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Electromagnetic nature of nuclear forces and the toroid structure of the helion and the alpha particle

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ABSTRACT

In the present paper, we consider the nucleons in the helium-3 and helium-4 nuclei as tori. These tori rotate with constant angular velocity around an axis, which is perpendicular to the rotation plane and passes through the centre of mass of the nuclei. Based on exact analytical expressions for the electrostatic interaction between two spheres with arbitrary radii and charges derived by us recently, we find that the well-known potential binding energy for the helion and for the alpha particle is of electromagnetic character. Using the above mentioned formulae, we find the interaction force in the nuclei under consideration. Our toroid model recovers the basic experimental results not only for the binding energy, but also for the stability, radii, spins and the magnetic moments of the helion and the alpha particle.

Keywords: Helion; Alpha Particle; Strong Interaction; Potential Binding Energy; Electrostatic Interaction

1. INTRODUCTION

There are two basic models in the theory of elementary particles: *the standard model* [1-3] and *the helicon model* [4-7].

In [8] and [9] the *toroid model* of nucleons has been proposed, which is in certain contradiction with the standard model, however in perfect agreement with the helicon model.

Every nucleon is modelled with an imaginary torus, which rotates with constant angular velocity around an axis z passing through its mass centre (the geometric centre) O and perpendicular to the rotation plane of its central circle. From quantum mechanical point of view, the nucleon is not a localized object in configuration space. Therefore, our model is valid in a formal heuristic sense a la Niels Bohr similar to his model for the electron in the hydrogen atom, with which he obtained good results for its spectrum within the framework of the old quantum mechanics.

Additional reasoning to consider the nucleons as spatially extended objects is the fact that they are located close to each other in the atomic nuclei. Thus, we assume that they are tori and their electric charge can be redistributed. Essentially, this idea does not contradict to the quark substructure model of nucleons, and it enables us to determine the electrostatic interaction between them. Based on the exact analytical expressions for the electrostatic interaction between two charged conducting spheres with arbitrary radii and charges derived for the first time in [10], we conclude in [8] that *strong interactions are electromagnetic in nature.*

In [9], we ascertain that the experimentally determined potential binding energy between nucleons in the deuteron and triton can be obtained taking into account the electrostatic interaction only. To do that, the values of the experimentally known radii, and masses of the nucleons and the corresponding nuclei have been utilized. In [9], the volume and the mass density of nucleons, as well as their interaction force in the deuteron and the triton have been calculated—important results in nuclear physics presented for the first time.

Applying the method developed in [8,9], we calculate in the present paper the *potential energy and the interaction force* between the nucleons in the helium-3 and helium-4 nuclei. Basic experimentally measured characteristics such as *stability*, *spin*, *radius and magnetic moment* of the helion and the alpha particle are also explained.

According to R. Feynman's conjecture at distances less than 10^{-15} m either Coulomb's law is not valid, or electrons and protons cannot be considered as point-like particles [11]. In accordance with this conjecture, we assume that the distance within the corresponding proton-neutron pairs is less 10^{-15} m.

2. TOROID MODEL OF NUCLEONS

In [8,9] the nucleons are modeled as tori. Moreover, we assume that they rotate with constant angular velocity around an axis *z* passing through their mass (geometric) centre *O* and perpendicular to the rotation plane of their central circle (**Figure 1**).

Next, we study the system consisting of a proton and a neutron and determine the electrostatic interaction between them.

The tori corresponding to the proton and the neutron are denoted by T_p and T_n, while their centres are denoted by O_p and O_n, respectively. We assume that the central circles of T_p and T_n lie in parallel or merging planes and rotate in the same or opposite direction with the same angular velocity $\boldsymbol{\omega}$ around the line *z*, which passes through O_p and O_n being perpendicular to the rotation plane. Then, if $O_pO_n = h$, it follows that $h \geq 0$ (**Figure 2**).

Let K_p and K_n be the centres of the forming circles of the tori T_p and T_n, respectively, and $R_p = O_pK_p$, $R_n = O_nK_n$ be the radii of the central circles of T_p and T_n. We assume that the distance between T_p and T_n is $0 < \tau < 10^{-15}$ m.

