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CONCERNING THE ATMOSPHERE OF MAGNETIC NEUTRON STARS (PULSARS)

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Of great importance in the theory of neutron stars and pulsars is the conclusion [1] that the star should, generally speaking, be surrounded by an extended "atmosphere," in spite of the action of the force of gravity. The point is that the neutron star, as follows from natural considerations (see, for example, [2]), should be magnetized and rotating, and the angular velocity Ω and the magnetic field B (say dipole field at the magnetic pole) are sufficiently large. As a result, an electric field $E \sim r_0 \Omega B/c$ is produced in the vacuum at the surface of a well-conducting star and its action on a particle with charge eZ and mass Am_p greatly exceeds the action of the force of gravity, under the condition

$$\Omega B >> \frac{m_p A}{eZ} \frac{c G M_0}{r_0^3} \sim 10^4 \text{ W/sec} , \tag{1}$$

where M_0 is the mass of the star, r_0 its radius, m_p the proton mass, and G the gravitational constant; the numerical value was obtained for $M_0 \sim M_\odot = 2 \times 10^{33}$ g, $r_0 \sim 10^6$ cm, and $A/Z \sim 1$.

If the field B is determined in the "vacuum approximation," i.e., if it is assumed that the pulsar emits magnetic-dipole radiation as in vacuum [2], then for the known pulsars ΩB ranges from 1.5×10^{12} for PSR 0808 to 5×10^{13} for PSR 0532 (see [3]), and condition (1) is satisfied with a tremendous margin. Therefore, insofar as we know, it has not been doubted that pulsars can be sources of particles that fill their magnetosphere and are responsible for the emission of electromagnetic waves. In fact, however, particles can escape only if a certain gas layer exists at the surface of the star or if extraction of ions from the solid surface of the star is possible. Both conditions may, incidentally, not be satisfied. Concretely, in a strong magnetic field $B >> B_c = 4.6 \times 10^9$ G, the surface of a neutron star is something in the nature of a "polymer" (quasi-one-dimensional) metal [4, 5] with density $\rho \gtrsim 10^4$ g/cm and binding energy in the lattice (per "atom" whose nucleus has a charge eZ)

$$\begin{aligned} W &\approx 13.6\, Z^3 \eta^{4/5} \text{ eV}, \qquad \eta = (B/B_c Z^3)^{1/2} >> 1 \\ W &\sim 27\, Z^3 \eta^{12/5} \text{ eV}, \qquad Z^{-3/2} << \eta << 1. \end{aligned} \tag{2}$$

In a field $B = 10^{13}$, the binding energy is $W \simeq 10^3$ eV for He and $W \simeq 6 \times 10^4$ eV for Fe. For most pulsars (age $\tau \gtrsim 10^5$ years) the surface temperature is $T \lesssim 10^5 - 10^6$°K $\sim 10 - 10^2$ eV, and only for PSR 0532 in the Crab nebula (τ = 918 years) can we possibly have $T \sim 2 \times 10^3$ eV (see [6]). Thus, in a sufficiently strong field, and particularly if Fe nuclei dominate in the external layer, as is frequently assumed, the thermal evaporation of the surfaces of the known pulsars should not play any role at all. As to the extraction of ions by an electric field, it is certainly appreciable if $E \gtrsim E_c = eQ^2/(eZ^*)^3$, where $Q = W + \sum_{n=1}^{Z^*} I_n - Z^* \phi_0$, I_n is the ionization potential of the n-th electron, ϕ_0 is the work function of the electron, eZ^* is the charge of the extracted ion, and a is a certain numerical coefficient (for details see [7]). It can be shown that if $\eta \gg 1$ the field E_c is minimal at $Z^* = Z$ and, say for He, we have $Q \simeq 2W$ (at $B \sim 10^{12}$). As a result, the extraction of He takes place under the condition (in the region $\eta \gg 1$)

$$\Omega B \gtrsim 4 \cdot 10^{13} a \left\{ \left[1 + 0.3 \ln\left(\frac{B}{10^{12}}\right) \right]^2 + 0.23 \left(\frac{B}{10^{12}}\right)^{2/5} \right\}^2 \quad \text{G/sec} \tag{3}$$

