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ELECTROMAGNETIC WAVE MODEL OF HYDROGEN AND HELIUM DISTRIBUTION AT THE FORMATION OF THE SOLAR SYSTEM

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This paper considers the formation process of the protosolar hydrogen-helium cloud in chronological order. From the list of hypotheses about the solar system formation, the electromagnetic hypothesis of Alfvén was selected since it is based on the plasma state of the protosolar hydrogen-helium cloud. It presumably describes a supernova explosion and its contribution to the solar system formation. The spatial-temporal dynamics of changes in the density and velocity of ions in a cylindrical two-component hydrogen-helium plasma is described. It is shown that the motion velocities of two-type particles represent Benard cells oscillating with different periods. The proposed electromagnetic wave model was used to calculate the distribution of hydrogen and helium ions in the solar system at the beginning of its formation and after a supernova explosion.

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INTRODUCTION

Many different models of the origin and development of the solar system are known [1, 2]. But none of them meets the characteristics of the generally accepted theory due to insufficient correspondence with observational data. It is a generally accepted fact that the primary composition of stellar matter was formed starting from the age of the Universe of 20 min, and consisted of helium – 4 (^4He), about 25...26 %, deuterium about 1 %, traces of heavier elements to boron, and the rest – hydrogen about 74...75 % [3]. In the further evolution of the Universe, its averaged composition with respect to hydrogen and helium did not change and corresponded to the ratio of 1 helium atom to 11 hydrogen atoms [4]. The formation of interstellar clouds began about 2.7 billion years ago [3]. As a result of gravitational compression one of these clouds gave rise to the formation of the solar system, which ended about 4.57 billion years ago [5] According to [6] hereinafter we will call the cloud that gave rise to the solar system the protosolar nebula. Before the formation of the protosolar nebula, at the end of The Epoch of Reionization (before the expiration of 2.7 billion years from the moment the Universe began [7]), helium and hydrogen, apparently, were in the ionization state. The hypothesis that the hydrogen-helium protosolar nebula is in the ionization state, i. e. in the form of plasma is known. One of the well-known modern hypotheses of the origin of the solar system is based on the plasma state of the hydrogen-helium cloud of the solar system – the electromagnetic hypothesis of the Swedish astrophysicist H. Alfven (1908–1995) and the English astrophysicist F. Hoyle (1915–2001). According to this hypothesis, the original gas cloud, from which both the Sun and the planets of the solar system were formed consisted of ionized gas exposed to the influence of electromagnetic fields [8]. At the same time, the primary plasma was concentrated in certain areas around the central body and recombined into small solid granules. Then under the influence of the gravitational force granules stuck together into so-called embryos, and during further accretion, large cosmic bodies were formed: planets, if the central body is the Sun, and satellites, if they are planets [9]. In this paper we will base on the electromagnetic hypothesis. All estimates and reasoning will be since the protosolar nebula was in the ionization state. Presumably, it is known that at the initial stage of the solar system formation, when it was an ionized hydrogen - helium dust cloud, there was a supernova explosion, which the researchers called Coatlicue [10]. The supernova had a mass of about 30 solar masses and was located at a distance of 5...10 pc [11, 12]. The fact of the existence of a supernova and its characteristics were determined from the presence of aluminum-26 in meteorites that were ejected by a massive star [11]. Obviously, the supernova underwent a thermonuclear explosion, since after the explosion nothing remained in its place [1, 12]. The main factor of the supernova influence on nearby objects in the solar system is, among other things, thermonuclear gamma quanta with energies up to 24 MeV [13]. As a result of photodisintegration, such gamma quanta can cause reactions of the nucleus decay of a helium ion into a neutron and a 3-helium ion $^4He(\gamma,n)^3He$ or into a hydrogen ion and a tritium ion $^4He(\gamma,p)^3He$ [14, 15]. Summarizing all the above, we can state with a certain degree of probability that the protosolar hydrogen – helium cloud (nebula) was in two states separated in time. In the first of them, the protosolar cloud was in the ionization state where electromagnetic waves could exist [16], which could lead to fluctuations of the mass fraction of hydrogen and helium ions in space and time.

