GENERATION OF MAGNETIC FIELD IN BINARY CELESTIAL SYSTEMS

A. Z. Dolginov
A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences
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It is customary to disregard the generation of magnetic fields by tidal flows in binary and multiple celestial systems (e.g., binary stars, the earth-moon-sun systems, stars surrounded by nebulae or protoplanetary clouds, etc), since the tidal deformations are almost reversible and the body resumes its previous configuration after a relatively short period. The energy is then reconverted to its gravitational form. We note, however, that the dissipative part of the tidal energy is usually quite sufficient to maintain a magnetic field. For example, the tidal energy dissipated in the earth's core exceeds 10^{19} erg/sec, whereas the Joule losses of the earth's magnetic field do not exceed apparently 10^{17} - 10^{18} erg/sec. Although the shapes of the bodies in binary systems return periodically to their previous configurations, the matter elements that take part in the tidal flows do not return to their previous positions. Their trajectories become more and more entangled, and this lengthens the magnetic-field force lines that are frozen in them, and by the same token strengthens the field.

Tidal flows in binary systems whose componeents rotate about axes inclined to the plane of orbital motion were investigated in [1]. The Navier-Stokes equation was solved with allowance for the gravitational, tidal, and Coriolis forces (disregarding viscosity, which is insignificant here). It was shown that the tidal-velocity components v_r, v_θ, and v_ϕ, in a reference frame rigidly coupled to the body, are given by

$$v_k(\mathbf{r},t) = \sum_{m=0,\pm 1} F_{km}(\mathbf{r},\beta)\cos[(\Omega + m\omega)t + \phi_{km}], \qquad (1)$$

where $\vec{r}(r\theta\phi)$ are the polar coordinates of a point inside or on the surface of a body of mass M and radius R; Ω is the angular velocity of rotation about the axis, $\omega^2 = GM_1R_1^{-3}$ is the square of the angular velocity of revolution of the tide-producing body of mass M_1 on its orbit, R_1 is the distance between the bodies, β is the angle between the rotation axis and the perpendicular to the orbit, and ϕ_{km} is a certain fixed angle determined, as is the function $F_{km}(\vec{r}, \beta)$, by the solution of the Navier-Stokes equation. The tidal velocities determined by (1) ensure the entanglement of the force line frozen into the matter. The precession motion also leads to entangling of the force lines. In binary systems with axis inclined to the orbit, the components v_ϕ and v_θ are anomalously large. Accurate to terms of order $(\omega/\omega_0)^2\Omega r$, where $\omega_0^2 = GMR^{-3}$, we have

$$v_\phi \approx v_\theta \cos\theta \,\mathrm{ctg}\,(\Omega t + \phi) \approx \frac{3}{4}\left(\frac{\omega}{\Omega}\right)^2 \Omega r \sin 2\beta \cos\theta \cos(\Omega t + \phi) . \qquad (2)$$

The radial velocity v_r is of the order $(\omega/\omega_0)^2\Omega r$, and since $\omega_0 \gg \omega$, it is much less than v_ϕ and v_θ if $\Omega \lesssim \omega$. For example, for a binary star with $M = M_1 = M_\odot$, $R = R_\odot$, $R_1 = 10R$, $\omega \approx \Omega \approx 10^{-5}$ $\sec^{-1}$, $\beta = 45°$ and $r = 7\times10^{10}$ cm we obtain $v_\phi \approx v_\theta \approx 5$ km/sec, while v_r is smaller by a factor 10 . At certain ratios of the frequencies, e.g., when $\omega_0^2\omega = g\Omega^3$, where g is a quantity of the order of unity, resonance sets in and the velocities are limited only by the dissipative and nonlinear phenomena. During the course of evolution, when ω_0, Ω, and ω all vary, resonance conditions can arise. At the same time, the regime of internal flow and heat transfer can change appreciably, especially in the radiative regions of stars, where there are no other large-scale high-velocity motions. This peculiarity of tidal flows in bodies having axes inclined to the orbit is particularly favorable for field generation. If the known equation of dynamo theory is averaged over the period of the tidal pulsations then, in analogy with the case of generation of a large-scael field by small-scale turbulence [2], we obtain an equation of the type

$$\frac{\partial \mathbf{B}}{\partial t} - \mathrm{rot}\,\alpha\mathbf{B} - D\nabla^2\mathbf{B} = 0 \qquad \alpha = -\frac{1}{3} < v(t)\int_0^t \mathrm{rot}\,v(t')\,dt' > . \qquad (3)$$

