Kirillov, 2012) and those modified in this paper

	v'	Energy $E_{v'}$, cm^{-1}	$q_{v'}$ (Kirillov, 2012)	Modified $q_{v'}$
$A^3\Sigma_u^+$	0	35010.2	3.23E-06	3.27E-06
	1	35784.6	7.77E-05	7.77E-05
	2	36528.6	9.87E-04	9.87E-04
	3	37239.6	7.07E-03	9.43E-03
	4	37914.9	3.03E-02	4.04E-02
	5	38551.0	8.22E-02	8.22E-02
	6	39143.3	1.51E-01	1.51E-01
	7	39686.0	2.00E-01	1.93E-01
	8	40171.6	2.06E-01	1.81E-01
	9	40589.5	1.79E-01	1.88E-01
	10	40925.8	1.42E-01	1.42E-01
	Sum:		1.00E+00	1.00E+00
$A^3\Delta_u$	0	34386.7	1.68E-07	1.68E-07
	1	35174.4	1.00E-05	1.00E-05
	2	35933.1	1.30E-04	1.30E-04
	3	36660.9	1.43E-03	7.15E-03
	4	37354.7	9.03E-03	1.40E-02
	5	38011	3.49E-02	3.49E-02
	6	38626.1	8.75E-02	8.75E-02
	7	39194.4	1.51E-01	1.71E-01
	8	39712.8	1.95E-01	1.82E-01
	9	40171.1	1.99E-01	1.99E-01
	10	40561.2	1.76E-01	1.76E-01
	11	40872.7	1.44E-01	1.44E-01
	Sum:		1.00E+00	1.00E+00

Modified values of quantum yields $q_{v'}$ are marked in bold type.

Peak National Observatory, Arizona, United States) at an altitude of 2080 m (Broadfoot and Kendall, 1968). At UV wavelengths (310–450 nm), a low brightness ultraviolet source was used (Broadfoot and Hunten, 1964). The observatory has been in operation since

1958, however, the authors Broadfoot and Kendall (1968) described observations referring to the measurements of 1961–1964 during a period of low solar activity. The theoretically calculated values of ten Chamberlain bands are presented in Fig. 4b. As can be seen from the comparison of panels a and b in Fig. 4, the calculated intensities of ten Chamberlain bands repeat the experimental data satisfactorily.

In this case, the satisfactory agreement between the results of calculations of the intensities of the molecular oxygen glow bands and the experimental data received from the Discovery Shuttle (STS-53) (Broadfoot and Bellaire, 1999) and at the Kitt Peak Observatory (Broadfoot and Kendall, 1968), was achieved due to the correction of quantum yields $q_{v'}$, which were approximated by the analytic formula (8) in (Kirillov, 2012). In most cases of spectral measurements (as in (Broadfoot and Bellaire, 1999; Broadfoot and Kendall, 1968)), the results are presented in the form of curves without rotation-structure resolution. Therefore, in this work, we compared the calculation results (histograms) with the maximum values of curves for each radiative transition.

The calculated values of $q_{v'}^A$ and $q_{v'}^{\Delta}$ for triple collisions (1) according to Kirillov (2012) and the values modified in this work are presented in Table 1 and in Fig. 5. The modified values are highlighted in bold type in Table 1. The modified values $q_{v'}^A$ and $q_{v'}^{\Delta}$ in Fig. 5 are represented by dashed lines.

Table 2 lists the emission intensities of the Chamberlain and Herzberg I bands $I_{v,v''}$ ($\text{cm}^{-2} \text{s}^{-1}$) for vibrational levels $v' = 3-8$ of radiative transitions (2) and (3) for October 1976 and 1986 at low solar activity $F10.7 = 75$. It can be seen from Table 2 that the emission intensity of the considered Chamberlain bands is ~40% of the emission intensity of the Herzberg I bands, which was indicated by the authors of (Broadfoot and Bellaire, 1999; Slanger and Copeland, 2003).