In the second state, thermonuclear gamma quanta from a supernova explosion in a short time could violate the conditions for the existence of electromagnetic waves and increase the mass fraction of hydrogen due to the decay of helium nuclei.

The purpose of this paper is to develop an electromagnetic hypothesis of the solar system formation.

FAST AND SLOW ISWs IN A CYLINDRICAL TWO-COMPONENT HYDROGEN-HELIUM PLASMA

Let us consider low-frequency fluctuations of a cylindrical plasma volume consisting of two ion types. In cylindrical coordinates, we orient the cylinder axis along the *Oz* axis**.** The height of the cylinder is *h*, and the cylinder is in the range $0 \le z \le h$. The radius of the cylinder is R_0. We will consider axially symmetric fluctuations. Therefore, all solutions depend on the variables r, z and do not depend on the azimuthal angleφ. Under the conditions mentioned above, in a two-component plasma there are independent unattenuated small perturbations of the velocity and density of plasma ions of each type, which are described as fast and slow ISWs. In this case, similarly to what was shown in [18] for a plasma consisting of two types of particles, it is possible to separately describe the motion of each of the plasma components in the quasi-hydrodynamic approximation:

$$\frac{\partial \vec{v}_\alpha}{\partial t} = \frac{Z_\alpha e}{m_\alpha}\vec{E}, \frac{\partial n_\alpha}{\partial t} + div(n_\alpha \vec{v}_\alpha) = 0, \quad (1)$$

where index α= *H, He* refers to hydrogen *H* or helium *He*, $n_\alpha \equiv n_\alpha(\vec{r},t)$ and $\vec{v}_\alpha \equiv \vec{v}_\alpha(\vec{r},t)$ – are the hydrodynamic density and velocity of α-type ions, $\vec{E}$ – is the electric field strength, $e > 0$ – is the electron charge. Equations (1) should be supplemented by the Poisson equation, which establishes a relationship between the perturbed values of the particle density and the electric field strength:

$$div(\vec{E}) = 4\pi e(\sum_\alpha Z_\alpha \hat{n}_\alpha - \hat{n}_e), \quad (2)$$

where $\hat{n}_\alpha = n_\alpha - n_{0\alpha}$, $\hat{n}_e = n_e - n_{0e}$are the deviations of particles density of α-type ions and electrons from equilibrium values. In (11), it is assumed that the condition of plasma quasineutrality is satisfied: $\Sigma_\alpha Z_\alpha n_{0\alpha} = n_{0e}$, where$n_{0e}$ – is the equilibrium plasma electron density. Since electrons are characterized by high thermal velocities, we will assume that at low-frequency fluctuations they are in equilibrium and their density is described by the Boltzmann formula:

$$n_e(r,t) = n_{0e}\, exp\left(-\sum_\alpha \frac{Z_\alpha e \varphi_\alpha(\vec{r},t)}{\Theta_\alpha}\right), \quad (3)$$

where $\varphi_\alpha(\vec{r},t)$ – is the potential of the electric field of α-type particle, $\vec{E} = -\nabla \sum_\alpha \varphi_\alpha$.

In (3) $Z_H = 1$, $Z_{He} = 2$, and the temperatureΘ_α is given in the form $\Theta_H = T_e$, $\Theta_{He} = T_e Z_{He} \Omega_{He}^2 n_{0e}/((\Omega_{He}^2 + \Omega_H^2) n_{0H})$ so that the equations (1)-(3) describe the spectra of a fast ISW, in the absence of a slow one, and vice versa.

