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Onboard Photometric Measurements of Airglow Intensity in the Atomic Oxygen Green Line $\lambda = 5577\text{Å}$ in Midlatitude Ionosphere

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ABSTRACT. Rocket photometric measurements of airglow intensity in the atomic oxygen green line at $\lambda = 5577\text{Å}$ are very important for understanding a great number of physico-chemical processes going on in the upper layers of the Earth's atmosphere. Basically, the onboard and terrestrial experiments carried out solved the problem of airglow generation and its altitudinal distribution as well as deactivation of corresponding excitation level of atomic oxygen. However, in the experiments of the second half of the last century the height of the maximum airglow intensity layer $\lambda = 5577\text{Å}$ was not defined with great precision. Rather, it was defined within the permissible error limit. The imperfections of other experiments has been partially removed within the present project. In particular, we carried out the experiment in the midlatitudes (site of Kapustin-Yar, Volgograd, 1986) in calm geomagnetic conditions of late twilight. Appropriate geomagnetic conditions and proper geometrical position of photometric measuring equipment allowed us to define the maximum height of the airglow layer. In the experiment, the measurements were made with a three-channel on-board spectrometer. Height dependence of airglow intensity in the range of 80÷140 km has been defined and the mechanism of generation of excited atomic oxygen has been provided for ascending and descending segments of the rocket trajectory. There are Chapman one-step mechanism and Barth's two-step process dominating in the excitation of atomic oxygen. *© 2013 Bull. Georg. Natl. Acad. Sci.*

Key words: *Rayleigh, on-board, threshold sensitivity, ascending, descending, deactivation.*

While repeating some measurements obtained in earlier experiments, the experimental results presented here supplement them to a certain extent [1-3].

The experiment was carried out in a midlatitude site in the region of the city of Volgograd in 1986. Meteorological rocket MP-12 was launched in the late twilight.

There was a set of measuring apparatus placed on board of the rocket. Ionosphere airglow intensity was measured by three-channel spectrophotometer developed and produced in the Kutaisi Polytechnic Institute (now Kutaisi Akaki Tsereteli State University) for measuring the atmospheric emissions and atomic oxygen $\lambda = 5577\text{Å}$, $\lambda = 6300\text{Å}$ and neutral lithium $\lambda = 6708Å$. Threshold sensitivity of the channels measuring emissions $\lambda = 5577Å$, $\lambda = 6300Å$, $\lambda = 6708Å$ was equal to 20± 5 Rayleigh, 80 ± 15 Rayleigh and 25 ± 5 Rayleigh, respectively. Angle of view, time constant and dynamic range were almost similar ~2.3°, ~0.15sec and ~10^4 for each channel.

The spectrophotometer was placed on board in perpendicular to the longitudinal axis of the rocket. Over the blend of the instrument at an angle of ~ 45° there were installed reflectors registering the airglows from the horizontal direction. The sampling rate of the telemeter was 100 Hz per channel. The apparatus was switched on from the Earth surface. However, the channel registering the airglows $\lambda = 6300Å$ malfunctioned. The other two channels worked normally throughout the flight.

The wings of the rocket opened at an altitude of ~70km. From that moment the apparatus began registering of the airglow intensity line $\lambda = 5577Å$. There was observed no increase of telemeter level on the channel registering airglows $\lambda = 6708Å$. Apparently, the volume of airglow intensity of the atmospheric neutral lithium was below the threshold sensitivity of the channel.

In processing the information of the telemeter, the report on airglow intensity was obtained every ~0.5 second.

The airglow intensity of atomic oxygen $\lambda = 5577Å$ was minimum at an altitude of ~85km and equaled ~50 Rayleigh. With increasing the altitude 95÷103 km the intensity also increased and reached its maximum (~180 Rayleigh). Then a rapid decrease of intensity followed up to the altitude of ~110 km and a slow decrease of intensity up to the ~150 km was observed. At the apogee it was equal to ~40 R.

In the descending segment of the rocket trajectory from the apogee to ~120 km, the airglow intensity was comparable to that of ascending segment. After that, it sharply increased reaching its maximum of ~200 Rayleigh at an altitude of 95÷100 km. Then there was a sharp decrease, when it reduced to a minimum of~70 Rayleigh at an altitude of ~83 km. In the descending segment the intensity of the registered airglow at an altitude of 80÷120 km was greater by 30 Rayleigh, on average, compared to that of the ascending segment. The thickness of the atmospheric layer of the maximum airglow was slightly greater compared to the analogous values of the other experiments [1, 3].

It is well known that the airglow of the atomic oxygen green line is generated at the expense of transition $^1S \to {}^1P_2$. In the midlatitude ionosphere the excited state of $O(^1S)$ is generated according to the Chapman one-step mechanism [6]:

$$O(^3P)+O(^3P)+O(^3P) \xrightarrow{k_1} O_2 + O(^1S) \qquad (1)$$

or according to the Barth two-step process [7,8]:

$$O(^3P)+O(^3P)+M \xrightarrow{k_2} O_2^* + M \qquad (2)$$

$$O_2^* + O(^3P) \xrightarrow{k_3} O_2 + O(^1S) \qquad (3)$$

where $O(^3P)$ is the atomic oxygen in ground state; M – the sum of concentration of molecular oxygen and nitrogen; O^*_2 - excited state of molecular oxygen; $k_{1,}$ k_2 and $k_{3\text{-}}$ reaction rate. In every case, the source of excitation is the combination of atomic oxygen and three components.

