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Abstract

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GEOPHYSICS

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MAGNESIUM AND CALCIUM IONS IN THE UPPER ATMOSPHERE OF THE EARTH

(Presented by Academician E. K. Fedorov, 11 X 1960)

More than 20 years ago, sodium was discovered in the upper atmosphere of the Earth ([1]). Its presence was established and confirmed by the presence of the *D* lines in the spectra of twilight and night-sky glow. In recent years, lines of lithium and ionized calcium ([2,3]) have also repeatedly been found in spectra of the twilight sky. The presence of other metals, as far as is known, has never been observed in the atmosphere.

Because most experiments on the study of the glow of the twilight and night sky are carried out from the Earth' s surface, data that are very important for understanding the physical conditions in the upper layers of the atmosphere—on the heights of emissions, the extent of the luminous layers, and their profile—are obtained with a rather large degree of uncertainty.

The estimate of the concentration of metal atoms made in measurements of this kind also cannot be considered absolutely reliable: it is determined indirectly, and its value depends substantially on a number of factors that are not very confidently determined. For the reasons set out above, it is naturally of interest to detect directly and measure the concentration of atoms (ions) of alkali and alkaline-earth metals in the upper atmosphere of the Earth.

During the launch of a geophysical rocket on the morning of 15 VI 1960 in the middle latitudes of the European part of the USSR, an ion radio-frequency mass spectrometer, along with the positive ions of nitric oxide NO^+ and molecular oxygen O_2^+ usual for these altitudes, recorded ions of magnesium Mg^+ and calcium Ca^+. The mass spectrometer was installed on a detachable container, which made it possible to carry out measurements in a region of the atmosphere uncontaminated by the rocket. The experimental method was completely analogous to that described earlier ([4]), but a mass spectrometer several times more sensitive than that used up to now was employed.

In all, at altitudes from 92 to 206 km, a little more than 100 spectra were obtained; in 5 of them there are peaks with mass numbers 24 and 26. Of these spectra, 3 were obtained on the ascending branch of the trajectory and 2 on the descending branch. These, as well as several preceding and subsequent spectra, are reproduced in Fig. 1. Noteworthy is the good agreement of the heights at which the peaks with $M = 24$ and 26 were recorded on the ascending and descending branches. Thus, the spectra with the maximum amplitude of these peaks were obtained, respectively, at altitudes of 103.5 and 105 km. Taking into account that the mass-scan period was ~ 3 sec, which in this case is equivalent to a change in altitude of ~ 4 km, such a coincidence of heights is more than satisfactory.

The element having mass number $M = 24$ is magnesium. In addition to the isotope Mg^{24}, there also exist the isotopes Mg^{25} and Mg^{26}: their relative abundances are, respectively, 78.6, 10.1, and 11.3% ([5]).

Ascending branch **Descending branch**

Figure 1. Mass spectra of positive ions obtained in the morning of 15 VI 1960. The indicated altitudes correspond to the time of appearance of the Mg^+ peaks. Atmospheric components are labeled with the corresponding chemical symbols. Unlabeled mass peaks in the spectra of the descending branch of the trajectory belong to contamination ions.

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If the recorded ions with $M = 24$ and 26 are magnesium ions, the ratio of the peak amplitudes i_{24}/i_{26} should be equal to 7.

The results of measurements of peak amplitudes in the spectra are given in Table 1.

Table 1

Time T, sec	Altitude H, km	Rel. intensities $\frac{i_{Mg^{24}}}{i_{Mg^{26}}}$	Rel. intensities $\frac{i_{Mg^+}}{i_{NO^+} + i_{O_2^+} + i_{Mg^+}}$	Concentration Mg^+, n_{Mg^+}, cm^{-3}
120	99.5	–	< 0.04	< 300
123	103.5	10 ± 2.4	0.17 ± 0.01	13 600
126	108.0	9 ± 6	0.02 ± 0.01	1 600
129	112.0	–	< 0.001	< 80
135	120.0	–	0.005 ± 0.001	400
418	109.0	–	0.03 ± 0.016	2400
421	105.0	9 ± 5	0.17 ± 0.02	13 600
424	100.5	–	< 0.01	< 800
Average		9.3 ± 5		

Taking into account possible systematic errors, the obtained mean value

$i_{Mg^{24}}/i_{Mg^{26}} = 9.3 \pm 5$ should be regarded as confirming the proposed identification of the ions with $M = 24$ and 26 as magnesium ions. The isotope Mg^{25} is not visible because of insufficient resolution. Its presence is indicated by a certain asymmetry at the base of the Mg^{24} peak (spectrum for $T = 123$ sec.).