The coefficient a, unfortunately, is unknown. It is probable that $a \sim 1$. If this is so, then for most pulsars the extraction condition (3) is not satisfied "with a margin" of one order of magnitude (for PSR 0527, the left-hand side of (3) is smaller than the right-hand side by a factor 30a). On the other hand, hydrogen can be extracted from the known pulsars. However, according to [8], only He can exist in the outer shells of pulsars besides Fe, and furthermore in an amount equal to 10^{21} g. At an escaping-matter concentration $n \sim 10^{10} - 10^{12}$ cm^{-3} (see below), the star loses He at a rate $dM/dt \sim 4 m_p nc \cdot 4\pi r_c^2 \sim 10^{10} - 10^{12}$ g/sec, and the entire He will be lost within 30 - 3000 years. The estimate of E_c for Fe is less reliable. If in this case $Z^* \sim Z = 26$, then $Q \sim 33(B/10^{12})^{2/5}$ keV, and the right-hand side of (3) should be replaced by

$$4 \cdot 10^{13} a \left\{ \left(\frac{B}{10^{12}}\right)^{2/5} + 0.1 \left(\frac{B}{10^{12}}\right)^{6/5} \right\}^2 .$$

As a result, the conditions for the extraction of Fe and He are approximately the same.

Thus, the escape of matter from neutron stars for which a condition of type (3) is violated can be completely blocked$^{1)}$. For the known pulsars, the question remains insufficiently clear (in view of the uncertainty of the coefficient a in a formula of the type (3), especially when $Z^* \gg 1$). It is worthy of persistent attention, particularly in connection with the problem of applicability of the "vacuum approximation." On the one hand, the assumption [2] that the vacuum approximation is not valid meets with objections (see, for example, [9, 10]). On the other hand, the observed slowing down of pulsars,

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$^{1)}$As emphasized in [5], the escape of electrons (cold emission) is easier than extraction of ions. However, when only electrons escape, the star becomes charged as a whole and the electron emission decreases rapidly to a low level. Thus, the characteristic electron concentration near the surface, $n_e(0) \sim \Omega B/2\pi ce \sim 10^{10} - 10^{12}$ cm^{-3} (see [1]) decreases in the absence of ion emission (at $t \gg t_0 \sim 0.1(10^2/B)(10^6/r_0)\Omega^{-2}$ sec) in accordance with the law $n_e(c) = n_e(0)t_0/t$; at $\Omega \sim 1$, $B \sim 10^{12}$, and $r_0 \sim 10^6$, the concentration n_e decreases by an approximate factor 10^6 in one day.

generally speaking, differs from the slowing down due to the magnetic-dipole radiation in vacuum [11]. If the escape of ions from the surface of a given neutron star is impossible, it can be a pulsar only under far reaching additional assumptions. Thus, worthy of special attention in this case is the "volcanism" hypothesis, namely the ejection of matter from within the star [12]. Another possibility is radiation of electromagnetic waves in the magnetosphere of a slowly rotating pulsar as a result of accretion [13]. The possibility of heating the surfaces of the observed pulsars by accretion (if the field is estimated from the vacuum approximation) is not realistic. To be sure, it is worth while to consider a related possibility, that of heating the surface by particles ejected by a given pulsar and accelerated in its own magnetosphere.

It seems to us that the problem touched upon in the present article should be taken to account in any consistent and self-consistent pulsar theory.

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HIGHLY EXCITED ELECTRONIC LEVELS OF THE H_2 MOLECULE IN ASTROPHYSICS

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The H_2 molecule is of great interest in astrophysics. Numerous theoretical investigations (see, for example, [1, 2]) and the first successful measurements outside the atmosphere [3] point to large content of the molecules in certain clouds of interstellar hydrogen (up to equality of the concentrations of H_2 and H). The fact that these molecules were not observed until recently is due to the peculiarity of the H_2 spectrum. All the lines from the ground state are in the ultraviolet or in the far infrared regions of the spectrum, to which the earth's atmosphere is opaque (see the table).

Electronic transitions	Terms	${}^1\Sigma_u^+ \rightarrow {}^1\Sigma_g^+$	${}^1\Pi_u \rightarrow {}^1\Sigma_g^+$
	$\lambda(v = J = 0)$	1008 Å	1108 Å
Vibrational transitions	v λ	0 - 1 2.2 μ	
Rotational transitions	J λ	0 - 2 28 μ	1 - 3 16 μ