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ON THE ORIGIN OF THE SOLAR WIND

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S U M M A R Y

The hydrodynamic description of solar corona expansion is retained by utilizing for larger ranges the microscopical model and kinetic equations, when the length of the free path $\lambda \ll r$, r being the characteristic scale of the problem.

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A hydrodynamic mechanism of solar corona expansion was proposed and worked out in detail in ref. [1 - 4]. However, the hydrodynamic description is applicable only for a small length of the free path $\lambda \ll r$, where r is the characteristic scale of the problem. Because of rapid density decrease, this inequality is disrupted already as near as at a distance of several solar radii. This is why, generally speaking, a further expansion should be described with the aid of microscopical model and kinetic equations.

Assume that in a spherical system of coordinates, r, θ, ϕ with polar axis directed along the Sun's angular velocity vector $\vec{\omega}$ and with origin at the center of the Sun, the interplanetary magnetic field $\vec{B}$ may be locally approximated by the Archimedes spiral [5]

$$B_r = \frac{B_0}{r^2}, \quad B_\theta = 0, \quad B_\varphi = -\frac{\omega B_0}{ur}\sin\theta, \tag{1}$$

where $B_0 = B_0(\theta)$ is an arbitrary function of the angle θ, u is the constant rate of corona radial expansion. As is well known, such a distribution of the magnetic field is the result of expansion of an ideally conducting plasma with constant radial velocity and of Sun's rotation under condition of axial symmetry. In a fixed system of coordinates the electric field is given by the expression

$$\mathbf{E} = -(1/c)\,[\mathbf{uB}],$$

whereupon the element of plasma volume is "glued" to the line of force, moving

(*) O PROISKHOZHDENII SOLNECHNOGO VETRA

with a velocity $\vec{w} = [\omega r]$, so that the components of velocities w and u across the magnetic line of force are identical: $\vec{w}_\perp = \vec{u}_\perp$. This is why the electric field may also be represented in the form

$$\vec{E} = -(1/c)\cdot[\vec{w}\vec{B}].$$

A separate charged particle undergoes drifting under the action of the electric, gravitational and nonuniform magnetic fields. It may be shown that for particles of nonrelativistic energies, the principal drift is the one in crossed electric and magnetic fields, whereas the drift conditioned by the inhomogeneity of the magnetic field and the gravitational drift are negligibly small.

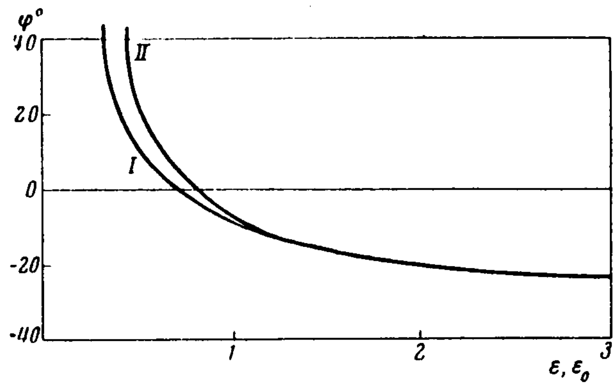

Fig.1

Since the fields do not depend on time, the energy is the integral of the motion, so that, finally, the drift equations take the simple form

$$\mathbf{v} = v_\parallel \mathbf{h} + \mathbf{u}_\perp, \qquad v_\parallel = \sqrt{\frac{2}{M}}\sqrt{\varepsilon_0 - \mu B - \Phi_0(1 - r_0/r)}, \tag{2}$$

where $v_\parallel$ is the velocity component along the unitary vector $\vec{h} = \vec{B}/B$, M and μ are the mass and the magnetic moment of the proton, $\varepsilon_0 = Mv_0^2/2$ and v_0 is the initial energy and the initial velocity of the proton at the distance r_0 from the Sun, $\Phi_0 = MGM_\odot/r_0$, $M_\odot$ and G being the mass of the Sun and the gravitational constant. The electrostatic potential is rejected in the second formula (2), for the meridional drift velocity is negligibly small. Taking into account relations (1), we may represent expressions (2) in the following form:

$$v_r/v_0 = \frac{1}{\sqrt{1+\beta^2\tau^2}}\sqrt{1 - \frac{\alpha^2}{\tau^2}\sqrt{1+\beta^2\tau^2} - \delta\left(1 - \frac{1}{\tau}\right)} + \frac{\gamma\beta\tau^2}{1+\beta^2\tau^2},$$

$$v_\varphi/v_0 = \frac{\gamma\tau}{1+\beta^2\tau^2} - \frac{\beta\tau}{\sqrt{1+\beta^2\tau^2}}\sqrt{1 - \frac{\alpha^2}{\tau^2}\sqrt{1+\beta^2\tau^2} - \delta\left(1 - \frac{1}{\tau}\right)}.$$

Introduced here are the dimensionless quantities $\alpha = v_{\perp 0}/v_0$, $\beta = (\omega r_0/u)\sin\theta$, $\gamma = (\omega r_0/v_0)\sin\theta$, $\delta = GM_\odot/r_0 v_0^2$, $\tau = r/r_0$, where $v_{0\perp}$ is the component of the initial velocity across the magnetic line of force.

Assume that $r_0 = 3R_\odot \approx 2{,}08\cdot 10^{11}$ cm, $u = 4\cdot 10^7$ cm/sec. We shall find the velocity of the proton, having outflown with initial energy ε_0, at the distance of Earth's orbit, that is for $r \approx 1.5 \cdot 10^{13}$ cm. At such a distance from the Sun the term $(\alpha^2/\tau^2)\sqrt{1+\beta^2\tau^2}$ in (3) is negligibly small. It is easy to see that the transverse component of proton velocity $\vec{u}$ does not depend on the initial velocity, and the longitudinal component $v_\parallel$ is determined by the initial energy and, at great distances it is not dependent on the magnetic moment. For a low-energy proton the motion velocity is perpendicular to the magnetic line of force, since the initial energy passes into the potential energy, while for a high energy proton the motion velocity is directed along $\vec{B}$. The intermediate cases are shown in Fig.1. The angle $\varphi = \mathrm{arc\,tg}\,(v_\varphi / v_r)$ is plotted in ordinates in degrees and the initial energy ε_0 of the proton, or $\varepsilon = M(v_r^2 + v_\varphi^2)/2$ kev — in abscissa. The dependence $\phi(\varepsilon_0)$ is illustrated by the curve I, the dependence $\phi(\varepsilon)$ — by the curve II. As should have been expected, protons with energy 0.83 kev move radially (such an energy corresponds to the velocity of 400 km/sec).

*** T H E   E N D ***

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