The maximum value of the relative intensity of the magnesium ion peaks with respect to the total intensity of all recorded ionospheric components is

$$i_{Mg^+}/(i_{NO^+} + i_{O_2{}^+} + i_{Mg^+}) = 0.17.$$

The electron concentration in this launch was measured with an ultrashort-wave dispersion interferometer, in a manner analogous to that described in [6]. At altitudes from 100 to 110 km $n_e \simeq 8 \cdot 10^4$ cm^{-3}, whence the value of the maximum concentration of magnesium ions at an altitude of 103.5–105 km is $n_{Mg^+} = 1.36 \cdot 10^4$ cm^{-3}.

Figure 2 gives the data obtained for the variation of the concentration of magnesium ions with altitude and shows a possible profile of the layer. Taking the half-width of the layer to be 5 km, the total number of ions in a column of unit cross section is $N_{Mg^+} \simeq 7 \cdot 10^9$ cm^{-2}.

Fig. 2. Variation of the concentration of magnesium ions in the atmosphere as a function of altitude: **a**—measurements on the ascending branch of the trajectory, **b**—measurements on the descending branch of the trajectory. The dashed line denotes a possible profile of the Mg^+ ion layer.

Upon careful study of the spectrum for $T = 123$ sec., obtained on the ascending branch of the trajectory at an altitude of 103.5 km, one can detect a noticeable ion-current peak with $M = 40$. Since in the preceding and following spectra the peak $M = 40$ is definitely not present, its recording is naturally to be associated with the simultaneous appearance of Mg^+ ions and to be attributed to the presence in the same layer of calcium ions Ca^+.* In view of the fact that the lines of ionized calcium Ca II are present in twilight-sky emission spectra [2, 3], the identification of the ions with $M = 40$ as Ca^+ ions is beyond doubt. The peak of Ca^+ ions cannot be traced in the other spectra of Fig. 1, since there its intensity is below the detection limit.

* The relative abundance of the isotope Ca^{40} is 97%.

The recorded ratio of the concentrations of magnesium and calcium ions is $n_{Mg^+}/n_{Ca^+} = 25 \pm 8$, while the concentration of ions is $n_{Ca^+} \simeq 540$ cm^{-3}. Taking the layer profile for Ca^+ ions to be the same as for Mg^+ ions, we obtain that the total number of Ca^+ ions in a column of unit cross section is $N_{Ca^+} \simeq 3 \cdot 10^8$ cm^{-2}. This value is close to the estimate made from the intensity of the twilight glow of the Ca II lines: $N_{Ca^+} \simeq 5 \cdot 10^8$ cm^{-2}, given in paper (3). The results of paper (3) are quite comparable with the data presented here, since they were obtained in the same month (June), during the period of activity of the daytime meteor showers of the Arietids and Perseids (7). It should also be noted that there is good agreement between the estimate of the altitude of the Ca II emission layer obtained in paper (3) ($H = 100$ km) and the altitudes at which the maximum concentration of Mg^+ and Ca^+ ions was recorded ($H = 103.5 \div 105$ km).

If the meteor hypothesis of the origin of Ca^+ ions in the atmosphere (3) is accepted, then the detection of a large number of Mg^+ ions is not surprising either. Magnesium is the most widespread metal in stony meteorites, which, as is known, predominate in meteor streams (8); its content averages 16 wt. % (9).

It is especially worth noting the closeness of the ratio of ion concentrations recorded in the present launch, $n_{\mathrm{Mg}^+}/n_{\mathrm{Ca}^+} = 25 \pm 8$, to the ratio of the numbers of atoms of the same elements in meteorites, $n_{\mathrm{Mg}}/n_{\mathrm{Ca}} = 15$ (9).

This circumstance can be easily explained by the fact that ionization of fast-flying evaporated Mg and Ca atoms upon their interaction with atmospheric molecules, as well as recombination of the resulting Mg^+ and Ca^+ ions, must proceed in exactly the same way. Owing to the similarity of the physicochemical properties of these metals, the constants of the ionization and recombination processes must be close.

The fact, interesting in itself, of the direct detection in the upper atmosphere, during the period of activity of daytime meteor streams, of significant quantities of magnesium and calcium ions located in a relatively thin layer, as well as the quantitative ratios and the values of the concentrations of these ions, serves as confirmation of the hypothesis of their meteoric origin.

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Note: Figure translations are in progress. See original paper for figures.