We will assume that all fluctuations are small in amplitude. According to (10) the relations are as follows:

$$\vec{v}_\alpha = \frac{Z_\alpha e}{m_\alpha}\vec{\nabla}\sum_\alpha \frac{1}{\omega} f_\alpha(r,z)\, cos(\omega t), \quad (4)$$
$$\hat{n}_\alpha = -n_{0\alpha}\frac{Z_\alpha e}{m_\alpha}\vec{\nabla}\sum_\alpha \frac{1}{\omega^2} f_\alpha(r,z)\, sin(\omega t).$$

From (3) for small perturbations of the electron density we have:

$$\hat{n}_\alpha = n_{0e}\sum_\alpha \frac{Z_\alpha e \varphi_\alpha(\vec{r},t)}{\Theta_\alpha}. \quad (5)$$

Using (4), (5), we obtain the Poisson equation (2), written in terms of the perturbed potentials of the electric field created by α-type ions:

$$\sum_\alpha \frac{\partial^2}{\partial t^2}\Delta\varphi_\alpha + 4\pi e(\sum_\alpha Z_\alpha \frac{Z_\alpha n_{0\alpha} e}{m_\alpha}\sum_\alpha \Delta\varphi_\alpha -$$
$$n_{0\alpha}\sum_\alpha \frac{Z_\alpha e}{\Theta_\alpha}\frac{\partial^2}{\partial t^2}\varphi_\alpha) = 0. \quad (6)$$

We will consider the potential perturbations as an axially symmetric function and define it in the form $\varphi_\alpha(\vec{r},t) = f_\alpha(r,z) sin(\omega_\alpha t)$, where $f_\alpha(r,z) = C_\alpha J_0(q_{r\alpha} r) sin(q_{z\alpha} z)$, $J_0(x)$ – the zero-order Bessel function of the first kind, C_α – are constants, $q_{r\alpha}$ and $q_{z\alpha}$ – are the radial and vertical wavenumbers of waves propagating in α-type particles. The choice of such a dependence of the electric potential on the coordinates is like the description of the spatial distribution of the velocity potential of a viscous incompressible fluid in a cylindrical Benard cell [19]. Assuming in (4) the factors for $sin(\omega_H t)$ and $sin(\omega_{He} t)$, equal to zero, we obtain the spectra of fast ω_H and slow ω_{He} ISWs in the long-wavelength limit:

$$\omega_H = q_H r_{De}\sqrt{\Omega_H^2 + \Omega_{He}^2}, \omega_{He} = q_{He} r_D \Omega_{He}, \quad (7)$$

where $q_\alpha = \sqrt{q_{r\alpha}^2 + q_{z\alpha}^2}$– are the wavenumbers of the ISW of α-type particles. From equations (4), considering the continuity equation (1), the perturbed densities $\hat{n}_\alpha$ and the velocity potentials $\psi_\alpha$of α-type ions, where $\vec{v}_\alpha = -\vec{\nabla}\psi_\alpha$, can be represented as:

$$n_\alpha = -A_\alpha J_0(q_{r\alpha} r)\, sin(q_{z\alpha} z)\, sin(\omega_\alpha t), \quad (8)$$
$$\psi_\alpha = -B_\alpha J_0(q_{r\alpha} r)\, sin(q_{z\alpha} z)\, cos(\omega_\alpha t),$$

where $A_\alpha \omega_\alpha = n_{0\alpha} q_\alpha^2 B_\alpha$.

To preserve the number of particles in the volume of a two-component plasma, we assume that the perturbed radial velocities of ions are equal to zero on the lateral and vertical boundaries of the cylinder:

$$v_{r\alpha}(\vec{r},t)|_{z=0,z=h,r=R_0} = 0. \quad (9)$$

The radial and vertical velocities are determined from the velocity potential (17) and have the form:

$$v_{z\alpha}(\vec{r},t) = \frac{\partial}{\partial z}\psi_\alpha(\vec{r},t) = \quad (10)$$
$$= -B_\alpha q_{z\alpha} J_0(q_{r\alpha} r)\, cos(q_{z\alpha} z)\, cos(\omega_\alpha t),$$
$$v_{r\alpha}(\vec{r},t) = \frac{\partial}{\partial r}\psi_\alpha(\vec{r},t) =$$
$$= B_\alpha q_{z\alpha} J_1(q_{r\alpha} r)\, sin(q_{z\alpha} z)\, sin(\omega_\alpha t).$$

