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ANOMALOUS COMPOSITION OF FORMING IONS AND CERTAIN EVENTS IN THE LOWER IONOSPHERE

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SUMMARY

The anomalous composition of ions forming in the lower ionosphere and some of the events in that region are discussed in detail with the view of elucidating the relative roles of x-ray and ultraviolet radiations in its ionization.

This discussion evolves mainly about the character of the variations of $[NO^+]/[O_2^+]$ and α' as a function of solar activity level and the position of the Sun relative to the horizon, the conclusions relative to it being important for the understanding of the variation of physical conditions in the lower ionosphere.

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The elucidation of the relative role of x-ray (Roentgen) and ultraviolet radiation in the ionization of the E-region is one of the basic questions in the theory of lower ionospheric ionization at the altitudes 100 - 200 km. There is a series of facts—the incompatibility between the variation of the square of electron concentration n_e^2 and the variation of the rate q of ion formation during the day and the solar activity cycle [1], the inconstancy of the ratio of the NO^+ and O_2^+ ion concentration according to he altitude and during the transition from maximum to minimum solar activity [2], being in contradiction with the theory in which it is usually accepted that the effective recombination coefficient α' in the lower ionospheric region at altitudes 100 - 200 km does not vary during the day and as a function of the solar activity cycle. As is shown in [3], one should expect, however, that α' is a constant quantity. It will be shown later that calculations of the composition of ions, forming during ionization by solar radiation,

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* ANOMALIYA SOSTAVA OBRAZUYUSHCHIKHSYA IONOV I HEKOTORYYE YAVLENIYA V NIZHNEY IONOSFERE

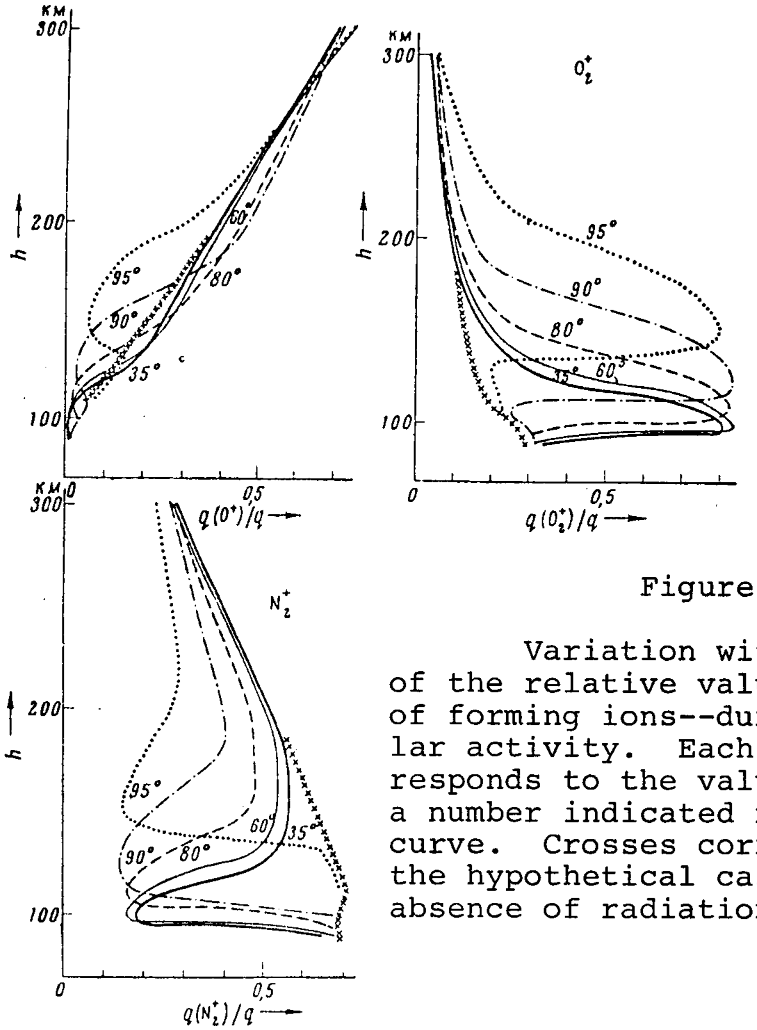

Figure 1

Variation with altitude of the relative values of rates of forming ions--during low solar activity. Each curve corresponds to the value of $z_\odot$ by a number indicated near the curve. Crosses correspond to the hypothetical case of the absence of radiation absorption.