The quantity α depends on the coordinates. In the spherical case it contains terms proportional to $\cos\theta$, i.e., having different signs in different hemispheres. This is important for the generation of a large-scale field. Equation (3) does not make it possible to determine the magnitude of the field, only its feasibility and its characteristic growth time. This time is of the order of $\tau \approx L/\alpha \approx 3L^2\omega_t/v_t^2$, where L, ω_t, and v_t are the average characteristic dimensions of the system, the frequencies, and velocities of the tidal flows. For growing solutions to exist we must have $v_t > 3D\omega_t$. The value of v_t is determined by precisely those velocity components that ensure the entanglement of the "liquid 'article" trajectory. In a star with $L \sim 10^{11}$ cm, $\omega_t \sim 10^{-5}$ sec^{-1}, and $v_t \sim 10^5$ cm/sec the value of τ is of the order of one year. Such a rapid filed growth can alter radically the character of the heat transfer and can lead by the same token to catastrophic processes such as flares. It is not excluded that outbursts of novas, all of which are binary, are due to this effect.

If the star surface has a well-conducting layer that is ineactive in field generation, then the field produced inside the star need not necessarily break through to the surface. If such a layer exists at the surface of the earth's core ($\sigma \sim 10^{16}$ cgs), then, regardless of the generation mechanism, fields with periods $\lesssim 10^4$ years will not penetrate to the earth's surface.

In binary systems, there should also act an inductive field-generation mechanism comprising typical dynamo enhancement for the case of doubly-connected geometry. Hertzenberg [3] has shown that a stationary field can be produced in a system of two rotating spheres in a conducting medium. From the fundamental point of view, this system does not differ essentially from a binary-star system. We have considered generation of a field in a star surrounded by a disk-like cloud that revolves around the star with its axis inclined to the rotation axis of this star. In first approximation, the conditions for field growth are satisfied for only those magnetic moment components of the star, which are perpendicular to its rotation axis. Since the magnetic moment is connected with the star, the cloud is acted upon by an alternating magnetic field and it must be taken into account that such a field does not penetrate deeply into the mantle. Nonetheless, the growth increment may be large enough to permit a strong field to be generated in a time much shorter than the evolution time. We note that unlike field generation by tidal flows that produce a field in the entire interior of the body, the inductive mechanism generates a field primarily in the surface layers, since the inner layers are screened, and only stochastic flows of various types can carry the field to the interior. Magnetic Ap stars are frequently single. There are data, however, indicating that many are surrounded by shells. The presence of a shell could explain such properties of these stars as the relatively slow rotation, the appreciable magnetic field, and the anomalies of the chemical composition. These anomalies could result from differentiation of the matter in the shell with subsequent accretion onto a star.

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NEUTRAL CURRENTS AND P-ODD EFFECTS IN DEEP INELASTIC MUON SCATTERING

N. N. Nikolaev, M. A. Shifman, and M. Zh. Shmatikov[1])
Institute of Theoretical and Experimental Physics
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We discuss the possibility of observing the neutral-current interactions predicted by weak-interaction gauge models, using P-odd effects in deep inelastic scattering of polarized muons

1. There have been many recent discussions of gauge models of weak interactions in which interaction takes place between neutral-vector and axial currents of leptons ℓ_α with the hadron current h_α [1]. The existing experimental limitations on the interaction constants of neutral currents with $\Delta S = 0$ are quite weak, and the best of them, which follows from an analysis of the process $\nu_\mu p \to \nu_\mu p \pi^0$ [2] yields

$$G_n^{(\nu)} \lesssim 0{,}4\, G_F . \qquad (1)$$

Moreover, in many models (see [1]) the neutral current contains no neutrinos, and in this case the neutrino experiment is generally insensitive to its existence. The experimental limitations on the interaction constants of a neutral current of charged leptons $G_n^{(e)}$ and $G_n^{(\mu)}$ with a hadron current with $\Delta S = 0$ is much worse than the limitation (1). The experimental data on muon scattering and on the test of -e universality yield only a very weak limitation[2]):

$$G_n^{(\mu)} \lesssim (500 - 1000)\, G_F . \qquad (2)$$