According to the available experimental data the proton radius r_p is not greater than the neutron radius r_n. That is why we must have $R_p \leq R_n$.

Let k_p and k_n be the radii of the forming circles K_p and K_n, respectively. It is clear that $k_p < R_p$ and $k_n < R_n$. Moreover,

$$R_p + k_p = r_p \quad \text{and} \quad R_n + k_n = r_n, \tag{1}$$

where r_p and r_n are the radii of the proton and the neutron in the configuration shown in **Figure 2**. It is worthwhile to note that in some nuclei r_p, k_p, R_p and r_n, k_n, R_n may take different values.

Since $O_pO_n = h$, simple geometric consideration yields

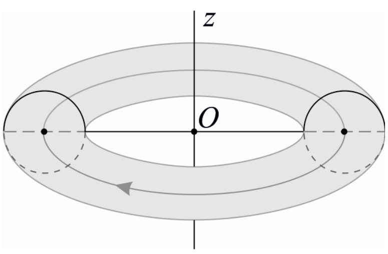

Figure 1. Toroid model of a nucleon.

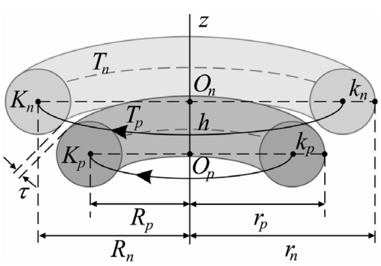

Figure 2. Cross section of the system containing a proton and a neutron.

$$h^2 = \left(k_n + k_p + \tau\right)^2 - \left(R_n - R_p\right)^2. \tag{2}$$

Obviously, $0 \leq h \leq k_p + k_n + \tau$.

We assume that the mass and number densities of the proton and the neutron are equal, that is $\rho_p = \rho_n$. If m_p and m_n are the masses of T_p and T_n, then

$$\rho_p = \frac{m_p}{V_p} \quad \text{and} \quad \rho_n = \frac{m_n}{V_n}. \tag{3}$$

According to [12], the volumes of the tori T_p and T_n are $V_p = 2\pi^2 k_p^2 R_p$ and $V_n = 2\pi^2 k_n^2 R_n$, respectively. Therefore, from $\rho_p = \rho_n$ and from **Eq.3** it follows that

$$k_n = k_p \sqrt{\frac{m_n R_p}{m_p R_n}}. \tag{4}$$

Eqs.3 and **4** contain the proton and the neutron mass whose values are experimentally known and can be readily substituted.

Let $q > 0$ be the radius of the of the empty part of the circle with radius equal to that of the proton r_p. Then

$$q = r_p - 2k_p. \tag{5}$$

In order to apply the results from [10] derived for the case of spheres, we remodel the tori as in [8,9].

Due to the spherical symmetry of the proton charge [13], we can assume that all its charge p is concentrated in the geometric centre O_p of the torus T_p.

We *remodel the proton with a sphere* S_p having the same centre O_p lying on the axis z, such that its area is equal to that of the torus T_p. Moreover, the charge p of the sphere is spherically symmetric and it can be redistributed.

According to [12] the area L_p of the torus T_p is

$$L_p = 4\pi^2 k_p R_p. \tag{6}$$

Since the areas of the torus T_p and the sphere S_p are equal, from **Eq.6** it follows that the radius $\overline{r}_p$ of S_p is

$$\overline{r}_p = \sqrt{\pi k_p R_p}. \tag{7}$$

Next, *we remodel the neutron* T_n *whose torus* T_N has equivalent area and the same centre O_n. The distance τ between its surface and that of S_p is the same as the distance between T_n and T_p (**Figure 3**).

