INVESTIGATION OF THE MERIDIONAL PROFILE OF Na EMISSION IN THEUPPER ATMOSPHERE AT HIGH LATITUDES

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The results of experimental investigations of the Na doublet emission in the upper atmosphere at high altitudes performed with the help of a scanning photometer are presented. The excitation of the upper atmosphere by an incoming electron flux was monitored by recording the N_2^+ emission at λ = 4278 Å. Analysis showed that when auroras with the brightness coefficient II–III are present in the northern sector of the sky the maximum of Na doublet emission occurs in the region of the zenith. When the auroras are displaced toward the region of the zenith and farther southward of the region the maximum of the emission in the N_2^+ band at λ = 4278 Å occurs close in space to the maximum of the Na emission at λ = 5890–5896 Å.

INTRODUCTION

The emission of Na atoms with λ = 5890 Å and λ = 5896 Å has been recorded in the spectrum of the aurora.[1,2] The current interest in the study of the Na emission lines at high latitudes stems from the potential great usefulness of high-altitude lidar sounding systems based on resonance scattering of lidar radiation by Na atoms in geophysical measurements.[3–5]

In this paper the meridional profiles of the Na doublet emission are studied with the help of a scanning photometer as part of the preparatory work on the development of a high-altitude laser sounding system at the Noril'sk test are at the Institute of the Magnetism of the Earth, Ionosphere, and the Propagation of Radio Waves of the Siberian Branch of the Academy of Sciences of the USSR, and preliminary results are presented.

EXPERIMENT

The measurements were performed with the help of a two-channel scanning photometer. The emission of Na atoms was recorded in one channel with the help of an interference filter centered at the wavelength λ = 5893 Å and a half-width of 30 Å. In the other channel one of the strongest bands of the aurora – the λ = 4278 Å band of the nitrogen molecular ion N_2^+ – was recorded synchronously with the Na emission. The λ = 4278 Å N_2^+ band was chosen owing to the fact that the intensity of the emission at this wavelength is proportional to the intensity of the electron flux of the plasma layer.[1] The sky was scanned along the meridian from horizon to horizon (from south to north), and the emission of the same regions of the ionospheric plasma was recorded in both channels. The total period of one scanning cycle was equal to 1 min. The viewing angle of the photometer was equal to ~ 1° The measurements were performed on Mart 30, April 4, and April 5, 1984 during which the level of geomagnetic activity was comparatively high (ΣK = 36, 46, and 47, respectively). Several geographical situations, which we shall study below, were realized during the measurements.

1. A band with the brightness coefficient III in the north. The measurements were performed in the interval $15^h\,29^m - 15^h37^m$ UT on April 5, 1984. A band of the aurora, oriented along the latitude and having the brightness coefficient III, was observed visually in the north; the band recorded in the form of a peak at λ = 4278 Å N_2^+ in the scan (Fig. 1a). At the zenith a band whose brightness is less them I was recorded at the start of the scan, and then vanished (the peak in the region of the zenith at λ = 4278 Å).The scan in the line Na λ = 5890–5896 Å shows the presence of a peak of intensity at the same location as the zenith peak at λ = 4278 Å, and a peak in the north in a region close to the zenith (z = 1°); the zenith angle is measured from the perpendicular to the Earth's surface and angles read in a direction southward are negative, while angles measured northward are positive. The amplitude of the peak at the zenith is much greater than the amplitude of the peak in the north. With time the intensity of the band at λ = 4278 Å, at the zenith drops, while the intensity of the auroral band in the

north at $\lambda = 4278$ Å increases. As the intensity of the $\lambda = 4278$ Å auroral band in the north increases the intensities of both peaks in the Na line increase; in the process the spatial position of the zenith peak in the Na emission remains unchanged, while the width of the zenith peak depends on the intensity. This dependence is illustrated in Fig. 2, which shows the behavior of the width of the zenith peak φ (curve 1) and the intensity of the emission line J (curve 2) in 15 successive scanning cycles.