From (18) and (19) it follows that the radial and vertical wavenumbers should have the values:

$$q_{r\alpha} = \frac{\sigma_{1,n_\alpha}}{R_0};\ q_{z\alpha} = \frac{m_\alpha n}{h}, \quad (11)$$

where $\sigma_{1,n\alpha}$– n_α-th zero of the Bessel function of the first kind of the first order, $J_1(\sigma_{1,n\alpha}) = 0$ [20, 21], $n_\alpha = 1, 2, 3...$; $m_\alpha = 1, 2, 3...,$ – integers, which for different αcan either coincide or take on different values. Thus, based on (9)-(11), fluctuations in the density and velocity of plasmaα-type ions are determined by the equations:

$$n_\alpha = n_{0\alpha} - A_\alpha J_0(q_{r\alpha} r)\sin(q_{z\alpha} z)\sin(\omega_\alpha t), \quad (12)$$

$$v_{r\alpha} = B_\alpha q_{z\alpha} J_1(q_{r\alpha} r)\sin(q_{z\alpha} z)\cos(\omega_\alpha t), \quad (13)$$
$$v_{z\alpha} = -B_\alpha q_{z\alpha} J_0(q_{r\alpha} r)\cos(q_{z\alpha} z)\cos(\omega_\alpha t).$$

SPATIAL-TEMPORAL DYNAMICS OF CHANGES IN ION DENSITY IN AN CYLINDRICAL TWO-COMPONENT HYDROGEN-HELIUM PLASMA

Let us analyze the dependence of the ion density distribution in space on time. As follows from (12), fluctuations in the density of different types of ions occur at different frequencies and with different amplitudes of deviation from the equilibrium background. For a description of fast and slow ISWs close to real conditions in a two-component cylindrical plasma of a cloud of the solar system protomatter, we will proceed from the condition that the radius of the cylinder significantly exceeds its height, i. e. $R_0 >> h$. When comparing the obtained theoretical results with experimental data on the distribution of the mass fraction of hydrogen and helium in the solar system [17], it can be seen that the radial modes n_α – should be bigger than 1, and the vertical modes m_α – should be equal to 1. The analysis of the dependences on the coordinates and time of the projections of the velocities of ions of different types (13) has its own specifics, and it is difficult to display it on a graph. Therefore, to simplify this analysis consider the graphs of the dependence of the Stokes lines, *on* $\psi_\alpha = B_\alpha J_0(q_{r\alpha} r)\sin(\pi z/h)$ the spatial coordinates. In this case, the projections of the vector outgoing from the Stokes line and tangent to it on the r and z axes determine the corresponding projections of the velocity, considering the sign of the velocity potential. To analyze the Stokes lines, we introduce the following simplifications: we assume that the wave numbers $q_{r\alpha}$, $q_{z\alpha}$ are the same for α-type ions. On this basis, in units of α the distribution of Stokes lines for the velocity of α-type ions in the coordinate intervals $0 \le r \le R_0$, $0 \le z \le h$ can be reduced to the same form $\psi = J_0(q_r r)\sin(q_z z)$. For this case, the Stokes lines are shown in Fig. 1.

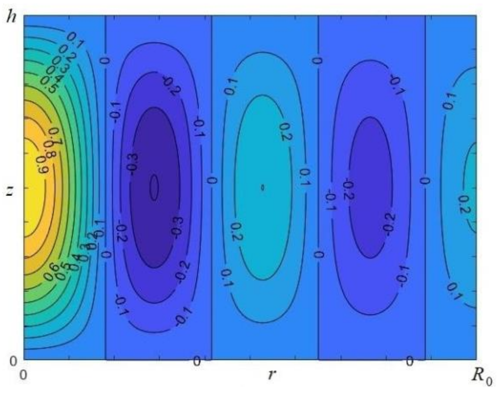

Fig. 1. Stokes lines $\psi = J_0(q_r r)\sin(q_z z)$ in relative units for the case $q_r = \sigma_{1,4}/R_0 \approx 13.3/R_0$; $q_z = \pi/h$

Fig. 1. shows that the ions in each of the vertical stripes make closed movements along the Stokes lines. In light colors, some move along closed trajectories in one direction, in dark ones – in the opposite direction. The direction of movement of ions changes in time proportionally to $\cos(\omega_\alpha t)$. In general, the motion velocities of α-type ions are Benard cells oscillating with different periods of the time.

