Determination of the Sun's charge by the parameters of heavy ions in the solar wind

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Abstract. As an asymptotic paradox, the presence of a constant uncompensated positive charge of the Sun is investigated. According to the type of ions experimentally detected in the solar wind, the total charge of the Sun is calculated. The formulated model makes it possible to explain the anomalous heating of the solar corona by a constant electric field and the presence of several times ionized heavy ions. Within the framework of this model, the energies of the solar wind particles in the Earth's region are calculated. The calculated parameters of the Sun and the solar wind are compared with the values known from experiments and the proposed mathematical model is thereby verified.

1. Introduction
At the moment, a large amount of data on the ion composition of the solar wind (SW) has been accumulated, and this information is constantly being updated. The following parameters are known: 1) the elements present in the SW; 2) the degree of ionization of the atoms – Z; 3) the mass of the ions - m that form the SW [1] and 4) the SW velocity near the Earth. Usually in mathematical models, the Sun and the SW are considered to be neutral plasma structures [2, 3]. However, the Sun, like any plasma structure that has free electrons in it, is charged with a positive charge [4]. This is due to the greater mobility of electrons with respect to positive ions, which because of their mass have less mobility. The presence of the same charge at the Sun and the ionic components of the SW leads to the appearance of Coulomb repulsive forces, which, with a sufficient charge of the Sun, can compensate gravitational attraction forces and form streams of positively charged ions from the Sun. The charge of the Sun arises and is maintained as a result of the processes of maxwellization of the electron distribution function, therefore in the Sun there will always be electrons possessing a sufficiently high energy in order to leave even the positively charged Sun forever. In this case, the shielding of the positive charge of the Sun at the Debye length is impossible due to the absence of the opposite charge. In the proposed spherically symmetric model, the solar positive charge is not compensated in the entire heliosphere and negative charge in the form of escaped electrons can be concentrated in planets and cosmic dust, thereby conditioning the Coulomb forces of mass cumulation to the Sun. It is known that the Earth is negatively charged and the field from its charge is of the order of 100 V/m on the Earth's surface. The electric field strength outside the Sun does not depend on the nature of the charge distribution over its volume. Since the electromagnetic interaction is stronger than gravitation, even the absence of a small number of electrons is sufficient for the formation of the SW made of protons, alpha particles and even 6-8 times ionized iron atoms. In the proposed model, all processes on the
Sun’s surface are considered averaged over time and do not affect the SW at distances more than 3 solar radii.

We believe that the phenomenon of the SW is analogous to the well-known phenomenon of the flow of a charge from a charged needle in air. If a sufficiently high (breakdown) voltage is applied to the charged needle, then an electric or ionic wind arises, caused in the case of a negative charge by the flow of electrons from the needle, their adhesion to air molecules, and the subsequent movement of negative ions in the field of negative charge of the needle. In the case of a positive charge of the needle, the breakdown voltage will ionize the air molecules surrounding the needle and the resulting positive ions will move away from the needle due to the field of positive charge. A similar electric and ionic wind has a sufficient flow strength to deflect the candle flame, which is demonstrated in the known experiment. The same phenomena occur also in the Franklin’s wheel, where an electric or ionic wind arising on spaced needles causes the wheel to rotate after a sufficient voltage is applied to the needles. It can be said that there is a kind of jet movement in which the air ions surrounding the needle are a discarded mass.

These considerations make it possible to modify the electric wind model to describe the nature of the SW and to investigate it for an explanation of all the accumulated paradoxes in the motion of the SW against the forces of gravity of the Sun.

According to the foregoing, the anomalous heating of the solar corona to temperatures of the order of a million degrees can be explained within the framework of the proposed model by simple heating of the electrons by the field of the charged Sun, similarly to how electrons are heated in a conventional gas discharge plasma. Moreover, as will be shown below, the minimum ratio of Z/m of iron ions makes it possible to estimate the minimal magnitude of the solar charge. In this case, ions with smaller Z/m fall on the Sun, as the gravitational forces exceed the Coulomb reflection forces, or such ions have not yet been detected experimentally in the SW.