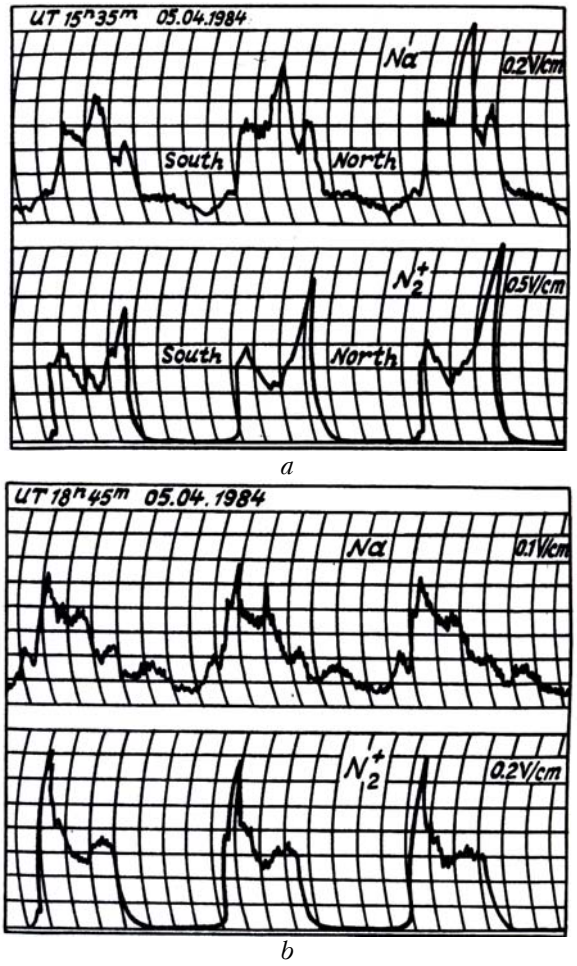

FIG. 1. The meridional profile of the N_2^+ and Na emissions of the upper atmosphere measured above Noril'sk on April 5, 1984: a — 15^h29^m–15^h37^m UT; b — 18^h40^m–18^h55^m UT.

Geophysical situations of this type have occurred repeatedly, for example, during the measurements in the interval 16^h39^m–16^h41^m UT on April 4, 1984. A band of the aurora with the brightness coefficient III was observed visually in the north, and a band with the coefficient less than I was observed at the zenith. The main features of the behavior of the Na emission line are identical to those described above. The maximum of the Na emission line is concentrated in the region of the zenith.

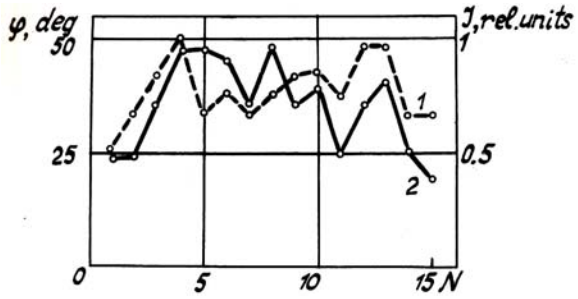

FIG. 2. The behavior of the angular width φ of the zenith peak of the emission of Na atoms and the emission intensity J with an auroral band present in the northern part of the sky.

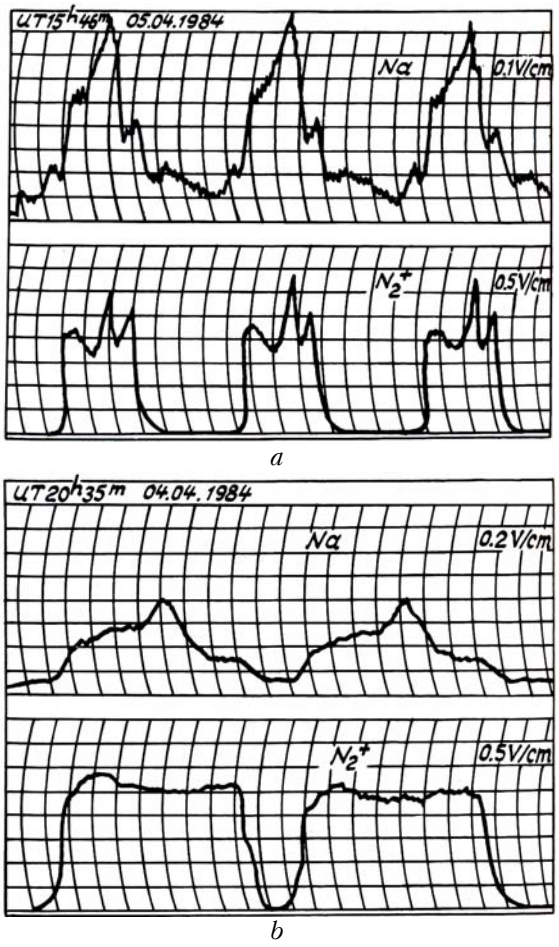

FIG. 3. The meridional profile of N_2^+ and Na emissions in the upper atmosphere measured above Noril'sk: a — in the time interval 15^h45–15^h57^m UT, April 5, 1984; b — 20^h33^m–20^h40^m UT, April 4, 1984.

