ESTIMATE OF THE CONCENTRATION OF NEGATIVE IONS IN THE D REGION OF THE IONOSPHERE

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Abstract

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ESTIMATE OF THE CONCENTRATION OF NEGATIVE IONS IN THE D REGION OF THE IONOSPHERE

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One of the most important questions in the modern study of the D region of the ionosphere is the question of the concentration of negative ions n_i^-. Rocket measurements of the electron concentration n_e at altitudes of 60-100 km make it possible to obtain, on the average, more or less reliable values of n_e ([1]), in agreement with ground-based measurements. At the same time, the rocket-measured values of n_i^+ and n_i^- reported by different authors differ by as much as 2-2.5 orders of magnitude ([1-5]). In this connection the relative values n_i^+/n_e and n_i^-/n_e turn out ([5]) to be an order of magnitude higher than is given by the theory ([6]), based on allowance for the mechanisms of formation and destruction of negative ions. The conclusions of the theory ([6]) are disputed in a number of works ([7,8]). Below an attempt is made to estimate the value $l^- = n_i^-/n_e$, starting from ionospheric data on the effective recombination coefficient α'.

As is known, changes in the electron concentration in the D region of the ionosphere are determined by the equation

$$dn_e/dt = q/(1 + l^-) - \alpha' n_e^2. \quad (1)$$

The effective recombination coefficient α' is related to the dissociative recombination coefficient α^* and the coefficient of mutual neutralization of positive and negative ions α_i by the relation

$$\alpha' = \alpha^* + \alpha_i l^-. \quad (2)$$

Thus, starting from α', one can determine the value l^- if the constants α^* and α_i are known. For the value α^* we use $(2–3) \cdot 10^{-7}$ cm$^3 \cdot$ sec^{-1}, which, according to the latest data ([9]), corresponds to the atmospheric temperature at the altitudes under consideration. Let us consider in more detail the available data on α'.

A review of the results of experimental measurements of α' in the D region of the ionosphere was given by Mitra ([10]). We note that individual measurements may differ from the mean values, shown by crosses in Fig. 1, by a factor of 2-3, which also characterizes the accuracy of the mean values of α'. Fig. 1 also gives the values q/n_e^2 for daytime conditions ([b]) during solar flares according to

([11]), and for nighttime conditions (a) during polar blackouts according to ([12]). According to (1), for stationary conditions the quantity q/n_e^2 should be greater than α' by a factor of $1+l^-$. Taking into account that the differences between the indicated quantities at altitudes of 60–80 km lie within a factor of 1.5-2.5, one may conclude that even at 60 km l^- is probably only slightly greater than unity. Apparently, more reliable estimates of l^- can be obtained from comparison of $\alpha' n_e^2$ (see Table 1) for quiet conditions (n_e taken from ground-based measurements ([13])) at altitudes of 50-60 km with the value of q, which here is determined only by cosmic rays. We used the latest calculations ([14,15]), which give values of q an order of magnitude higher than in ([6]). The values of l^- obtained for altitudes of 50 and 60 km are used to estimate the constant α_i, and then we determine l^- from α' for greater altitudes.

The excess of α' over α^* is equal to $\alpha_i l^-$. The dashed line in Fig. 1 gives the lower limit of α'. Hence, from the data on l^- for altitudes of 50-60 km we find $\alpha_i = (0.7\text{–}2)\cdot 10^{-6}$ cm$^3\cdot$sec^{-1}, which is close to the value $\alpha_i = 1.6\cdot 10^{-6}$ cm$^3\cdot$sec^{-1} obtained from data on ionization at low altitudes of 5-30 km (it is given in the handbook ([16])). Using this value of α_i,

one can obtain the values of l^- (and, taking into account n_e, the values of n_i^-) given in Table 1. It is seen that at heights of 50-70 km the values $n_i^+ = n_i^- + n_e$ are close to the new results of rocket measurements ([2]). The values of l^- are apparently determined to within a factor of 2-3. It is important to emphasize that the variation of l^- with height is determined only by the data on α' and α^*.

Thus, the use of data on the profile $\alpha'(h)$ makes it possible to estimate the relative concentration of negative ions at heights of 50–80 km.

Let us compare the obtained values of l^- with the theoretical values determined by the formula

$$l^- = \frac{1.5\cdot 10^{-30}[O_2]^2}{\rho + kn}, \tag{3}$$

where n and $[O_2]$ are the concentrations of neutral particles and oxygen molecules, respectively; k may be regarded as an effective constant for reactions of electron detachment from negative ions as a result of collision processes. Using the data on the atmospheric model in ([16]), one can find that the values of l^- in Table 1 satisfy formula (3) for ρ = 0.2-0.45 sec^{-1} and $k = (3\text{-}10)\cdot 10^{-17}$ cm$^3\cdot$sec^{-1}. We note that the value of ρ agrees with modern data ([15]), while the value of k is close to Bailey' s estimates from independent data during PCA ([17]). Indeed, as is known, the diurnal variations of radio-wave absorption during PCA are equal to ~ 4, whence it follows that $\rho + kn \approx 4k$. Taking into account that, according to rocket measurements, absorption occurs at heights of 65-75 km ([1]), we obtain $k = (3\text{-}6)\cdot 10^{-17}$ cm$^3\cdot$sec^{-1}. These conclusions are important for the photochemistry of the D region.

(Figure: Fig. 1)

Fig. 1

Table 1

	h, km			
	50	60	70	80
α', $cm^3 \cdot sec^{-1}$ ([10])	$2.5 \cdot 10^{-5}$	$8 \cdot 10^{-6}$	$2.1 \cdot 10^{-6}$	$4.7 \cdot 10^{-7}$
n_e, cm^{-3} ([1, 13])	20	50	160	800
$\alpha' n_e^2$, $cm^{-3} \cdot sec^{-1}$	0.01	0.02	–	–
q, $cm^{-3} \cdot sec^{-1}$ ([14])	0.35	0.1	–	–
l^-	35	4	1.1	0.1
n_i^-, cm^{-3}	700	200	180	240

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