53 Meetings and Conferences

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A scientific session of the Division of General Physics and Astronomy and of the Division of Nuclear Physics of the USSR Academy of Sciences was held on 23 and 24 December 1970 in the Conference Hall of the P. N. Lebedev Physics Institute (Leninskii prospekt 53).

The following papers were delivered:

1. A. V. Gurevich, E. E. Tsedilina, and V. P. Shcherbakov, Resonant Protons and the Electric Field in the Earth's Magnetosphere.
2. Yu. I. Gal'perin, Auroras and "Resonance" Concept of a Magnetic Storm.
3. N. S. Kardashev, Yu. N. Pariiskii, and A. G. Sokolov, Cosmic Radioastronomy.
4. V. L. Indenbom and F. N. Chukhovskii, X-ray Optics.
5. A. G. Fleer, Correlation between Changes in the Phase Velocity of Propagation of Ultralong Radio Waves and of the Earth's Motion About the Mass Center.
6. G. A. Askar'yan, V. G. Mikhalevich, and G. P. Shipula, Aureole Refraction and Nonlinear Scattering of Powerful Light by Inhomogeneities in Transparent Media.
7. B. B. Kadomtsev, Matter in a Superstrong Magnetic Field.
8. I. I. Gurevich, Investigation of the Condensed State of Matter with the Aid of Positive Muons.

We publish below brief contents of the papers.

A. V. Gurevich, E. E. Tsedilina, and V. P. Shcherbakov, Resonant Protons and the Electric Field in the Earth's Magnetosphere.

Recently obtained interesting data point to the important role played by protons with energies $\epsilon \sim 5-50$ keV in the dynamics of the Earth's magnetosphere during the period of magnetic storms. Experimental measurements on satellites of the OGO series[1] have shown that protons having the indicated energies appear suddenly in the solar wind. After a few hours, proton having the same energies are already observed in the magnetosphere. They fill a wide zone (from $L \sim 4$ to $L \sim 9$) in the night-evening sector of the magnetosphere with concentration $L \sim 1-5$ cm^{-3} (L is the equatorial distance from the earth's center in units of the earth's radius R_0).

The drift motion of protons having the indicated energies in the magnetosphere has a number of significant features[2]. The earth's magnetic field, as is well known[3], acts as a trap for fast charged particles—protons and electrons. Their drift orbits lie on the L shells produced by rotation of the force lines about the axis of the dipole. The magnetic field is frozen into the ionosphere plasma and rotates together with the earth. The protons drift around the earth in the opposite direction. Therefore the protons whose angular drift velocity is equal to the angular velocity of the earth's rotation are at rest in the immobile coordinate system connected with the sun. Their energy ϵ_r in the dipole field satisfies the condition

$$\varepsilon_r = \frac{30.7}{L}\ \text{keV} \tag{1}$$

Such protons are naturally called "resonant." The magnetic field of the dipole at large distances from the earth ($L > 5$) is noticeably distorted by the action of the solar wind. The drift trajectories of the "resonant" protons are determined mainly by the asymmetrical part of the magnetic field, since the effects of the principal (dipole) field and of the earth's rotation are mutually cancelled for them. Examples of trajectories of protons with energies close to "resonant" are shown in Fig. 1. Attention is called to the "sickel-like" particle orbits. They exist at $\epsilon \sim 4-12$ keV at distances $L \sim 4-9$ and form in the nighttime side, as it were, an equatorial radiation belt of captured particles. We note also their strong displacement across the L shells, from $L \sim 5$ up to $L \sim 9$.

At higher energies (6–15 keV, depending on L), the "sickles" open up and the particles pass freely from the "tail" or from the boundary of the magnetosphere to $L \sim 5$. We note also that the kinetic energy of the protons on the elongated sickle-like orbits varies noticeably during the course of motion, namely, $\epsilon > 6-10$ keV on the part of the trajectory closer to the earth $\epsilon \sim 4$ keV and on the far part. The change of energy is the consequence of betatron acceleration and deceleration of the protons in the earth's rotating magnetic field.

Thus, protons with energies $\epsilon \sim 4-15$ keV lie in the nighttime zone of the magnetosphere and are easily displaced, owing to the drift, across the L shells from the boundary or "tail" of the magnetosphere to $L \sim 5$. The presence of such a sectorial radiation zone serves as one of the sources of the electric field in the magnetosphere and ionosphere of the earth[4].