2. Band with brightness coefficient I in the south. A band in the south, having the brightness coefficient I and oriented along the latitude, was observed in the interval 18^h40^m–$18^h55^{,n}$ UT on April 5, 1984. The scan showing the behavior of the N_2^+ and

Na emissions is presented in Fig. 1b. Analysis of the scan shows the presence of a peak of intensity in the south both in the N_2^+ emission band with $\lambda = 4278$ Å and in the Na emission line with $\lambda = 5890$–5896 Å; in addition, the spatial position of the peaks of intensity is the same in both emissions. In the region of the zenith no appreciable increase of the intensity is observed in the Na line.

3. Band with brightness coefficient II at the zenith. A band having the brightness coefficient II and oriented in latitude direction was observed at the zenith in the interval 15^h45^m–15^h57^m UT on April 5, 1984. The scan showing the behavior of the N_2^+ and Na emissions is presented in Fig. 3a. Analysis of the scan shows that the peak of intensity in the N_2^+ band with $\lambda = 4278$ Å lies in the region $z = 9°$ and its spatial position remains constant. The peak in the Na line lies southward of the zenith and drifts into the region of zenith angles ranging from $-30°$ to $-17°$. Drift was recorded both northward and southward, and in addition the drift velocity lies in the range 100–200 m/s, i.e., in the range of velocities of the main components of the ionospheric plasma.[7] In calculating the velocities the fact that the free atoms of alkali metals are concentrated in a layer at altitudes of 90–100 km from the Earth's surface was taken into account.[8]

In the interval 20^h16^m–20^h18^m UT on April 5, 1984 a band having the brightness coefficient II was also recorded in the region of the zenith ($z = -7°$), and the meridional profile of the intensity of the band has a maximum at $z = -7°$. The meridional profile of the Na line contains two peaks of intensity with $z = -20°$ and $-7°$, and in addition the peak at $z = -7°$ occurs at the same location in space as the peak at $\lambda = 4278$ Å.

4. Band with brightness coefficient I at the zenith. According to the theory the homogeneous forms of the aurora are usually oriented along the magnetic parallels (see, for example, Ref. 9). In the case analyzed here the band has an anomalous submeridional orientation. According to data from visual and instrumental observations in the region of Noril'sk, cases of the anomalous submeridional arrangement of the homogeneous forms, which contribute to the formation of the local structure of the spatial distribution of auroras in the Noril'sk region,[9–10] are not rare. Measurements were performed in the interval 20^h33^m–20^h40^m UT on April 4, 1984 and made it possible to obtain information both about the parameters of the band at $\lambda = 4278$ Å and the behavior of the Na emission line. A scan illustrating the described geophysical situation is presented in Fig. 3b. Analysis of the scan shows that the brightness in the band at $\lambda = 4278$ Å is distributed uniformly along the meridian. The meridional profile of the Na emission line has a peak of intensity at $z = -2°$, and the position of the peak does not change during the measurements.

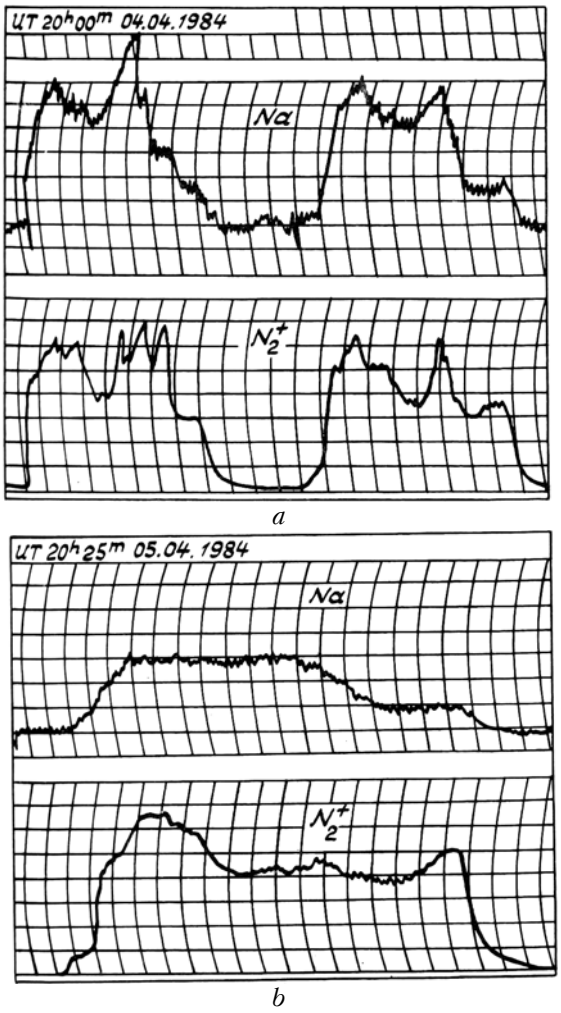

FIG. 4. The meridional profile of the N_2^+ and Na emissions of the upper atmosphere measured above Noril'sk on April 5, 1984: a — in the time interval 19^h59^m–20^h09^m UT; b — 20^h23^m–20^h44^m UT.

