STATIONARY ELECTRICAL POLARIZING FIELD AND CHARGE IN PLASMA OF THE SOLAR ATMOSPHERE

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The dependence of the proton velocity and concentration, electric field, electric charge and electron density on a distance from the centre of the Sun is derived within the framework of hydrodynamical two-zoned model.

INTRODUCTION

A system of four equations including the continuity, ion motion, local electron equilibrium equations and equation of quasineutrality of stationary spherically symmetric plasma flow under the homogeneous temperature of components is presented in [1]. The dependence of the proton velocity and concentration, electric field, electric charge and electron density on a distance from the centre of the Sun is derived in [1–3] for isothermal solar corona. The present work is based on these same simplifying assumptions, excepting the assumption of isothermal solar corona. The purpose of the present work is the consideration of a stationary expansion of plasma in vacuum within the framework of hydrodynamical two-temperature-zoned model (T is the temperature of high-temperature zone and T' is the temperature of low-temperature zone).

BASIC EQUATIONS

We denote the proton density of high-temperature zone by $n(r)$, and its radial velocity by $V(r)$. We shall suppose the conditions at boundary of high-temperature zone at $r = a$ to be given n_0. If as well as [1] the electron mass m_e is neglected, the equation of motion for electrons for a stationary task turns to a condition of local equilibrium:

$$0 = -\frac{k}{n}\frac{d(Tn)}{dr} - eE. \tag{1}$$

The equation of motion for protons for a stationary task takes the form:

$$mV\frac{dV}{dr} = -\frac{k}{n}\frac{d(Tn)}{dr} + eE - m\frac{M_S G}{r^2}\,, \tag{2}$$

where G is the gravitational constant, M_S denotes the mass of the Sun, E is radial component of an electric field, V is radial component of ions velocity, m denotes the mass of a proton, $-e$ is the charge of an electron.

The condition of charge neutrality of plasma is designated

$$n_e = n_p = n. \tag{3}$$

The continuity equation is:

$$\frac{1}{r^2}\frac{d}{dr}(nVr^2) = 0. \tag{4}$$

The Eqs. (1), (2), (3), and (4) form a system of equations for stationary expansion of plasma with homogeneous distribution of electrons and protons temperatures allowing one to find spherical symmetric distributions electrons $n_e(r)$, protons $n_p(r)$, velocity of protons $V(r)$, and electrical field $E(r)$ under given boundary conditions.

In low-temperature zone, in Eqs. (1)–(4) we substitute T, n, E, V, n_e, n_p for T', n', E', V', n'_e, n'_p.

Density particles, n'_0, at $r = a$ in low-temperature zone was defined from the condition of the continuity of the flow at aspiration of width of a transitive zone between high and low temperatures to zero.

SOLUTION FOR HIGH-TEMPERATURE ZONE

Eqs. (1)–(4) are so simple that they may be integrated analytically to give $V(r)$ implicitly from

$$\left(\frac{V}{V_c}\right)^2 - \ln\left(\frac{V}{V_c}\right)^2 = 4\ln\frac{r}{r_c} + \frac{4r_c}{r} + Const. \tag{5}$$

Five types of solution are presented in [4], depending on the value of *Const*. The solar wind solution (type IV) corresponds to the value $Const = -3$, obtained by putting $V = V_c$ and $r = r_c$ in Eq. (5).

An approximate expression in a solar corona with locations near r_c can be derived for V, n, E, and q.

At distances $r < r_c$ the dependence of the proton velocity on a distance from the centre of the Sun is:

$$V = V_c\left[1 - \sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\right]. \tag{6}$$

The dependence of the proton concentration on a distance from the centre of the Sun is:

$$n = \frac{n_0 a^2}{r^2}\frac{\left[1 - \sqrt{2}\sqrt{\ln\frac{a}{r_c} + \frac{r_c}{a} - 1}\right]}{\left[1 - \sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\right]}. \tag{7}$$

The dependence of the electric field on a distance from the centre of the Sun is:

$$E(r) = \frac{2kT}{er}\left[1 + \frac{\frac{r_c}{r} - 1}{2\sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\left[1 - \sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\right]}\right]. \tag{8}$$