Let S_N be the sphere, whose central circle is forming the torus T_N. We denote the centre of S_N with K_N so that $O_nK_N = R_N$, and let $\overline{r}_N$ be the radius of S_N. If $O_pK_N = \overline{R}$, then $\overline{R} = \overline{r}_p + \overline{r}_N + \tau$ and $O_pO_n = h$ implies $R_N^2 = \overline{R}^2 - h^2$, that is

$$R_N = \sqrt{\left(\overline{r}_p + \overline{r}_N + \tau\right)^2 - h^2}. \tag{8}$$

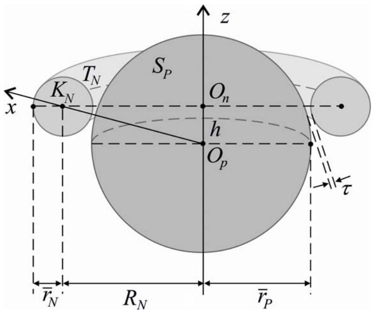

Figure 3. Cross section of the reduced model of the proton-neutron system.

Clearly, $\max R_N = \overline{r}_p + \overline{r}_N + \tau$ and $\min R_N = \overline{r}_N$.

The equality of the areas L_N and L_n of the tori T_N and T_n, together with **Eq.6** yields

$$\overline{r}_N = k_n \frac{R_n}{R_N}. \quad (9)$$

For the number l of the spheres S_N whose total area is equal to that of the torus T_N, the following relation $l.4\pi\overline{r}_N^2 = 4\pi^2 R_N \overline{r}_N$ holds. Therefore

$$l = \pi \frac{R_N}{\overline{r}_N}. \quad (10)$$

Let us assume that the centre O_p is fixed with respect to some inertial reference frame J. Next, we introduce a rigid inertial coordinate system G, which rotates with the constant angular velocity $\boldsymbol{\omega}$ of the torus T_N rotation with respect to J. The point O_p is the centre of the coordinate system $O_p xyz$, which is firmly fixed with G and the spheres S_P and S_N are at rest one against the other (**Figure 3**).

Thus, taking into account the experimentally found value for $r_k = r_n$ (r_k is the radius of the considering nucleus), assigning different values for q and varying $0 < \tau < 10^{-15}$ m and $0 \le h \le k_p + k_n + \tau$, from **Eqs.1-5** we can find R_n, k_n and R_p, k_p, r_p. Combining with **Eq.7** we determine the radius $\overline{r}_P = \sqrt{\pi k_p R_p}$ of the sphere S_P with equivalent area. From **Eqs.8** and **9** we determine the radius $\overline{r}_N$ of the forming sphere S_N.

From $\overline{R} = \overline{r}_P + \overline{r}_N + \tau$ and taking into account ([10], **Eqs.10** and **11** therein), we can determine the interaction force $F(S_P, S_N)$ and the binding energy $W(S_P, S_N)$. According to **Eq.10** the binding energy $W(T_p, T_n)$ and the interaction force $F(T_p, T_n)$ between the proton and the neutron become

$$W(T_p, T_n) = \pi \frac{R_N}{r_N} W(S_P, S_N)$$

and (11)

$$F(T_p, T_n) = \pi \frac{R_N}{r_N} F(S_P, S_N).$$

Eq.11 hold because the forming spheres of the torus T_N are located symmetrically with respect to the centre of the sphere S_P.

3. VOLUME MASS DENSITY OF NUCLEONS

Let us consider the proton in a free state as the torus T_p^0. According to [14] its radius is $r_p^0 = 0.84184 \times 10^{-15}$ m. Let K_p^0 is the centre of forming circle of the torus T_p^0 and let k_p^0 is the radius of this circle. Moreover, $R_p^0 = OK_p^0$.

Utilizing expressions (1) and (5) for different values of the radius q of the empty part of the circle with radius r_p, we have calculated in [9] the quantities k_p^0, R_p^0 and the volume of the proton torus $V_p^0 = 2\pi^2 \left(k_p^0\right)^2 R_p^0$ [12]. The mass of the proton in a free state is $m_p^0 = 1.672621638 \times 10^{-27}$ kg [15]. This can be used to calculate ρ_p^0.

These results are depicted in **Table 1** for various values of q.

Since, the mass of the neutron $m_n^0 = 1.674927212 \times 10^{-27}$ kg [15] is also known, its volume V_n^0 in a free state can be determined, where $\rho_p^0 = \rho_n^0$ has been taken into account as already mentioned in Section 2.