PROCESSES ACCOMPANYING THE PHOTODISINTEGRATION OF HELIUM IONS BY HIGH-ENERGY THERMONUCLEAR GAMMA QUANTA

Let us briefly characterize the conditions and process of photodisintegration of a helium ion by a high-energy thermonuclear gamma quantum. This process is accompanied by the decay of a helium nucleus into a neutron and a helium-3 ion or into a hydrogen ion and a tritium ion [13]. As follows from [22], the reaction threshold $E_{(\gamma,n)}$ = 20.6 MeV is higher than the $E_{(\gamma,p)}$ = 19.8 MeV threshold, but they are all less than the gamma quantum energy E_γ. In addition, the ratio of the cross sections of reactions $\lambda = \sigma(\gamma,p)/\sigma(\gamma,n) = 1.13$ is bigger than unity, where $\sigma(\gamma,p)$ = 1.5 *mb*, $\sigma(\gamma,n)$ = 1.5 *mb* – are the cross sections for the reaction with the formation of a proton and a neutron respectively.

For somewhat higher energies of gamma quanta of (25±0.5) MeV the ratio of the reaction cross sections also exceeds unity: λ=1.35±0.1 [23].

An important fact is the asymmetry of the cross sections for the reactions $^4He(\gamma,p)^3H$ which consists in the fact that in the center-of-mass system the maximum of the reaction cross section is observed for nucleons emitted almost perpendicular to the direction of gamma quantum propagation. Such asymmetry has been demonstrated experimentally for linearly polarized gamma quanta with energy of 21...30 MeV with a proton yield [24], and with energy of 27...30 MeV with a neutron yield [25], as well as for linearly polarized gamma quanta with energy of 40 MeV for protons and neutrons [26, 27]. In papers [26, 27] it is shown that the cross section of the reaction (γ,p) is maximum for polar angles of the order of $\theta \approx \pi/2$, measured from the direction of gamma quanta propagation. However, measurements were carried out for azimuthal angles $\varphi \approx \pi/2$, measured from the polarization vector of linearly polarized gamma quanta (Fig. 2), when the reaction cross section for this angle is minimal [26, 27].

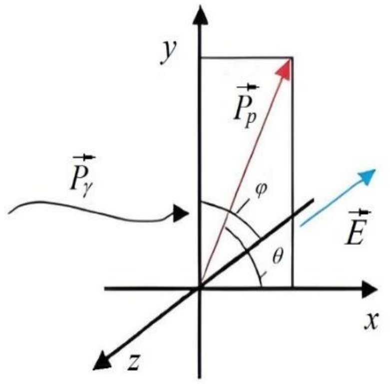

Fig. 2. Diagram of the direction of the proton emission because of the reaction (γ,p)

In the experimental paper [24], the gamma quanta of the collimated beam of bremsstrahlung of the synchrotron were linearly polarized with the electric field vector located in the plane of the axial section of the Wilson chamber and perpendicular to the direction of their propagation. The vectors of the emission direction of fission reaction products *(γ,p)* and the vector of the direction of gamma quanta propagation are coplanar.

From the experimental results obtained in [24-27], the following conclusions can be drawn:

– gamma quanta enter mainly into the reaction *(γ,p)*;

– the maximum yield of reaction products *(γ,p)* is observed for polar angles of the order of $\theta \approx \pi/2$, measured from the direction of propagation of gamma quanta, and the minimum for azimuthal angles $\varphi \approx 0$, measured from the polarization vector of linearly polarized gamma quanta;

– protons emit at a polar angle $\theta \leq \pi/2$ relative to the direction of propagation of gamma quanta, and at an azimuthal angle $\varphi \approx \pi/2$, when the reaction cross section is minimal. In this case, the traces of the expansion of the reaction products in the polar angle for the proton $\theta$and the polar angle for tritium φsatisfy the conditions $\psi = \theta + \varphi \geq 160°$and the transverse components of the impulses are equal;

