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A joint 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 March 30 and 31, 1983 at the P. N. Lebedev Physics Institute of the USSR Academy of Sciences. The following reports were heard at the session:

March 30

1. *V. S. Beskin, A. V. Gurevich, and Ya. N. Istomin,* Electrodynamics of the magnetosphere of pulsars.
2. *E. P. Mazets,* Cosmic gamma bursts.

March 31

3. *Yu. M. Kagan,* Quantum diffusion in nonideal crystals.
4. *V. A. Mikheev,* Quantum diffusion and localization of He^3 atoms in solid He^4.

We present below a brief review of these reports.

V. S. Beskin, A. V. Gurevich, and Ya. N. Istomin. *Electrodynamics of the magnetosphere of pulsars.* A pulsar is a rapidly rotating neutron star with a very strong magnetic field $B_0 \sim 10^{12}$ G. Due to the rotation, a strong electric field arises as well, reaching values of $E_0 \sim (v/c)B_0 \sim 10^{11}$ V/cm near the star. It is important that the electric field has, in this case, a component parallel to the magnetic field. Particles, falling into such a strong field, are accelerated and emit hard gamma rays, which, being absorbed in the magnetic field, generate electron-positron pairs.[1] This is how the magnetosphere, formed by the electron-positron plasma rotating in the magnetic field of the star, is generated.

The presence of the plasma has a definite effect on the structure of the magnetic field at large distances from the star. If the field has a dipole character for comparatively small values of r, then for $r \sim c/\Omega$ (c is the velocity of light, Ω is the angular rotational velocity of the star), due to the motion of the plasma, the lines of force are sharply deformed, stretched out, and extend to infinity. Therefore, the lines of force, leaving regions near the magnetic poles, are open in the pulsar's magnetosphere, just as in the magnetospheres of the earth or other planets.

The electron-positron plasma escapes along open lines of force. For this reason, it must be continuously generated in regions near the poles. This is the reason for the appearance of active regions in the vicinity of the poles, which permit observing the pulsar. To maintain the active processes, an energy source is required. The rotational energy of the star is such a source. The slowing down of the rotation, observed experimentally in all pulsars,[2] is due to the ponderomotive action of electric currents, which flow on the surface of the star, run off into the magnetosphere, and return again. Electric currents thus determine not only the structure of the magnetic field, but also the energetics of the basic processes occurring in the magnetosphere of the pulsar, as well as the dynamics of the star.

In our work, we are studying the structure of the magnetosphere of a pulsar taking into account the electric fields and field-aligned currents arising in it with arbitrary angle of inclination of the axis of rotation to the axis of the magnetic dipole. Starting from the general system of kinetic equations and Maxwell's equations, it is possible to derive closed nonlinear equations, describing the quasistationary electrodynamic processes occurring in the magnetosphere of the pulsar, in the form:

$$\begin{aligned}&\operatorname{rot}\{\mathbf{B}(1-\beta_r^2)+\boldsymbol{\beta}_r(\boldsymbol{\beta}_r\mathbf{B})+[\boldsymbol{\beta}_r\nabla\psi]\}\\&\quad=\frac{4\pi}{1-\beta_r^2+\boldsymbol{\beta}_r[\nabla\psi\mathbf{B}]/B^2}\left\{\frac{i_\parallel}{c}[(1-\beta_r^2)\mathbf{B}+[\boldsymbol{\beta}_r\nabla\psi]]\right.\\&\quad\left.+\frac{[\nabla\psi\mathbf{B}]}{B^2}\left[\frac{\Omega\mathbf{B}}{2\pi c}+\frac{1}{4\pi}(\Delta\psi-\boldsymbol{\beta}_r\nabla(\boldsymbol{\beta}_r\nabla\psi))\right]\right\},\end{aligned} \tag{1}$$

$$\operatorname{div}\mathbf{B}=0,\quad \boldsymbol{\beta}_r=\frac{[\boldsymbol{\Omega}\mathbf{r}]}{c};$$

where $\mathbf{B}$ is the intensity of the magnetic field, $-\nabla\psi$ is the deviation of the electric field in the magnetosphere from the field that gives rise to complete corotation of the plasma (i.e., its rotation with angular velocity Ω), $\mathbf{j}_\parallel = i_\parallel \mathbf{B}$ is the field-aligned current. The electrical potential φ and the longitudinal current $i_\parallel$ serve as sources of the field $\mathbf{B}$ in Eqs. (1). In deriving Eqs. (1), aside from their quasistationariness, only certain restrictions on the efficiency of the source generating the electron-positron plasma were used; in reality, these conditions are usually well satisfied. The motion of the electrons and positrons was described in (1) using the drift approximation.

The nature of the structure of the magnetosphere, determined according to (1), is evident from examples shown in Figs. 1 and 2. In the absence of sources ($\psi = 0, i_\parallel = 0$, Fig. 1), the entire magnetosphere rotates together with the star with angular velocity Ω. In this case, the drift velocities of the particles reach the velocity of light c on the "light cylinder"—the cylinder with radius $\rho = c/\Omega$ (i.e., with $\beta_r = 1$). In the presence of sources (Fig. 2), corotation with the star occurs only in the region of the closed magnetosphere. The region of open lines of force rotates with a lower angular velocity. In this case the "light surface," on which $E = B$, no longer coincides with the light cylinder.