Due to the mass defect in the atomic nuclei, the volumes of the nucleons change. We conjecture however, that the mass densities of the proton and the neutron in all nuclei do not change $\rho_p^0 = \rho_n^0 = \rho = \text{const}$. Based on the values presented in **Table 1**, we ascertain the potential binding energy and calculate the interaction force in the deuteron and the triton in [9].

We model *the deuteron* as two immersed concentric tori. The inner one T_p corresponds to the proton, while the outer T_n corresponds to the neutron, such that the distance between T_p and T_n is of the order of $0 < \tau < 10^{-15}$ m. In addition, we assume that the two tori rotate in the same direction with constant angular velocity $\boldsymbol{\omega}$ around a straight line z passing through their common centre and perpendicular to the rotation plane.

We model *the triton* with three tori whose central circles

Table 1. Dimensions, volume and mass density of the proton.

q	k_p^0	R_p^0	V_p^0	ρ_p^0
m	$m \times 10^{-15}$	$m \times 10^{-15}$	$m^3 \times 10^{-45}$	$\text{kg} \cdot \text{m}^{-3} \times 10^{18}$
0.3 r_p	0.294644	0.547196	0.93771	1.78373
0.4 r_p	0.252552	0.589288	0.74192	2.25444
0.5 r_p	0.21046	0.63138	0.55203	3.02997
0.6 r_p	0.168368	0.673472	0.37685	4.43843
0.7 r_p	0.126276	0.715564	0.22523	7.42639

lie in three parallel planes. The tori T_n^1 and T_n^2 representing the neutrons are located symmetrically on both sides of the torus T_p representing the proton. The distance between the neutron tori T_n^1, T_n^2 and the proton one T_p is the same and of the order of $0 < \tau < 10^{-15}$ m. The tori T_p and T_n^i $(i = 1,2)$ rotate around an axis z, which passes through their centres and is perpendicular to the rotation plane. The tori T_p and T_n^1 rotate with constant angular velocity $\boldsymbol{\omega}$ in the same direction (clockwise, for example), while T_n^2 rotates with the same angular velocity in the opposite direction.

In the subsequent exposition we will model the helium-3 and the helium-4 nuclei. The nucleon disposition must comply with the principle of the minimum of potential energy. Taking into account the mass defect in atomic nuclei, the potential energy of interaction can be calculated according to the following formula [16]

$$W_K = \left(N_p m_p + N_n m_n - m_K\right)c^2 . \qquad (12)$$

Here N_p is the number of protons, N_n is the number of neutrons, while $m_p = 1.672621638 \times 10^{-27}$ kg and $m_n = 1.674927212 \times 10^{-27}$ kg are the proton and the neutron mass, respectively [15], m_K is the mass of the nucleus and $c = 2.99792458 \times 10^8$ ms^{-1} is the speed of light in vacuum [15].

Based on the values for mass densities in **Table 1**, we calculate the corresponding values of W_K for the helion and the alpha particle, we follow the procedure described in Section 2. Finally, our results will be compared with the values obtained by virtue of **Eq.12**.

4. MODEL OF THE HELION

The helion is a mirror nucleus of the triton and therefore its structure is analogous to that of the latter [9]. It consists of one neutron T_n and two protons T_p^1 and T_p^2. Since the proton tori T_p^1 and T_p^2 repel due to the electrostatic interaction between them, their central circles will lie in two parallel planes symmetrically located on both sides of the plane in which the central circle of the neutron torus T_n is located. In addition, the distance between the surfaces of T_p^1, T_p^2 and that of T_n will be the same $0 < \tau < 10^{-15}$ m (**Figure 4**).

This configuration ensures symmetry with respect to the mass centre (the geometric centre) of the helion. This also implies the helion *stability* $T_{{}^3_2He} = \infty$.

The centres O_p^1, O_p^2 and O_n of the tori T_p^1, T_p^2 and T_n, respectively lie on one axis z perpendicular to their plane of rotation with $O_n = O$ being the mass centre of the helion. The tori T_p^1 and T_n rotate with constant angular velocity $\boldsymbol{\omega}$ in a certain direction, while T_p^2 rotates with the same angular velocity but in the opposite direction. From here it follows directly that *the spin of the helion* is $s_{{}^3_2He} = 1/2$, which is an experimentally established fact [16].