2. Comparison of Coulomb and gravitational forces between different objects

For two identical particles with masses \( m \) and charges \( e \), the ratio of the electric potential \( K\epsilon^2/r \) to the gravitational potential \( Gm^2/r \) is \( Ke^2/Gm^2 \). In the case of an electron, this value is equal to \( 4.17\times10^{-12} \), also known as the Eddington number [5]. If we compare the Coulomb and gravitational forces between a proton and an electron, we get \( Ke^2/Gm_pr \approx 2.27\times10^{39} \) (Dirac number) [5]. Here \( m_p, m_e \) are the masses of the proton and electron, respectively. However, if we consider different objects of the cosmos, such as planets, stars, etc., rather than elementary particles, one must take into account that the ordinary nuclear matter consists of nucleons (protons and neutrons), which are 1836 times heavier than electrons. Therefore, when estimating the mass of macroworld structures, we can neglect the mass of electrons that leave it.

When comparing the forces of Coulomb repulsion and gravitational attraction between different parts of a charged gravitating structure, according to the laws of Coulomb and Newton, the forces \( K\epsilon^2/N_e \), \( N \) should be compared. Here, \( K = 1/4\pi\epsilon_0 \) is the electric constant, \( \alpha_2 \) is the degree of uncompensated bulk charge of protons in the whole structure, \( N \) is the average nucleon density in the sphere of the structure of radius \( R \), \( \alpha_1 \) is the degree of uncompensated bulk charge of protons in the investigated part of the structure, \( n \) is the mean density of nucleons in this part of the structure. The degree of uncompensated bulk charge of a structure can be represented as \( \alpha_1 = n_i/N \), where \( n_i \) is the average density of positively charged ions (that are not compensated by electrons) which form a bulk charge of the whole positively charged structure, and \( N \) is the average density of the total number of nucleons determining the mass of the structure.

With this approach [4], the Eddington and Dirac numbers are modified to the number:

\[
K\epsilon^2/Gm^2_0 = 4.17\times10^{-12} \rightarrow K\epsilon^2/Gm_pr = 2.27\times10^{39} \rightarrow K\alpha_1\alpha_2\epsilon^2/Gm^2_p = 1.
\]  \( (1) \)

The condition of equality of the forces of gravity and Coulomb forces leads to instability of the star, galaxy and other structures in a manner analogous to the rotational 2D instability. On the charged
gravitating structure and its separated part will act, on the one hand, the forces of gravitational attraction, and on the other hand, the Coulomb repulsive forces (figure 1).

Condition (1) allows us to determine:

\[ ((a_{i1}^* a_{i2}^*)^{0.5})^* = a_{i}^* = 0.9 \cdot 10^{-18} . \]  
(2)

\( a_{i}^* \) is the critical degree of a violation of neutrality (VN) of the structure when it ceases to contract under the action of gravitational forces and, as in the case of rotational instability, parts of a charged quasineutral plasma in the form of a plasma wind begin to be ejected from its surface.

The parameter \( a_{i}^* \) is determined by two parameters: \( a_{i1} \) - the VN parameter of the structure as a whole, and \( a_{i2} \) - the VN parameter of the element which investigated on the Coulomb instability. An element can have the value \( a_{i2} = 1, 1/2, 1/3 \) or less. In the case of the proton, \( a_{i2} = 1 \) (since the ratio \( Z/m = 1 \)), the instability will begin at the VN parameter for the entire star \( a_{i1} \geq 0.81 \cdot 10^{-36} \). At these values of \( a_{i1} \) and \( a_{i2} \), the value of \( a_{i} \) will reach the critical degree of VN, see relation (2). The VN parameters do not depend on the size and other physical parameters of the structure. Their magnitudes are small, but the electromagnetic interaction is much stronger than the gravitational one. When the star reaches \( a_{i1} \geq 0.81 \cdot 10^{-36} \), for the proton, Coulomb repulsive forces will dominate gravitational attraction for a positively charged star of any type [4].

![Figure 1](image.png)

**Figure 1.** Model of the Sun as a positively charged structure with a weak violation of neutrality.

3. **Calculations of the parameters of the Sun and solar wind**

As an example of calculating the parameters of stars with allowance for VN, we calculate the positive charge of the Sun, which is necessary for the reflection of protons. It will be further shown that the magnitude of the solar charge in our model directly depends on the ratio \( Z/m \), which takes into account the real ion composition of the solar wind. Knowing the mass of the Sun, and therefore the number of nucleons in the Sun \( 1.2 \cdot 10^5 \), the radius of the Sun \( R_S = 6.96 \cdot 10^5 \) m and the VN parameter for the proton reflection \( a_{i1} \approx 0.81 \cdot 10^{-36} \), we find the solar charge and the electric field magnitude on its surface. These quantities will be equal to \( q_S = e a_{i1} N_S = 154 \) C and \( E_S = k e a_{i1} N_S / R_S^2 = 2.86 \cdot 10^6 \) V/m, respectively. The number \( a_{i1} \approx 0.81 \cdot 10^{-36} \) is negligible, but a violation of neutrality at this level leads to the formation of a solar wind even without taking into account the generation of Alfven waves.

