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EFFECT OF NEGATIVE IONS ON THE DIFFUSION OF CHARGED PARTICLES IN THE LOWER IONOSPHERE

by

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EFFECT OF NEGATIVE IONS ON THE DIFFUSION OF CHARGED PARTICLES IN THE LOWER IONOSPHERE *

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SUMMARY

The solution of this problem is arrived at by a method analogous to that expounded in [3] and is based upon the fact that the diffusion process in a plasma in the presence of a magnetic field takes place at the rate of the velocity of slower particles (electrons and positive ions), inasmuch as the electric field, emerging on account of the difference in the diffusion rates of electrons and ions, hampers a further separation of these particles and this is evidence that the presence of negative ions may substantially modify the character of the diffusion process.

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* *

In the conditions of the lower ionosphere the influence of negative ions is significant to heights of the order of 80 km [1]. However, in the works [2, 3] on the diffusion in the ionosphere the influence of negative ions on the diffusion process was not taken into account.

The method, applied below, is analogous to that proposed in [3]: in the case, when the concentration of particles varies little over the length of the free path and when for the description of these particles' motion auring the free path time, macroscopic equations can be applied (in our case it concerns electrons, negative and positive ions). The linearized system of these equations is resolved alongside with the equation for the longitudinal electric field by way of expansion of the functions searched for into the Fourier integral by the coordinates $\delta n_k = \int \delta n(r) e^{-ikr} d^3 r$.

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* VLIYANIYE OTRITSATEL'NYKH IONOV NA DIFFUZIYU ZARYAZHENNYKH CHASTITS V NIZHNEY IONOSFERE.

At the same time we obtain for the Fourier-components of the functions δn_k the equations

$$\begin{aligned}
&\partial\delta n_{ek}/\partial t + \alpha_{He}[D_e k^2 \delta n_{ek} + 4\pi\sigma_e(\delta n_{ek} + \delta n_{jk} - \delta n_{lk})] = 0;\\
&\partial\delta n_{lk}/\partial t + \alpha_{Hl}[D_l k^2 \delta n_{lk} + 4\pi\sigma_l(\delta n_{lk} - \delta n_{ek} - \delta n_{jk})] = 0;\\
&\partial\delta n_{jk}/\partial t + \alpha_{Hj}[D_j k^2 \delta n_{jk} + 4\pi\sigma_j(\delta n_{jk} + \delta n_{ek} - \delta n_{lk})] = 0.
\end{aligned} \tag{1}$$

Here $D_e = \varkappa T_e/m\nu_{em}$ is the coefficient of longitudinal diffusion, $\sigma_e = e^2 n_{0e}/m\nu_{em}$ is the conductivity, $\omega_{He} = eH_0/mc$ is the gyrofrequency for electrons, $\alpha_{He} = [1 + (\omega_{He}/\nu_{em})^2\cos^2\beta][1 + (\omega_{He}/\nu_{em})^2]^{-1}$, β is the angle between **k** and H_0, $D_l, D_j, \sigma_l, \sigma_j, \omega_{Hl}, \omega_{Hl}, \alpha_{Hl}$ are the corresponding quantities for the ions, $\delta n_e, \delta n_l, \delta n_j$ is the residual concentration respectively for the electrons, positive and negative ions, n_{oe}, n_{ol}, n_{oj} is the mean concentration of these particles $(\delta n \ll n_o, n_{oe} + n_{oj} = n_{ol}), m, M_l, M_j$ are the masses of electrons and ions, e is the charge of the electrons, T_e, T_i are the temperatures respectively of electrons and ions, $\varkappa$ is the Boltzmann constant, $\nu_{em}, \nu_{lm}, \nu_{jm}$ are the frequencies of electrons' and ions' collisions with neutral particles, E is the electric field strength, H_o is the constant Earth's magnetic field.

We shall write the solution of the system (1) in the form

$$\begin{aligned}
&\delta n_{ek}(t) = \delta n_{ek}^{(1)} e^{-q_1 t} + \delta n_{ek}^{(2)} e^{-q_2 t} + \delta n_{ek}^{(3)} e^{-q_3 t};\\
&\delta n_{lk}(t) = \delta n_{ik}^{(1)} e^{-q_1 t} + \delta n_{lk}^{(2)} e^{-q_2 t} + \delta n_{lk}^{3} e^{-q_3 t};\\
&\delta n_{jk}(t) = \delta n_{jk}^{(1)} e^{-q_1 t} + \delta n_{jk}^{(2)} e^{-q_2 t} + \delta n_{jk}^{3} e^{-q_3 t},
\end{aligned} \tag{2}$$

where q_1, q_2, q_3 are the radicals of the characteristic equation.