– for linearly polarized gamma quanta, the reaction $^4He(\gamma,p)^3H$ has a maximum cross section (maximum number of decays) for polar proton emission angles $\theta \approx \pi/2$, and azimuthal angles $\varphi \approx 0$ relative to the polarization direction of the gamma quantum. Fig. 2 represents the implemented in [24] diagram of the direction of the proton emission as a result of the reaction *(γ,p)* showing the designation of certain angles. In the figure $\vec{p}_p, \vec{p}_y$ – are the impulses of the proton (red arrow) and the gamma quantum, $\vec{E}$ – is the vector of the electric field of the linearly polarized gamma quantum (blue arrow). As a result of the reaction *(γ,p)* a certain amount of accelerated hydrogen ions and tritium ions are additionally formed in the plasma volume due to the decay of helium ions.

EVOLUTION OF PROTOSOLAR NEBULA TAKING INTO ACCOUNT THE SUPERNOVA EXPLOSION

Some of the accelerated hydrogen ions, due to the path length comparable to the cylinder height *h*, will remain in the plasma volume. The peripheral part of the accelerated plasma ions and the accelerated tritium ions, due to their large mean free path, will leave the plasma volume. How exactly this separation of accelerated ions can take place will be considered in the next section. Thus, after a supernova explosion, the number of hydrogen ions in the plasma will increase, while the number of helium ions will decrease. In this state, the hydrogen-helium ionized cloud will continue its evolution, which consists in the expansion of the Universe and, therefore, the general cooling of the plasma. At temperatures below 4000 K, electrons and atomic nuclei will recombine, and the plasma will turn into a neutral gas [28]. In the future, gravitational attraction will come into force, as a result of which protoplanetary rings will be formed, and then the planets of the solar system will appear [6]. However, this stage of the formation of the solar system is not considered in the paper. In further calculations, we will proceed from the fact that the content of hydrogen and helium in the Sun and the planets of the solar system should correspond to the moment of the supernova explosion, which caused the ISW attenuation and coincided with the onset of plasma recombination. To confirm the proposed theoretical model of the influence of fast and slow ISWs on the solar system formation, we will use the data on the abundance of hydrogen and helium in the solar system at the present time [17, 29]. These data are comparable with the conclusions of the electromagnetic wave model of the solar system formation proposed in this paper. Let us start the comparison with the fact that the mole fractions of hydrogen and helium, calculated from the number of their atoms in the Universe, are the values of the order of 92 and 8 %, respectively [4, 29]. Hence, it follows that the mass fraction of hydrogen and helium is determined by values of the order of 74 and 26 % [4]. In the calculations, it is necessary to consider that the mass fractions of α-type ions are proportional to their densities (20). As a result, to describe the spatial-temporal dynamics of the mass fraction of α-type ions in the solar system, we obtain the equations:

$$C_\alpha = C_{0,\alpha} - D_\alpha J_0\left(\frac{\sigma_{1,n_\alpha}}{R_0} r\right) sin\left(\frac{n}{h} z\right) sin(\omega_\alpha t), \quad (14)$$

where $C_{O,H} \approx 74$, $C_{O,He} \approx 26$ − initial abundance of α-type ions by mass in the solar system (%), D_α – constants.

We use (14) to describe experimental data on the mass content of hydrogen and helium in the planets of the solar system. In Fig. 3. markers show the mass fraction of hydrogen and helium atoms in the planets of the solar system at the present time. The dashed lines show the mass fractions of hydrogen and helium ions obtained using (14) in the two-component hydrogen-helium plasma of the solar system protomatter cloud at the moment before the supernova explosion.

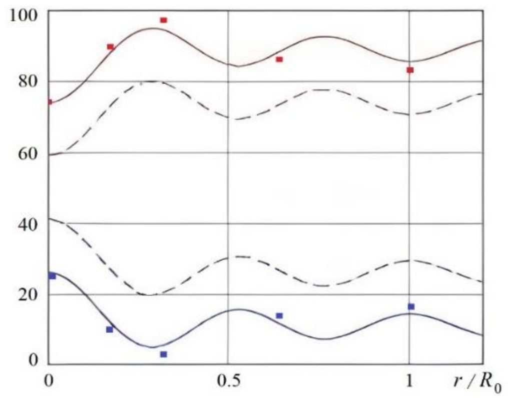

Fig. 3. Distribution of hydrogen and helium atoms in the solar system. Markers – experimental data [16, 17], dashed lines are described by formulas (14)

Comparison of the content of hydrogen and helium atoms at present with the data of formula (14) shows that after the supernova explosion the mass fraction of hydrogen ions jumped by 15 %, and the mass fraction of helium ions decreased by 15 %.