Using Maxwell's equation for integral on the closed spherical surface S of radius r, we derive a charge of high-temperature zone of solar corona near the Sun at distances $r < r_c$

$$q(r) = \frac{8\pi\varepsilon_0 kTr}{e}\left[1 - \frac{\frac{r_c}{r} - 1}{2\sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\left[1 - \sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\right]}\right], \tag{9}$$

where the designations are entered:

$$V_c = \sqrt{\frac{2kT}{m}}, \tag{10}$$

$$r_c = \frac{GM_S m}{4kT}. \tag{11}$$

At distances $r > r_c$ the dependence of the proton velocity is:

$$V = V_c\left[1 + \sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\right]. \tag{12}$$

The dependence of the proton concentration is:

$$n = \frac{n_0 a^2}{r^2}\frac{\left[1 + \sqrt{2}\sqrt{\ln\frac{a}{r_c} + \frac{r_c}{a} - 1}\right]}{\left[1 + \sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\right]}. \tag{13}$$

The dependence of the electric field is:

$$E(r) = \frac{2kT}{er}\left[1 - \frac{\frac{r_c}{r} - 1}{2\sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\left[1 + \sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\right]}\right]. \tag{14}$$

Using (14), we derive a charge of high-temperature zone of solar corona near the Sun at distances $r > r_c$:

$$q(r) = \frac{8\pi\varepsilon_0 kTr}{e}\left[1 + \frac{\frac{r_c}{r} - 1}{2\sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\left[1 + \sqrt{2}\sqrt{\ln\frac{r}{r_c} + \frac{r_c}{r} - 1}\right]}\right]. \tag{15}$$

SOLUTION FOR LOW-TEMPERATURE ZONE

Eqs. (1) – (4) may be integrated analytically as well.

By analogy for V', n', E', and q' an approximate expression in low-temperature of a solar corona with locations at distances $r \ll r'_c$ may be derived.

At distances $r \ll r'_c$ where $V' \ll V'_c$ we shall obtain an approximate expression for distribution of protons velocity in stationary spherical symmetric flow in low-temperature zone of the solar corona

$$V'(r) = V'_c \left(\frac{r'_c}{r}\right)^2 \exp\left(\frac{3}{2} - \frac{2r'_c}{r}\right), \tag{16}$$

where V'_c and r'_c we defined from (10) and (11) substitution T for T'.

Density particles in low-temperature zone were defined from a condition of continuity of the flow at aspiration of width of a transitive zone between high and low temperatures to zero.

$$n'(r) = n'_0 \exp\left(\frac{2r'_c}{r} - \frac{2r'_c}{a}\right), \tag{17}$$

where

$$n'_0 = n_0 \frac{V_c}{V'_c} \left(\frac{a}{r'_c}\right)^2 \left[1 - \sqrt{2}\sqrt{\ln\frac{a}{r_c} + \frac{r_c}{a} - 1}\right] \exp\left(\frac{2r'_c}{a} - \frac{3}{2}\right). \tag{18}$$

We derive an approximate expression for an electrical field in low-temperature zone of solar corona near the Sun:

$$E = \frac{GM_S m}{2er^2}\,. \tag{19}$$

Using Maxwell's equation for the integral on the closed spherical surface S of radius r, we derive a charge of low-temperature zone of the solar corona near the Sun:

$$q'(r) = \frac{2\pi\varepsilon_0 GM_S m}{e}\,. \tag{20}$$

CONCLUSION. ELECTRICAL AND GRAVITATIONAL FORCES NEAR THE SUN

Using (7) and (8) let us carry out a comparison of forces of the electron and proton gas pressure, electrical and gravitational forces acting on protons and electrons near layer of the solar corona at $r = r_c$. Electrical force acting on electron is equal to the force of the electron gas pressure:

$$F_{Ee} = -F_{Pe} = \frac{-12\,(kT)^2}{GM_S m}\,. \tag{21}$$

The forces of the proton gas pressure, electrical and gravitational forces acting on protons near the solar corona layer at $r = rc$ are equal to:

$$F_{Ep} = -\frac{4}{3}F_{Pp} = \frac{-16\,(kT)^2}{GM_S m}\,. \tag{22}$$

Estimations show that force of the proton gas pressure and electrostatic force acting on proton are the main accelerating forces. The ratings of values of electrical fields and charge of the Sun show that they are very small. However, near the surface of the Sun the electrical force acting on a proton is comparable with gravitational one. The sum of proton gas pressure force and electrical force acting on a proton is 1.5 times stronger than force of the gravitational attraction of a proton to the Sun. The electrical force acting on an electron surpasses gravitational force many times over. All this can play a decisive role in finding a mechanism of solar activity.

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