We shall limit ourselves to the case, when the masses and the collision frequencies for various kinds of ions are identical (for the lower ionosphere it is realized in the presence of molecular oxygen ions only). At the same time, $M_l = M_j = M, \nu_{lm} = \nu_{jm}$ and

$$q_3 = \alpha_{Hl} D_l k^2, \quad \delta n_{ke}^{(3)} = 0. \tag{3}$$

If the characteristic dimensions of the perturbed region are large by comparison with the Debye radius R_D,

$$(kR_D)^2 = k^2 \varkappa T_l T_e / 4\pi e^2 n_0 (T_e + T_l) \ll 1, \tag{4}$$

then we shall have for the remaining quantities in (2)

$$q_1 = 4\pi\sigma_e \alpha_{He} + 4\pi\sigma_u \alpha_{Hi}, \tag{5}$$

where

$$\sigma_u = \sigma_i + \sigma_j = e^2(n_{oi} + n_{oj})/M\nu_{im},$$

$$q_2 = k^2 \frac{(\sigma_u D_e + \sigma_e D_i)\alpha_{He}\alpha_{Hi}}{\sigma_u \alpha_{Hi} + \sigma_e \alpha_{He}}, \tag{6}$$

$$\delta n^{(1)}_{ck}/\sigma_e \alpha_{He} = - \delta n^{(1)}_{ik}/\sigma_i \alpha_{Hi} = \delta n^{(1)}_{jk}/\sigma_j \alpha_{Hj} = \frac{\delta n_{ek}(0) + \delta n_{jk}(0) - \delta n_{ik}(0)}{\sigma_e \alpha_{He} + \sigma_u \alpha_{Hi}}, \tag{7}$$

$$\delta n^{(2)}_{ik}/n_{oi} = - \delta n^{(2)}_{jk}/n_{oj} = \delta n^{(2)}_{ek}/(n_{oi} + n_{oj}),$$

$$\delta n^{(3)}_{ik} = \delta n^{(3)}_{jk} = \{n_{oi}\delta n_{jk}(0) + n_{oj}\delta n_{ik}(0)\}/(n_{oi} + n_{oj}).$$

Here $\delta n_{kc}(0)$, $\delta n_{ik}(0)$, $\delta n_{jk}(0)$ are the Fourier components of the initial disturbance of the density of electrons and ions.

One of the characteristic radicals (q_1 in our case) describes the spreading out of the initial charge in the plasma, as should have been expected [3]. Inasmuch as q_1 is significantly greater than q_2 and q_3, the process of diffusion takes place mainly at compensated plasma charge (ambipolar diffusion). At the same time $\delta n^{(2)}_{ek} = \delta n^{(2)}$. The electrons and the noncompensated ion charge, equal to $e(\delta n^{(2)}_{ik} - \delta n^{(2)}_{jk}) = e\delta n_{ek}(0)$, take part in the ambipolar diffusion process described by the radical q_2. The compensated ion charge spreads out with the ion diffusion rate described by the radical q_3. In the first approximation by kR_D the electrons do not take part in this process. The coefficient of ambipolar diffusion is

$$D(\beta) = \varkappa(\lambda T_e + T_i)\,(\lambda m\nu_{em}/\alpha_{He} + M\nu_{im}/\alpha_{Hi})^{-1}, \tag{8}$$

where $\lambda = (n_{oi} + n_{oj})/n_{oe}$.

Note that for the lower ionosphere λ may be significantly greater than the unity. That is why the anisotropy of the diffusion process may be manifest at very small heights in the ionosphere. At heights where

$$(\omega_{He}/\nu_{em})^2 \ll 1, \tag{9}$$

the character of the diffusion is isotropic regardless of the form of the inhomogeneity. The dependence of inhomogeneity 's spreading our process on its initial structure was discussed at length in the work [3]. Here we shall note only that if it is not too strongly stretched out along the magnetic field (see [3]), the diffusion isotropy may take place to heights, where the condition (9) is disrupted. To that effect it is sufficient that we have $(\omega_{Hi}/\nu_{im})^2 \ll 1$.

The coefficient of isotropic diffusion is

$$D = \varkappa(\lambda T_e + T_i)/(M\nu_{im} + \lambda m\nu_{em}). \qquad (10)$$

If we neglect the influence of negative ions on the diffusion, we shall have $\lambda = 1$ and the diffusion coefficient will be substantially underrated.

**** THE END ****

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