SCENARIO OF CONFINEMENT OF ACCELERATED HYDROGEN IONS IN PLASMA

To substantiate the above process of redistribution of the mass fraction of plasma ions, let us briefly discuss the conditions under which the photodecomposition of $^4He(\gamma,p)^3H$ by thermonuclear gamma quanta with an energy of 24 MeV can occur. From experimental studies it follows that in the photodecomposition of $^4He(\gamma,p)^3H$ by gamma quanta the cross section of the fission reaction is anisotropic for emitted nucleons and is maximum at a polar angle $\vartheta\approx\pi/2\approx90$ with respect to the direction of gamma quanta propagation [26, 27, 30]. The change in the mass fraction of helium ions by – 15 % and hydrogen by 15 % noted in the previous section is possible provided that instead of four helium ions, one hydrogen ion appears in the plasma volume, the remaining 3 accelerated hydrogen ions and 4 accelerated tritium ions must leave its limits. It should be noted that such a clear correspondence of the transformation of helium ions into hydrogen ions is possible under conditions when gamma quanta are linearly polarized. And that's why. From [27] it follows that the traces of hydrogen and tritium ions are coplanar with the beam of gamma quanta, their emission angle satisfies the condition, $\psi = \theta + \phi \geq 160$ and the transverse components of the pulses are equal. From the solution of equations (2)-(4) it follows that in the laboratory system a proton emits at an angle close to $\theta = \pi/2$ and a tritium ion at an angle $\varphi = 0.41\pi \approx 73.9°$, which corresponds to the condition $\psi \geq 160°$.This direction of the proton trajectory corresponds to the maximum value of the cross section for the reaction $^4He(\gamma,p)^3H$ [26, 27, 30] along the polar angle. According to the azimuthal angle $0\leq\varphi\leq2\pi$, measured from the direction of the polarization vector of the gamma quanta beam, the distribution of the reaction cross-section is proportional to $(1+\lambda\cos(2\phi))$, where λ – is a constant determined by the degree of polarization of gamma quanta, and the registered N scattering events in the range of polar angles $\Delta\Theta_N$ and φ_N [27]. From this it follows that in the azimuthal angle the reaction cross section is maximum at $\varphi \approx 0$. Thus, it can be concluded that with linear polarization of gamma quanta directed along the cylinder axis, the decay reaction cross section is maximum. In this case, the protons move parallelly to the axis of the plasma cylinder, which ensures a 15 % increase in the mass fraction of hydrogen uniform along the radius of the cylinder. To calculate the possibility of such ions separation, let us determine the velocities of fission products. From the law of momentum conservation, it follows that the velocities of ion emission are approximately correlated as $V_p\approx3V_T$, where V_p, V_T – are the velocities of hydrogen (proton) and tritium ions respectively. It follows from the law of energy conservation that the velocity of a proton is of the order of $V_p\approx 3\cdot10^{-2}$ s, where c is the light speed, and it propagates perpendicular to the direction of gamma quantum propagation. Tritium ions move in the direction opposite to the proton with a polar angle $\varphi = 0.41\pi \approx 73.9$ relative to the direction of the gamma quantum propagation.