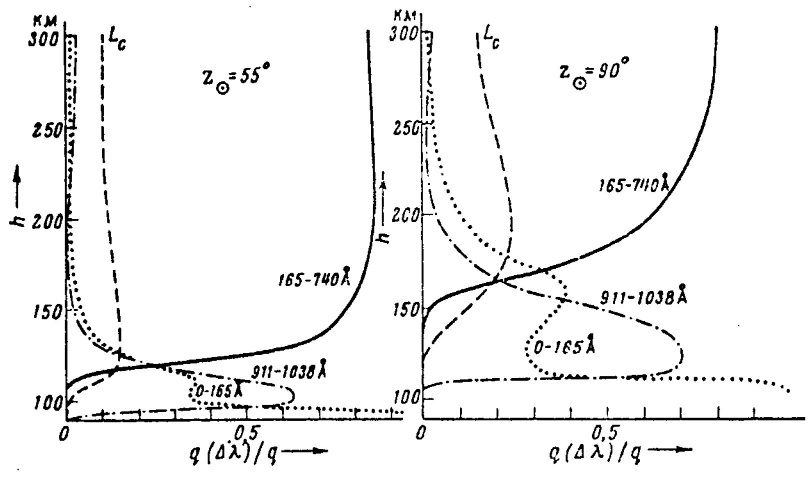

Figure 2

Variation with the altitude ion rate for four basic portions of the spectrum--the computation was made for low solar activity at $z_\odot = 55^\circ$ and $z_\odot = 90^\circ$.

confirm such a deduction and this permits us to eliminate the indicated differences between experiment and theory.

The relative composition of primary ions O^+, O_2^+ and N_2^+, forming under the action of solar radiation, was determined during calculations of the general rate of ion formation q [4] with the aid of M-20. The results of computation in conditions of low solar activity are shown in Figure 1. The curves of various $z_\odot$ are similar for every ion but are shifted upward and some of them are somewhat elongated by the altitude scale as $z_\odot$ increases. For each ion at the altitudes 200 - 300 km, the rate of ion formation is changed about proportionally to the neutral composition of the atmosphere just as is the case at low altitudes $\sim$100 km. But at intermediate altitudes $q(O_2^+)/q$ anomalously increases whereas $q(N_2^+)/q$ anomalously decreases with the result that the ratio $q(O_2^+)/q(N_2^+)$ increases up to 1.5 - 2 orders. The zone of anomalous increase of $q(O_2^+)/q(N_2^+)$ occupied an altitude region equal to about 2 - 3 altitudes of uniform atmosphere, its center shifting at $z_\odot$ variation from 0 - 50° to 80 - 90° from $\sim$105 km to $\sim$ 125 km. The cause of such an anomalous variation in the composition of forming ions consists in the spectral variation of solar ionizing radiation during its passage through the upper atmosphere.

Let us indeed consider Figure 2 on which the variation with the altitude of the relative rate of ion formation $q(\Delta\lambda)/q$, calculated for four basic spectral regions $\Delta\lambda$: 0 - 165 A, 165 - 740 A, 740 - 911 A and 911 - 1038 A, is shown for $z_\odot = 55°$ and $z_\odot = 90°$. It is evident that above $\sim$150 km ions are mainly formed under the action of shortwave radiation 165 - 740 A and that contribution of radiation in the range 740 - 911 A is 4 - 5 times less below $\sim$90 km, the x-ray radiation (with the wavelength shorter than $\sim$10 A) is the basic ionization source. It is noteworthy that in the 100 - 115 km altitude range, the fundamental contribution to ion formation is made by ultraviolet radiation in the range 911 - 1038 A. As seen from Figure 2, for great zenithal angles $z_\odot$, the pattern is the same as for $z_\odot$ = 0 - 55°, but it is shifted upward and somewhat stretched along the scale of altitudes. Inasmuch as the radiation 911 - 1038 A forms only O_2^+ ions, the anomalous growth $q(O_2^+)/q$ on the examined altitudes at $z_\odot = 55°$ is understandable. The curve drawn by crosses on Figure 1 represents the assumed variation of ion formation rate, which would be realized in the absence of radiation absorption. In the given case, the variations of $q(O_2^+)/q(N_2^+)$ are proportional to the variation of $[O_2]/[N_2]$.