Assuming the Chapman process to be basic in the green line airglow we can explain the trend of the curve obtained in the experiment. The observed trend is explicitly determined by concentration of atomic oxygen, which is one of the main components of the upper atmosphere at the altitudes considered in the experiment. The increase of intensity at the apogee up to ~100km was caused by the increase of concentration of atomic oxygen, while the decrease of airglow intensity below ~100 km was conditioned by the decrease of concentration of atomic oxygen and by the increase of efficiency of the deactivation process in excited state of $O(^1S)$ [10]:

$$O(^1S)+O(^3P) \xrightarrow{k_4} O(^1D)+0.255\text{ eV} \qquad (4)$$

$$O(^1S)+O_2 \xrightarrow{k_5} O(^1D,^3P)+O_2 \tag{5}$$

$$O(^1S)+N_2 \xrightarrow{k_6} O(^1D,^3P)+N_2 \tag{6}$$

Here, K_4, K_5 and K_6 are the coefficients of deactivation; $O(^1D)$ and $O(^3P)$ states of the atomic oxygen. It is difficult to determine a dominating role of any of the above-mentioned mechanisms in of $O(^1S)$ state.

Difference between the thickness of maximum airglow of the observed experiment and those of the other experiments appears to be caused by gas emission from the rocket and formation of additional reagents of the atomic oxygen excitation. Certain difference in the airglow intensities in the ascending and descending segments of the trajectory is also caused by different levels of gas emission from the rocket and by the geometry of relative position of the airglow layer and the apparatus.

The registered distribution of intensity according to altitudes can also be explained by Barth mechanism. According to the laboratory measurements [11], basically, excitation of $O(^1S)$ occurred by that mechanism. Confirmation of such a conclusion was obtained in the rocket experiments [12-14].

The profile of the green line airglow intensity allows to define the atomic oxygen concentration, deactivation coefficient of the excited state $O(^1S)$, coefficient of vertical turbulent diffusion and other peculiar aeronomic parameters of the upper atmosphere that are imperative for controlling the balance of the atmospheric oxygen. The measurements carried out can also be used as the basis for other similar projects in future.

გეოფიზიკა

ატომური ჟანგბადის $\lambda = 5577Å$ ხაზის ნათების ინტენსივობის საბორტო ფოტომეტრიული გაზომვები საშუალოგანედოვან იონოსფეროში

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ატომური ჟანგბადის $\lambda = 5577Å$ მწვანე ხაზის ნათების ინტენსივობის რაკეტულ-ფოტომეტრიულ გაზომვებს გააჩნია განსაკუთრებული მნიშვნელობა დედამიწის ზედა ატმოსფერულ ფენაში მიმდინარე რიგი ფიზიკურ-ქიმიური პროცესების ახსნისათვის. ამასთან დაკავშირებით ჩატარებულმა საბორტო და მიწისპირა ექსპერიმენტებმა, ძირითადად გადაწყვიტეს ამ გამოსხივების გენერაციის საკითხი, მისი მაღლივი განაწილება და დეზაქტივაცია ატომური ჟანგბადის შესაბამისი აღგზნებული დონის. თუმცა გასული საუკუნის მეორე ნახევარში განხორციელებულ ანალოგიური კლასის ექსპერიმენტში $\lambda = 5577Å$ გამოსხივების ხაზის მაქსიმალური ინტენსივობის ფენის სიმაღლის განსაზღვრა ხდებოდა არც ისე ზუსტად, მაგრამ ცდომილების დასაშვებ საზღვრებში, რაც აისახებოდა მდგომარეობის მექანიზმების დაზუსტებაში. განსხვავებით ჩატარებული ექსპერიმენტებისაგან, ჩვენს მიერ განხილულ პროექტში ეს ხარვეზები ნაწილობრივ გამოსწორებული იყო. კერძოდ, ჩვენი ექსპერიმენტი ტარდებოდა საშუალო განედებზე (ქ. ვოლგოგრადის რაიონში, კაპუსტინ-იარის პოლიგონზე) გვიანი ბინდისას წყნარ გეომაგნიტურ პირობებში. ჩატარებულ

ექსპერიმენტში გაზომვები ტარდებოდა სამარხიანი საბორტო სპექტროფოტომეტრით. აგებულია $\lambda = 5577\text{Å}$ ინტენსივობის მაღლივი დამოკიდებულება კმ სიმაღლეებზე, წარმოდგენილია აღგზნებული დონის გენერაციის მექანიზმები რაკეტის ტრაექტორიის აღმავალ და დაღმავალ უბნებზე. მდგომარეობის აღგზნების მთავარ მექანიზმებს წარმოადგენს ჩეპმენის ერთსაფეხურიანი მექანიზმი და ბარტის ორსაფეხურიანი პროცესი.

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