4. CONCLUSIONS

The intensities of the Chamberlain and Herzberg I band emissions due to radiative transitions from vibrational levels $v' = 3-6$ of electronically excited oxygen

Table 2. The emission intensities of Chamberlain bands and Herzberg I bands (in Rayleighs, $1R = 10^6$ photon/($\text{cm}^2 \text{s}$)) for vibrational levels $v' = 3-8$

Vibrational level v'	3	4	5	6	7	8	The ratio of the total intensity of the Chamberlain bands to the intensity of the Herzberg I bands
Chamberlain bands	14.5	42.6	69.2	92.9	108	60.7	42%
Herzberg I bands	39.9	103	218	248	206	114	

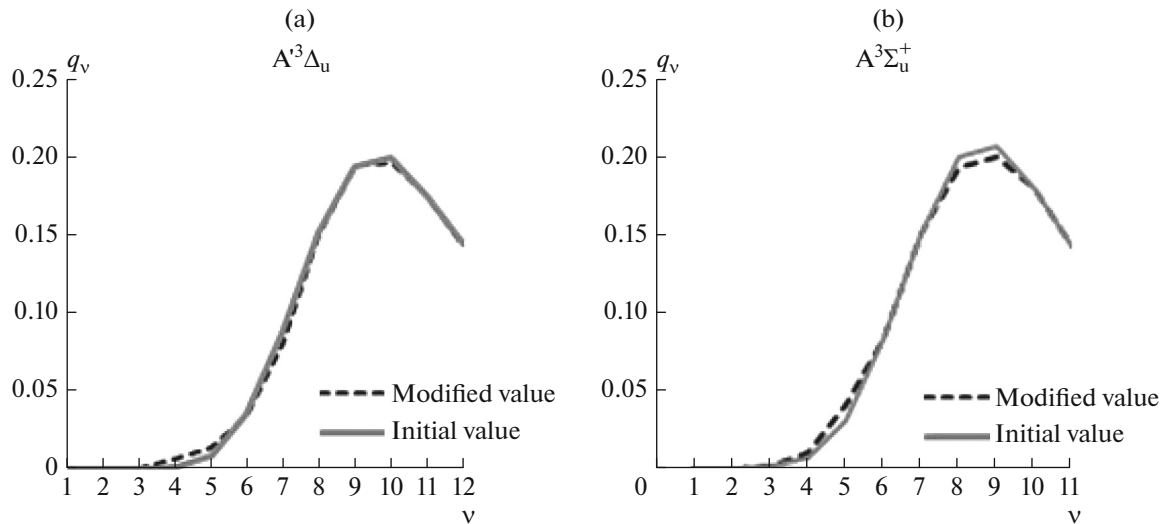


Fig. 5. (a) The values of the initial and modified quantum yields for the $A^3\Delta_u$ state. Along the vertical axis are the quantum yields q_v^A ; along the horizontal axis are the vibrational levels v' . (b) The values of the initial and modified quantum yields for the state $A^3\Sigma_u^+$. Along the vertical axis are the quantum yields q_v^A ; along the horizontal axis are the vibrational levels v' .

$O_2(A^3\Delta_u)$ and from vibrational levels $v' = 3-8$ of electronically excited oxygen $O_2(A^3\Sigma_u^+)$ have been obtained for low ($F10.7 = 75$ in 1976 and 1986) solar activity in middle latitudes. The calculated values of the emission intensity of the Chamberlain bands under conditions of low solar activity have been compared with the experimental data obtained in the wavelength range of 370–440 nm by a spectrograph from the Space Shuttle (Broadfoot and Bellaire, 1999) and at the Kitt Peak Observatory (Broadfoot and Kendall, 1968) under the same conditions. In addition, for conditions of low solar activity, the calculated values of the emission intensity of the Herzberg I bands were compared with experimental data obtained within the wavelength range of 250–360 nm by a spectrograph from the Space Shuttle (Broadfoot and Bellaire, 1999). The comparison of the experimental data with the calculated values of intensities of the bands showed that the best agreement is observed after correcting the quantum yields of vibrational levels of the $A^3\Delta_u$ state q_v^A and of vibrational levels of the $A^3\Sigma_u^+$ state q_v^A as a result of triple collisions (1), which were presented in (Kirillov, 2012).

It has been shown that the ratio of the calculated values of intensities of the Chamberlain and Herzberg I band emission from vibrational levels $v' = 3-8$ of the $A^3\Delta_u$ and $A^3\Sigma_u^+$ states corresponds to the ratio of the values in (Broadfoot and Bellaire, 1999; Slanger and Copeland, 2003), i.e., the glow intensity of the Chamberlain bands is $\approx 40\%$ of the glow intensity of the Herzberg I bands.

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Translated by M. Samokhina