The calculations, conducted for high solar activity, also reveal an anomalous variation of the ratio $q(O_2^+)/q(N_2^+)$ but with less amplitude. This is conditioned by the fact that during the transition from minimum to maximum solar activity, the radiation intensity in the range 911 - 1038 A forming only O_2^+ ions varies less than 1.5 times and the radiation intensity 0 - 740 A by more than 4 - 5 times.

Utilizing the data in Figure 2, the character of the variation of the equilibrium concentrations of basic molecular ions O_2^+ and NO^+ can be found. It follows from [2] that the ratio of concentrations of these ions at the altitudes 200 - 150 km is

$$\frac{[NO^+]}{[O_2^+]} = \gamma \frac{\alpha_{O_2^+}}{\alpha_{NO^+}} \left[1 + \frac{(1+\gamma)\, q\,(O_2^+)}{q\,(O^+) + q\,(N_2^+)}\right]^{-1}, \tag{1}$$

where α_{O_2} and α_{NO^+} are the coefficients of dissociative recombination of ions O_2^+ and NO^+; here $\gamma = [N_2]\gamma_1 / [O_2]\gamma_2$; γ_1 and γ_2 are respectively the constants of the rate of ion-molecular reactions $O^+ + N_2 \rightarrow NO^+ + N$ and $O^+ + O_2 \rightarrow O_2^+ + O$. In expression (1), the ratio $\alpha_{O_2^+}/\alpha_{NO^+}$ and the value of γ depend little on the altitude or $z_\odot$, and this is why the variations of the ratio $[NO^+]/[O_2^+]$ are mainly determined by the variations of the expression included in brackets in (1). It is seen from Figure 2 that with the decrease of the altitude in the region 200 - 150 km and $z_\odot$ rise in the interval 60 - 90°, the ratio $q(O_2^+)/(q(O^+) + q(N_2^+))$ increases, and consequently, the ratio $[NO^+]/[O_2^+]$ must decrease. During high solar activity, first, the value of the ratio $q(O_2^+)/(q(O^+) + q(N_2^+))$ is less (and consequently, $[NO^+]/[O_2^+]$ is greater), and in the second place, it varies less strongly as a function of the altitude and $z_\odot$ which leads to the smaller variations of $[NO^+]$ and $[O_2^+]$.

In the region of anomalous increase of the ratio $q(O_2^+)/(q(O^+) + q(N_2^+))$, the primary ion O_2^+ is mainly formed. The ion NO^+ can apparently be formed only by the reaction $O_2^+ + N_2 \rightarrow NO^+ + NO$ (with the constant rate γ_3), therefore, for its equilibrium, we shall have

$$\gamma_3[N_2][O^+] = \alpha_{NO^+}[NO^+]n_e, \tag{2}$$

whence we obtain

$$[NO^+] / [O_2^+] = \gamma_3[N_2] / \alpha_{NO^+}n_e. \tag{3}$$

During the increase of $z_\odot$ or the decrease of solar activity, n_e decreases and this is why, in contrast to the altitude range 150 - 200 km, the ratio $[NO^+]/[O_2^+]$ must increase below ∿150 km. Hence, it follows that $\gamma_3 \approx (3 - 10) \cdot 10^{-11}\ cm^3 sec^{-1}$

These conclusions are important in two respects:

1) They explain one of the basic contradictions between theory and experiment, indicated in the beginning of the article. Depending upon $z_\odot$ and the solar activity level, the above predicted character of $[NO^+]/[O_2^+]$ variations as a function of $z_\odot$ and the level of solar activity (opposite for the 150 - 200 km range and below 150 km) corresponds to the data of the most reliable mass-spectrometric measurements, in particular, according to the data of [5, 6].

2) They point to the inconstancy of the effective recombination coefficient α' in the ionosphere and permit the prediction of the character of its variation as a function of the altitude of $z_\odot$ and of the solar activity level. We shall pause at this question in order to examine two methods of determination of α'.