We shall characterize the energy of charged plasma particles in the chromosphere and solar corona by the parameter \( E/N \). \( E \) is the electric field magnitude in the region of the charged Sun, and \( N \) is the particle density in this region. This parameter introduced A. Stoletov and later used J.S. Townsend in his work on the study of gas-discharge plasma. The reduced electric field, measured in Td (Townsend), \( E/N \) (where \( N \) is the density of hydrogen atoms or number of nucleons), significantly depends on the density of heavy plasma particles and rapidly grows from the photosphere \( (h = 0) \) to the chromosphere \( (0 < h < 10000 \) km). We take the relation of \( N \) with the height from [6], taking into
account that the electron concentration is approximately equal to the concentration of nucleons. On the basis of these data, we calculate the relation of \( E/N \) with the height (table 1).

| \( h \) [km] / \( r [R_S] \) | \( N_{He} \), cm\(^{-3}\) | \( E/N \), Td | \( E/N^* \), Td | \( E/N^{**} \), Td |
|---|---|---|---|---|
| 0 | \( 3.98 \times 10^{15} \) | \( 7.19 \times 10^7 \) | \( E/N \times 2 \) or \( 4 \times 4 \) | \( E/N \times 9 \) |
| 1 000 | \( 3.16 \times 10^{13} \) | \( 9.05 \times 10^5 \) | | |
| 2 000 | \( 6.31 \times 10^{12} \) | \( 4.53 \times 10^4 \) | | |
| 3 000 | \( 1.99 \times 10^{12} \) | \( 1.44 \times 10^3 \) | | |
| 4 000 | \( 7.94 \times 10^{11} \) | \( 3.6 \times 10^3 \) | | |
| 6 000 | \( 2.51 \times 10^9 \) | 1.14 | | |
| 8 000 | \( 1 \times 10^9 \) | 2.86 | | |
| 10 000 | \( 6.31 \times 10^8 \) | 4.53 | | |
| 15 000 | \( 1.99 \times 10^8 \) | 13.78 | | |
| 70 000 | \( 7.94 \times 10^7 \) | 29.75 | | |
| 280 000 | \( 1.26 \times 10^7 \) | 115.79 | | |
| 420 000 | \( 5.01 \times 10^6 \) | 223.31 | | |
| 700 000/2 | \( 1.58 \times 10^6 \) | 452.28 | | |
| 1 400 000/3 | \( 3.98 \times 10^5 \) | 798 | | |
| 2 800 000/5 | \( 6.31 \times 10^4 \) | 1812 | | |
| 6 200 000/10 | \( 1 \times 10^9 \) | 2942 | | |
| 13 000 000/20 | \( 2.51 \times 10^3 \) | 2973 | | | 26757 |
| 44 000 000/65 | \( 1 \times 10^9 \) | 701 | | |
| 150 000 000/215 | \( 6.31 \times 10^2 \) | 97.7 | | |

It can be seen from the table 1 that in the photosphere region, where the concentration of plasma particles is large, the parameter \( E/N \) is very small, but in the chromosphere this parameter grows rapidly with the height and reaches breakdown values (several tens of Td) in the corona at the height of 15 000 km, which apparently leads to a substantial heating of the electrons already in this region of the positively charged Sun. According to the above model, even in the lower corona, a non-equilibrium plasma is formed in the external electric field of the positively charged Sun with \( E/N \) values much larger than the breakdown fields in the plasma of completely ionized hydrogen. This generates the SW into outer space.

