B. A. Tverskoi. *Magnetospheric-ionospheric interaction and polar auroras.* Alfvén[1] showed more than forty years ago that plasma convection in the field of a magnetic dipole is accompanied by charge separation due to magnetic drift, and he proposed that for the earth, quasineutrality is maintained by currents along magnetic force lines. These currents are closed up through the ionosphere. A self-consistent theory of such convection was developed in Refs. 2 and 3, taking into account redistribution of potentials due to the finite resistance of the ionosphere.

The basic equations of the theory are

$$\mathrm{div}_2\,\hat{\Sigma}\,\mathrm{grad}_2\,U_i = j_\nu;\quad j_\nu = c\,(\boldsymbol{\nu}\,[\nabla W \nabla P]),\quad W = \int \frac{dl}{H}\,; \tag{1}$$

where U_i is the ionospheric potential, which is constant along the magnetic field within the E layer; j_ν is the component of the current normal to the ionosphere; $\boldsymbol{\nu}$ is a unit vector normal to the ionosphere; W is the volume of a tube of force with unit magnetic flux; $\hat{\Sigma}$ is the two-dimensional height-integrated ionospheric conductivity tensor; and, P is the pressure of the magnetospheric plasma, which is assumed to be constant along a line of force. The quantities U, P, and W are interpreted in (1) as functions of latitude and longitude in the ionosphere, which is emphasized by the subscripts 2 in the vector operators.

The theory constructed based on (1) is confirmed by many experiments and, in particular, by direct measurements of the currents j_ν.[4] Here the maximum values $j_\nu > 0$ are many times greater than the currents j^*, accompanying free gas-dynamic efflux of magnetospheric electrons into the ionosphere. It was shown in Refs. 5 and 6 that to create observed currents $j_\nu > 0$ a potential difference

$$U_i = U_m + \frac{T_e}{e}\,\frac{j_\nu - j^*}{j^*},\quad j^* = N_e\sqrt{\frac{T_e}{2\pi m}} \tag{2}$$

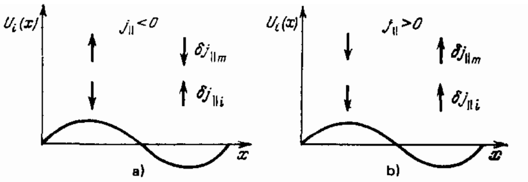

FIG. 1.

must exist between the ionosphere and sufficiently distant (by many thousands of kilometers) regions of the magnetosphere (m and e are the electron mass and charge, N and T_e are the electron density and temperature at high altitudes). The experiment shows that in the region of strong currents $j_\nu > 0$ the electron energy spectrum contains peaks at energies corresponding to the potential difference (2).[7] It is in these regions that the brightest polar auroral formations—homogeneous arcs, bands, and draperies—are observed.

Separation of arcs and bands into several parallel bright formations must be viewed as an instability of the system of interacting magnetospheric-ionospheric electric fields and currents. The mechanism for this instability is illustrated in Fig. 1. Assume that a wave disturbance with potential $u_i(x)$ arises in a region $j_\nu \neq 0$ in the ionosphere. Evidently, disturbances $j_\nu'(x) < 0$ will arise near maxima in U_1, while near minima $j_\nu'(x) > 0$. On the other hand, under the action of efficient collisions, hot ions in the magnetosphere will collect in regions of potential minima. Assuming that $W = W(x)$, $P = P_0(x) + P_1(x)$, y, $\Sigma = \text{const}$ and $P' = -PeU/T_i$ (for simplicity we assume that $U_i = U_m$), we obtain from (1) the following equation for U:

$$\frac{d^2U}{dx^2} + j_{0\nu}(x)\frac{e}{T_i\Sigma}U = 0 \quad (T_i - \text{ ion temperature}). \tag{3}$$

For $j_{0\nu} > 0$, (3) has the form of a Schroedinger equation for the potential well and the condition for instability reduces to the condition for existence of levels. For example, for $j_{0\nu} = j_0/ch^2\varkappa x$, these levels are

$$j_{0n} = \frac{\Sigma T_i \varkappa^2}{e} n(n+1) \quad (n = 1, 2, \ldots). \tag{4}$$

The number n corresponds to the number of arcs. For intermediate values of j_0, the arcs are slightly tilted away from the direction $W = \text{const}$.

If there is an electric field E_y, then (for small scales of variation of $j_0(x)$ along x) due to electric drift the role of collisions sharply decreases, and the expression $j' = -j_0eU/T_i$ is valid only on scales where near the plane of the equator the characteristic wavelength λ satisfies the relation $2\pi\bar{v}_i \lesssim \Omega_H\lambda$ ($\bar{v}_i$ and Ω_H are the average thermal velocity and Larmor frequency of magnetospheric ions). Projected on the ionosphere along lines of force, this gives (with $v_0 \approx 10^8$ cm/s, $\Omega_H \approx 6\ \text{s}^{-1}$) $\lambda \lesssim 40$ km. The presence of electric drift along the x axis together with stratification likewise leads to the appearance of longitudinal currents, related to the presence of an ionic density gradient:

$$j'' = \frac{cE_y e^2 WN}{T_i}\frac{\partial U}{\partial x}. \tag{5}$$

In this case, the condition for instability is supplemented by the requirement

$$\left|\frac{cE_y e^2 WN}{T_i \varkappa \Sigma}\right| < 1,$$

while on the equatorial side of the arc, an additional surge in brightness appears.

If the ion distribution function is non-Maxwellian and has a maximum, then $U_i \neq U_m$. Linearizing (2) leads to the relation

$$U_m = U_i\left|1 - \beta\frac{j_0(x)}{j^*(x)}\frac{T_e}{T_i}\right|, \tag{6}$$

where β is a dimensional factor ~1. If the denominator in (6) is close to zero, then many arcs can form.

[1] H. Alfvén, Kungl. Sv.-Vet.-Akademiens Handl. **111**, 18 (1939).
[2] B. A. Tverskoi, Dokl. Akad. Nauk SSSR **188**, 575 (1969).
[3] V. M. Vasyliunas in: Magnetospheric Processes, Ed. by B. M. McCormac, D. Reidel, Dordrecht, Holland (1972).
[4] T. Iijimo and T. A. Potemra, J. Geophys. Res. **83**, 599 (1978).
[5] L. Knight, Planet. Space Sci. **21**, 741 (1973).
[6] E. E. Antonov and B. A. Tverskoĭ, Geomagn. Aeron. **15**, 85 (1975).
[7] L. R. Lyons, D. S. Evans, and R. Lundin, J. Geophys. Res. **84**, 457 (1979).

Translated by M. E. Alferieff