The electric field exerts a strong influence on the dynamics of the magnetosphere and the ionosphere. It determines the convection in the magnetosphere, the drifts and currents in the ionosphere, the variation of the earth's magnetic field, and to a considerable degree

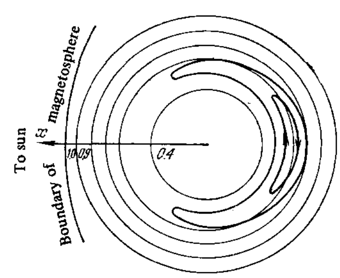

FIG. 1. Drift trajectories of resonant protons in the plane of the geomagnetic equator. The unit of length is the distance from the earth's center to the boundary of the magnetosphere (L ≈ 12). The arrows indicate the direction of the proton drift.

the stability and inhomogeneous structure of the ionosphere and the magnetosphere. Experimental measurements of the electric field have recently been the subject of a large number of studies (see the review[5]). The quasistationary electric field in the plane of the geomagnetic equator $\mathbf{E} = -\text{grad}\,\Psi$ is determined by the equation[6]

$$\frac{\partial}{\partial L}\left\{\frac{L}{\sqrt{1-(1/L)}}\left[[4-(3/L)]\,\bar{\sigma}_{\perp}E_L+[4-(3/L)]^{1/2}\,\bar{\sigma}_{\Lambda}E_{\varphi}\right]\right\}+ + \frac{1}{\sqrt{1-(1/L)}}\frac{\partial}{\partial\varphi}\left(\bar{\sigma}_{\perp}E_{\varphi}-\sqrt{4-(3/L)}\,\bar{\sigma}_{\Lambda}E_L\right)=eR_0\left[\frac{\partial\bar{N}_{fe}}{\partial t}+\omega_0\frac{\partial\bar{N}_{fe}}{\partial\varphi}-\frac{\partial\bar{N}_{fi}}{\partial t} -\omega_0\frac{\partial\bar{N}_{fi}}{\partial\varphi}\right]+Q_g. \quad (2)$$

We have taken into account here the fact that the high longitudinal conductivity of the magnetosphere causes the surfaces on which the force lines of the magnetic field are situated to be equipotential surfaces for the electric field, $\Psi = \Psi(L, \varphi)$ (φ is the longitude); $\bar{\sigma}_{\perp}$ and $\bar{\sigma}_{\Lambda}$ are the transverse and Hall conductivities of the ionosphere, averaged over the altitude. The term in the square brackets determines the generation of the field by the fast electrons or ions of the magnetosphere. Here $\bar{N}_{fe}$ and $\bar{N}_{fi}$ are the fast-particle concentrations averaged over the force line, and ω_0 is the angular frequency of the earth's rotation. The term Q_g determines the generation of the field under the influence of the wind of neutral molecules in the ionosphere (the "dynamo field")[7].

Near the geomagnetic equator ($L \to 1$) a singularity appears in (2). An analysis of the solution in the vicinity of the singularity shows that the electric field in a narrow layer of the ionosphere near the geomagnetic equator increases by 20–30 times (the equatorial current jet)[8]. In the polar ionosphere ($L \gg 1$) the intensity of the electric field also increases by more than one order of magnitude. This is the consequence of the geometry of the force lines: the field E_i in the ionosphere is connected with the field in the plane of the geomagnetic equator E by the relations $E_{i\varphi} = E_{\varphi}L^{3/2}$ and $E_{iL} = E_L \cdot 2L^{3/2}[1 - (3/4L)]^{1/2}$. The action of the electric field on the fast electrons and ions is determined by the parameter[6]