5. Corona with brightness coefficient II–III at the zenith. The measurements were performed in the interval $19^h59'$"–20^h09^m UT on April 5, 1984. Peaks of intensity with maxima at zenith angles $-3°$ and $-57°$ and close in spatial coordinates can be seen in the scan (Fig. 4a) for both emission lines. The amplitudes of the peaks in each line are comparable.

6. Diffusive spots. Diffusive spots in the sector southward of the zenith were recorded in the measurement interval of 20^h23^l"–20^h44^m UT on April 5, 1984. The scan (Fig. 4b) of the N_2^+ band shows a weak rise of the intensity and an increase of intensity in the southern sector and reflects the distribution of intensity of diffuse-spots in the $\lambda = 4278$ Å band. The intensity of the Na emission line in the region away from the zenith toward the southern horizon ($z = -70°$ and $-15°$), and in addition southward of the zenith the emission intensity in the line

λ = 5890–5896 Å is distributed uniformly along the meridian.

In the absence of auroras the scan of the N_2^+ band has an even character of the type described in Ref. 6, while the scan of the Na line exhibits a weak rise of intensity in the region of the zenith. In the case of measurements performed under cloudy conditions the scans of both emissions are featureless; this indicates that artificial sources of light make an insignificant contribution of the meridional profiles obtained. To determine the possible instrumental distortions the filters in the channels of the scanning photometer were permuted, i.e., the filter with λ = 5893 Å was placed in the channel which previously recorded the λ = 4278 Å emission. Permutations of the filters showed that the photometer channels were identical.

CONCLUSIONS

Analysis of the obtained seems leads to the following conclusions. In the presence of bright forms of the auroras in the northern sector the maximum of emission in the range of wavelengths close to the wavelength of emission of sodium atoms approaches the zenith. As the auroras shift toward the zenith and farther southward the spatial coordinates of the regions of the maxima of emission in the N_2^+ band at λ = 4278 Å become close to the spatial coordinates of the maxima of emission at wavelengths close to the wavelength of Na emission.

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REFERENCES

1. A. Omhold, *The Optical Aurora*, Springer-Verlag, No. 4, (1971) [Russian translation] (Mir, Moscow, 1974).
2. J. Chamberlain, *The Physics of the Aurora and Airflow*, Academic Press, No. 4 (1961) [Russian translation] (Mir, Moscow, 1963).
3. V.E. Zuev and M.'V. Kabanov, *Propagation of Optical Signals in the Earth's Atmosphere* (Sov. Radio, Moscow, 1977).
4. M.F. Lagutin, Tr. Inst, of eksperim. meteorol. Chief Director, of Hydrometeorol. Service by Council of Minis, of the USSR, No. 7/75, 43 (1977).
5. G.F. Tulinov, Yu.P. Dudoladov, M.L. Shanen, and M. Mezhi, *Ionospheric Investigations* (Nauka, Moscow, 1982).
6. K.I. Gorelyi and V.V. Netkachev, *Investigations in Geomagnetism, Aeronomy, and Solar Physics* No. 3, 93, (Nauka, Moscow 1977).
7. S.I. Len'kov, G.A. Zherebtsov, E.A. Ponomarev, and L.N. Popov, *The Atmosphere at High Latitudes and Magnitosphere-Ionosphere Couplings*, Kola Affiliate of the USSR Academy of Sciences, 86, Apatity (1986).
8. J. Chamberlain, *Theory of Planetary Atmospheres*, Academic Press, No. 4 (1978) [Russian translation], (Mir, Moscow, 1981).
9. Yu.K. Krakovetskii, O.I. Platonov, L.N. Popov; and I.D. Doronina, *Investigations in Geomagnetism, Aeronomy, and Solar Physics* No. 62, 155, (Nauka, Moscow, 1982).
10. T.P. Vail, Yu.A.Nadubovich, and N.N.Shumilova, *Investigations in Geomagnetism, Aeronomy, and Solar Physics*, No. 66, 99 (Nauka, Moscow, 1983).