1. The neutralization in the ionosphere is materialized at the expense of the dissociative recombination of molecular ions, as a consequence of which

$$\alpha' = \alpha_{NO^+}[NO^+] / n_e + \alpha_{O_2^+} + [O_2^+] / n_e. \tag{4}$$

When $([NO^+] + [O_2^+])n_e$ = const and $\alpha_{O_2^+} > \alpha_{NO^+}$, the variation of the quantity α' is opposite to the variation of the ratio $[NO^+]/[O_2^+]$. Therefore, according to the above account during the transition from low solar activity to high at the altitudes below 150 km, an increase of α' must occur, and at the altitudes 150 - 200 km the values of α' must decrease. Actually, starting from the most reliable data on mass-spectrometric measurements of the concentration of $[NO^+]$ and $[O_2^+]$ precisely such variations of the value of α' depending upon $z_\odot$ and the solar activity level, were found in [3].

2. As is well known, in the equilibrium conditions

$$\alpha' = q/n_e \tag{5}$$

Using the data on $q(h)$ in [4] and the rocket data on $n_e(h)$ in [1] as a basis, we calculated the profiles of $\alpha'(h)$ plotted in Figure 3 for two zenithal angles $z_\odot$ 55° (2) and 80° (3) during low solar activity conditions. Let us note the basic peculiarities of the profile of $\alpha'(h)$: at altitudes 130 - 150 km the maximum of α' is observed; during the increase of $z_\odot$ in the region above 150 km α' increases, but below 150 km, it decreases. An analogous pattern is observed during high solar activity, but at greater altitudes, the quantity α' is somewhat greater. These deductions for $z_0 = 55°$ agree with the conclusions of the relative variations obtained from (4) and [3]. For the comparison of the profile $\alpha'(h)$ for $z_\odot = 55°$, borrowed from [3], is drawn in Figure 3 in dashes, which within the limits of the factor 1.5 coincides with the profile calculated according to (5).

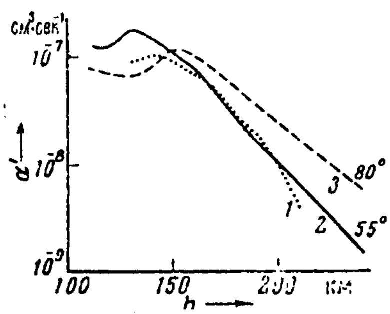

Figure 3

Variation of the effective recombination coefficient α' with the altitude. The curve 1 is borrowed from [3], 2 and 3 from the equation (5) at $z_\odot = 55°$ and $z_\odot = 80°$ respectively.

We shall compare conclusions

about the variations of α', obtained by the first and second methods with the experimental data.

a) Thus, above $\sim$150 km α' increases as the Sun approaches the horizon and during solar activity decrease, that is, it varies in opposite phase with q, whereas below $\sim$150 km, α' varies in phase with q. Because of this, the variation of the value of n_e^2 somewhat digresses from the variation of the value of q during the day (at α' = const n_e^2/q = const) whereupon the digressions have a different sign at altitudes above and below 150 km according to the deductions from the rocket data in [1].

b) The decrease of α' during the decrease of q at altitudes $\sim$150 km explains why in the E-region of the ionosphere during the transition from maximum to minimum solar activity, n_e^2 decreases twice slower than q. This is connected with the fact that at solar activity minimum, the value of α' is about twice smaller than at solar activity maximum. As far as in the E-region $[NO^+] + [O_2^+] \approx n_e$ and $\alpha_{O_2^+} > \alpha_{NO^+}$, the calculation of (3), in agreement with the deductions adduced hence, it follows that at minimum solar activity, the ratio must be increased. This corresponds to the result of the mass-spectrometric measurements at these altitudes by V. G. Istomin [5, 6], but is in contradiction with the new data of [8, 9], according to which the ratio $[NO^+]/[O_2^+]$ is underrated almost by one order of magnitude.

The obtained conclusions about the character of the variation of $[NO^+]/[O_2^+]$ and α' are important for the understanding of the variation of the physical conditions in the ionosphere at altitudes 100 - 200 km.

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