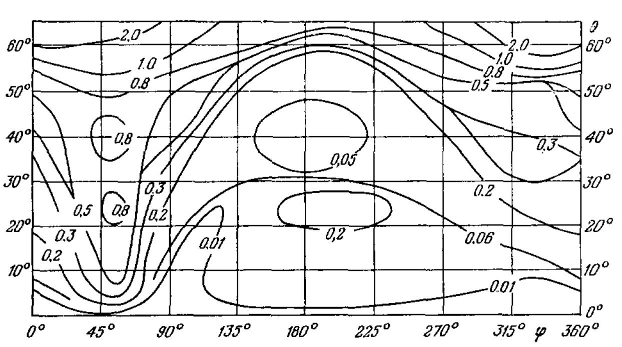

FIG. 2. Electric field intensity in the earth's ionosphere at $t \approx 6$ min after the burst of the electrons on the force line $\varphi = 0$, $L = 1, 2$ (i.e., $\theta \approx 25°$). φ—longitude, θ—geomagnetic latitude. The curves are labeled with the values of E/E_1, where E_1 is a constant that depends on the total number of fast electrons n and on the integral conductivity $\bar{\sigma}_{\perp}$ of the ionosphere ($E_1 \approx 30$ mV/m at $n = 10^{26}$ and $\sigma_{\perp} = 10^{12}$ cm/sec).

$$\lambda \approx 2.7 \cdot 10^{-2} L^4 [1-(1/L)]^{1/2} N_{f0}\left(\frac{10^{12}}{\bar{\sigma}_{\perp}}\right); \quad (3)$$

here N_{f0} is the average concentration of the fast particles in cm^{-3}, and $\bar{\sigma}_{\perp}$ is expressed in cm/sec ($10^{12}/\bar{\sigma}_{\perp} \sim 1$). We see that in the polar zone ($L \sim 5$–10) we have $\lambda \gtrsim 1$ already at low values of N_{f0}. Instabilities of the flute type arise in this case, and the electric field acquires an oscillator structure[9,6].

Figure 2 shows the results of a numerical solution of Eq. (1) jointly with the kinetic equation for the fast electrons under conditions when an artificial radiation belt is produced[10,11]. We see that the field is maximal in the polar region. Ion-acoustic waves are excited here[12] and considerable heating of the ionosphere takes place.

[1] L. A. Frank, J. Geophys. Res. 75, 707 (1970).
[2] A. V. Gurevich and V. P. Shcherbakov, Geomagnetizm i aéronomiya 10, 791 (1970).
[3] B. A. Tverskoĭ, Dinamika radiatsionnykh poyasov (Dynamics of the Radiation Belts), Nauka, 1968.
[4] A. V. Gurevich and V. P. Shcherbakov, Kratkie soobshcheniya po fizike (Brief Reports of Physics), No. 6, 52 (1970).
[5] G. Haerendal, MPI/PAE 44/70, Internat. Symp. on "Sun-Earth" Physics, Leningrad, 1970.
[6] A. V. Gurevich and E. E. Tsedilina, Geomagnetizm i aéronomiya 9, 458, 642, 818 (1969).
[7] J. Feyer, J. Atm. Terr. Phys. 4, 184 (1953).
[8] A. V. Gurevich, A. L. Krylov, and V. P. Shcherbakov, Geomagnetizm i aéronomiya (1971).
[9] D. B. Chang, L. D. Pearlstein, and M. N. Rosenbluth, J. Geophys. Res. 70, 3085 (1965).
[10] E. E. Tsedilina, Geomagnetizm i aéronomiya 10, 408 (1970).
[11] T. N. Soboleva and E. E. Tsedilina, ibid. 11, 469 (1970).
[12] E. E. Tsedilina, ibid. 11, 464 (1971).
[13] E. E. Tsedilina, ibid. (1971).

Yu. I. Gal'perin, Auroras and the "Resonance" Concept of a Magnetic Storm

The concept described below[1,2] constitutes, in fact, an attempt to construct a cohesive phenomenological picture of the processes occurring in the magnetosphere during the time of an "elementary magnetic storm"—the so called substorm, based on extensive results of measurements on satellites and on land-based geophysical observatories, and also attempts at their theoretical analysis.

The groundwork was laid by theoretical calculations[3] that revealed the possibility of existence, in the nighttime magnetosphere, of a special "resonant" component p_r^0 (Fig. 1) of protons (ions) with energy $E_0 \sim 10$ keV (more accurately, $E_0/Z \sim 10$ keV, where Z is the charge of the ion), having a longitudinal drift frequency ω_{dr} close to the frequency ω_E of the earth's rotation. According to[3] this captured component in a non-rotating coordinate system should have an asymmetrical component and becomes concentrated in the near-midnight region; the motion of these particles is