When analyzing the ion composition of the solar wind, we are interested in the minimum ratio of the ion charge to its mass, \( Z/m \). The smaller this ratio, the greater the positive charge of the Sun for the equality of Coulomb repulsive forces and the gravitational forces of attraction for a given ion. Since helium ions are observed in the SW, this means that all the parameters of the Sun are 2 (if helium is ionized twice, \( Z/m = 1/2 \)) or 4 times (if helium is ionized 1 time, \( Z/m = 1/4 \)) greater (see table 1 - \( E/N^* \)). Data from the ACE spacecraft [1] for 2011 indicate the presence of the following ions in the composition of the SW: \( C^4+, O^5+, Ne^8+, Mg^6+, Si^6+, Fe^6+ \). The last iron ion has a minimum value of \( Z/m = 0.107 \) among those observed in the SW. This means, in comparison with the calculations of the effective charge of the Sun for the SW consisting of protons, it is necessary to increase the charge of the Sun by 9 times, so that the heavy iron ions \( Fe^6+ \) are repelled by Coulomb forces. Such an increase in charge leads to a corresponding change in the electric field magnitude and the parameter \( E/N \) (see table 1 - \( E/N^{**} \)).

4. Calculation of energy of solar wind particles in the Earth’s region

The Coulomb potential energy of a proton born at a distance \( r \) from the Sun will be:

\[
W = K \cdot q_S \cdot e / r
\]
This potential energy can be completely changed to the kinetic energy of a charged particle far from the Sun if the particle does not experience inelastic collisions that substantially change its kinetic energy. For protons born in the Earth's orbit, \( W = 1.5 \cdot 10^{-18} \text{ J (9.2 eV)} \), where \( r \) is the astronomical unit (the distance from the positively charged Sun to the Earth) if the solar charge is 154 K.

From the experimental studies of the SW in the region of the Earth, it is known that the velocity of protons and ions in it reaches from \( V = 400 \text{ km/s to 1000 km/s} \) [2]. Consequently, these protons came from a region close to the Sun. Knowing from the experiments the average speed of the solar wind near the Earth - \( V \), we can estimate the kinetic energy of the protons in the solar wind:

\[
W = m \cdot V^2 / 2 = 1.34 \cdot 10^{-16} \div 8.36 \cdot 10^{-16} \text{ J (835 ÷ 5 200 eV)} \tag{4}
\]

Such energy can be obtained by protons born in the corona of the positively charged Sun and accelerated by its charge to such velocities in the region of the Earth. In this case, the mean free path, in which protons flying to the Earth, do not experience collisions with other nucleons, can be estimated from the formula:

\[
L = 1/(\sigma N) \tag{5}
\]

\( \sigma \) is the effective collision cross section of protons, which for energies of the order of 1 keV is equal to \( 2 \times 10^{-17} \text{ cm}^2 \) [7]. In this case, protons born at distances of the order of 2 800 000 km to 6 000 000 km (5 ÷ 10 solar radii) will arrive to the Earth with a small number of collisions. At these distances, their potential energy at birth is about 3 keV, if the solar charge is of the order of 1000 K, i.e. protons, alpha particles and even six times ionized iron ions are reflected from the Sun (figure 1).

If we consider that the Sun reflects alpha particles, iron ions, then we get an increase in the energy of positively charged particles in the region of the Earth also by two, four and nine times, respectively. Thus, experimental observations in the interplanetary space of the mass and charge compositions of the SW ions already provide valuable information not only about the solar atmosphere, but also about the average parameters of the Sun, such as its total charge, the electric field magnitude in the corona, and make a significant contribution to the verification of mathematical models of processes on the Sun.

Conclusion
For the first time, a specific mechanism is proposed for heating the solar wind plasma in its corona and heliosphere in the constant Coulomb field of the Sun, as a positively charged structure. In this model, we combine such phenomena as electric wind, plasma wind and solar wind into a single phenomenon caused by a violation of neutrality and substantial heating of plasma particles in the electric field of a charged structure (a charged needle, the Sun, etc.). As proved by analytical calculations, having determined in the experiments the ion composition of the solar wind and finding the minimum value of the ratio \( Z/m \), according to the method proposed in this paper, it is possible to calculate the minimum electrical parameters of the Sun itself, its corona and analytically calculate the energy parameters of the solar wind in the region of the Earth. The smaller the \( Z/m \) ratio, the greater the positive charge of the Sun for the equality of Coulomb repulsive forces and gravitational attraction forces for a given ion. The ion velocity in the solar wind is also essentially dependent on this parameter and on the place where the ion was born. This determines the variance of the solar wind velocity from the ratio \( Z/m \).

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