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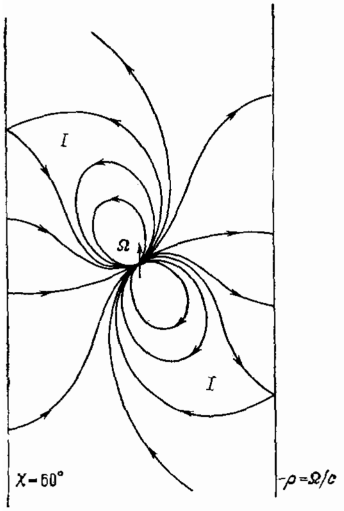

FIG. 1. Structure of the magnetic field with the axis of the magnetic dipole inclined at an angle of $\chi = 60°$ to the rotational axis ($\psi = 0$, $i_{\|} = 0$). The region I is the region of closed lines of force.

A special boundary layer appears near the light surface. Here, the drift approximation breaks down, so that a more accurate description of the motion of electrons and positrons is required. The solution of the problem in the boundary layer shows that electrons and protons are strongly accelerated in this layer, reaching very high energies:

$$\varepsilon = \frac{\varepsilon_m j_{\|}}{nec}, \quad \varepsilon_m = \frac{eB_0\Omega^2R^3}{4c^2} \approx 10^{13}\,\mathrm{eV}$$

It is evident that the maximum particle energy is proportional to the field-aligned current density $j_{\|}$ and inversely proportional to the plasma density n. In the boundary layer, a strong current jet, flowing along the light surface across the lines of force of the magnetic field, is also forward (see Fig. 2). Reaching the separatrix, separating the region of closed and open lines of force, the current jet turns and returns along the separatrix to the surface of the star. This is how the field-aligned electric currents are closed in the magnetosphere of the pulsar.

The nonlinear equations (1) can be solved only when the following important "matching" condition, relating the magnitude of the dimensionless field-aligned current $i_0 = j_{\|} \cdot 4\pi/\Omega B$ and of the electric field β is satisfied:

$$\beta = -b(\chi)\left(1 - \sqrt{1 - a(\chi)\, i_0^2}\right). \tag{2}$$

Here $\beta\alpha|\nabla\psi|$ is the dimensionless electric field intensity, while $a(\chi)$ and $b(\chi)$ are constants that depend on χ, i.e., on the angle of inclination of the axis of the magnetic dipole relative to the rotational axis. The matching relation (2) plays the role of a nonlinear Ohm's law for the magnetosphere of the pulsar. For low currents $i_0 \ll 1$, the electric field $\beta \sim -i_0^2$. The negative sign of β indicates that the rotation of the open magnetosphere is always slowed down in the presence of the current. The magnitude of the field-aligned current, as is evident from (2), has an upper limit $i_0 \leqslant i_{oc}(\chi) = a^{-1/2}(\chi)$.

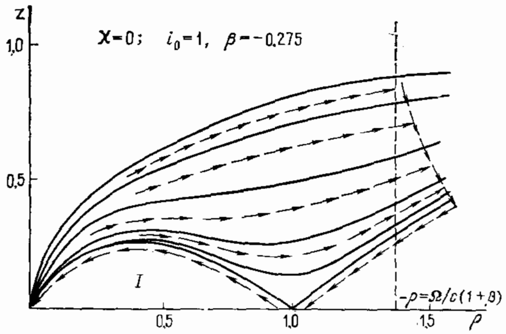

FIG. 2. Structure of the magnetic field in the presence of a field-aligned current ($i_0 = 1$). The magnitude of the electric field $\beta = -0.275$ corresponds to the matching condition (2). Region I is the region of closed lines of force. The arrows indicate the orientation of the currents flowing in the magnetosphere.

The field-aligned currents are closed by the current I_s, flowing along the surface of the star. The ponderomotive action of the current I_s slows down the rotation of the star and causes the angle of inclination of the axes χ to change with time:

$$\frac{dP}{dt} \approx \frac{B_0^2R^6}{Pc^3J_r} i_0 \cos\chi, \quad \sin\chi = \frac{P}{P_0}\sin\chi_0, \quad P = \frac{2\pi}{\Omega}. \tag{3}$$

It is evident that the increase in the period of rotation of the star P is proportional to the magnitude of the field-aligned current i_0. The angle of inclination of the axes χ increases with increasing period. If there is no field-aligned current (i.e., with complete corotation $\psi = 0$, $i_0 = 0$, Fig. 1), then the pulsar does not slow down, independently of the angle of inclination of the axes χ.

The results obtained (within the framework of the Ruderman-Sutherland "gap" model[1]) were used to analyze the observed parameters of pulsars. In spite of the fact that with evolution the angle χ in every pulsar approaches 90°, the number of pulsars, for which it is currently possible to observe both magnetic poles, agrees with the number of pulsars for which an interim pulse is observed. On the other hand, the theory predicts that when the sensitivity of the existing receiving apparatus will increase by 1–3 orders of magnitude, the number of pulsars for which interim pulses will be observed should increase dramatically.

It has also been demonstrated that within the framework of our model, the magnetic field for each pulsar may be assumed to be constant. This result agrees with the short lifetime of pulsars $\tau \sim 3$–10 million years, following from the theory, which also agrees well with the observed distribution of pulsars in the galaxy.[2]

[1] M. A. Ruderman and P. G. Sutherland, Astrophys. J. **196**, 51 (1975).
[2] R. Manchester and J. Taylor, Pulsary (Pulsars), Mir, Moscow (1980).