With the above parameters the mean free path of a hydrogen ion is $l_H\approx V_H\nu_{H,H}^{-1}\approx0.5\cdot10^{10}$ cm, where $\nu_{H,H}$ – is the frequency of collisions of accelerated hydrogen ions with hydrogen ions of plasma. It can be a little less than h. In this case, some part of the accelerated hydrogen ions will be retained in the plasma volume. Tritium ions have a path length $l_T\approx V_T\nu_{T,H}^{-1}\approx 3\cdot10^{12}$ cm, where $\nu_{T,H}$ – is the frequency of collisions of accelerated tritium ions with hydrogen ions of plasma, and therefore, they will fly out of the plasma cylinder without encountering obstacles. To implement the above scenario of ion separation as result of photodisintegration of helium, it is necessary that the supernova be in a plane passing perpendicular to the axis of the cylinder and dividing the cylinder in half. In this case, the supernova should generate linearly polarized gamma radiation, the polarization vector of which is collinear with the cylinder axis. Such polarized radiation can be generated by distributed cosmic matter around a supernova [31]. The polarization of gamma quanta provides the predominant production of accelerated hydrogen ions, which move parallelly to the axis of the plasma cylinder. In this case, the change in the mass fractions of hydrogen and helium along the radius of the plasma cylinder will be the same.

CONCLUSIONS

The paper briefly, in chronological order, considers the process of the protosolar hydrogen-helium cloud formation. From a large list of hypotheses of the solar system formation, the electromagnetic hypothesis of the solar system formation of Alfvén was selected, since it is based on the plasma state of the protosolar hydrogen-helium cloud. A supernova explosion is presumably described and its contribution to the solar system formation is estimated. This contribution consists in the fact that before the supernova explosion, the protosolar hydrogen-helium cloud was in the ionization state, and electromagnetic waves propagated in it leading to fluctuations in the mass fraction of hydrogen and helium. Due to the supernova explosion, the electromagnetic waves were attenuated, the redistribution of the mass fraction of hydrogen and helium occurred in the protosolar hydrogen-helium cloud, which did not change after the action of gravitational forces and corresponds to that at the present time. Based on the assumptions made, an electromagnetic wave model is proposed for describing the density distribution of hydrogen and helium ions during the solar system formation. To substantiate the existence of electromagnetic waves in such plasma, an estimate of its parameters was carried out. It is proposed to consider fast and slow ion-sound waves in a cylindrical two-component hydrogen-helium plasma as electromagnetic waves. The spatial-temporal dynamics of changes in the density and velocity of ions in a cylindrical two-component hydrogen-helium plasma is described. It is shown that the motion velocities of α-type particles are Benard cells oscillating with different periods. The proposed wave model is used to calculate the distribution of hydrogen and helium ions in the solar system at the beginning of its formation and after a supernova explosion. It has been suggested that the redistribution of the mass fractions of hydrogen and helium was due to the photodisintegration of helium ions by high-energy 24 *MeV* thermonuclear gamma quanta from a supernova in reactions *(γ,p)*. The parameters and conditions of such reactions are described. It is noted that for 15 % of the redistribution of the mass fractions of hydrogen and helium, the gamma quanta of the supernova should be linearly polarized, with an electric field strength vector collinear to the axis of the solar system. With such an arrangement of the supernova and the solar system, a part of the accelerated protons will remain in the plasma volume due to their path length comparable to the transverse size of the solar system, and the accelerated tritium ions will leave the plasma region due to their large path length. Comparison of the electromagnetic wave model describing the distribution of hydrogen and helium during the solar system formation with observational data has a high quantitative agreement.

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ЕЛЕКТРОМАГНІТНА ХВИЛЬОВА МОДЕЛЬ ОПИСУ РОЗПОДІЛУ ВОДНЮ І ГЕЛІЮ ПРИ ФОРМУВАННІ СОНЯЧНОЇ СИСТЕМИ

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У хронологічній послідовності розглянуто процес формування протосонячної воднево-гелієвої хмари. Електромагнітна гіпотеза Альфвена була обрана зі списку гіпотез про формування Сонячної системи, оскільки в її основі лежить плазмовий стан воднево-гелієвої хмари. Описаний, ймовірно, вибух наднової та оцінений його внесок у формування Сонячної системи. Описано просторово-часову динаміку зміни ~~і~~ густини та швидкості іонів у циліндричній двокомпонентній воднево-гелієвій плазмі. Показано, що швидкості руху частинок сорту α є осцилюючими з різними періодами осередку Бенара. На основі запропонованої електромагнітної хвильової моделі проведено розрахунок розподілу іонів водню та гелію в Сонячній системі на початку її формування та після вибуху наднової.