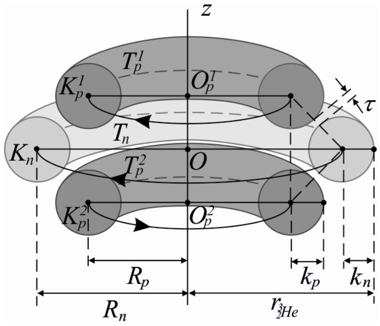

Figure 4. Cross section of the helion model.

The proton rotating in an opposite direction decreases the centrifugal force, which is originated by the two nucleons rotating in the same direction. That is why *the helion radius* $r_{{}^3_2He} = 1.9506 \times 10^{-15}$ m [17] is smaller than that of the deuteron $r_{{}^2_1H} = 2.1402 \times 10^{-15}$ m [15].

The magnetic moments due to the proton charges compensate each other. Thus, the magnetic moment of the helion is generated by the charge of the neutron only. As a consequence of the enlarged neutron radius as compared to that in a free state, *the magnetic moment of the helion* $\mu_{{}^3_2He} = -1.0746 \times 10^{-26}$ JT^{-1} is greater in absolute value than the magnetic moment of the neutron $\mu_n = -0.9662 \times 10^{-26}$ JT^{-1}, which is in agreement with the experimental data [15].

Let K_n and K_p^i be the centres of the forming circles of T_n and T_p^i, respectively with radii k_n and $k_p = k_p^i$ $(i = 1,2)$. We introduce the notations $R_n = OK_n$ and for $i = 1,2$, $R_p = O_p^i K_p^i$ (**Figure 4**).

This means that $h = OO_p^i$. Since the neutron radius is equal to the radius of the helion, it follows that $r_n = r_{{}^3_2He}$ and $R_n = r_{{}^3_2He} - k_n$.

Due to the spherical symmetry of the proton charges, we can assume that their charges $p = 1.602176487 \times 10^{-19}$ C are concentrated in their geometric centres O_p^i $(i = 1,2)$. On these grounds we can model the protons with spheres S_P^i having the same centres O_p^i and radii $\bar{r}_P = \bar{r}_P^i$ $(i = 1,2)$ with areas equal to the areas of T_p^i. Moreover, the charge of each S_P^i is p, which is spherically symmetric and can be redistributed.

With T_N we denote the torus which is equivalent in area to T_n with the same centre O. The distance between S_P^i and T_N is equal to the distance τ between T_p^i and T_n. Let us denote: with S_N the sphere whose central circle is the forming circle of the torus T_N; with

K_N the center of the sphere and with $\bar{r}_N$ the radius of the sphere (**Figure 5**).

We assume that the points O_p^i are at rest with respect to an inertial frame J. Let us also introduce two rigid non inertial reference frames G_1 and G_2 rotating with respect to J with angular velocity equal to that of the rotation of the torus T_N.

The point O_p^i is the centre of the coordinate system Ox_iy_iz and is fixed firmly with the reference frame G_i $(i=1,2)$ relative to which the spheres S_P^i and S_N are at rest one against the other (**Figure 5**).

The torus T_N is located symmetrically with respect to the two spheres S_P^i. It suffices to analyse the electrostatic interaction between T_N and any of the spheres. Based on the calculations presented in [8], we assume that the electrostatic interaction between the spheres S_P^1 and S_P^2 can be approximated with interaction between point-like charges p, p concentrated in their centres, *i.e.* $W\left(S_p^1,S_p^2\right)=W\left(p,p\right)$ and $F\left(S_p^1,S_p^2\right)=F\left(p,p\right)$. For the sake of simplicity, we assume that the distance τ_p between the surfaces of the protons T_p^1 and T_p^2 is the same as the distance between T_p^i and T_n, *i.e.* $\tau_p=\tau$. Therefore, we must have $O_P^iO=h=k_p+\frac{\tau}{2}$ (**Figure 4**).

Using **Eqs.1-5** from Section 2, we calculate k_n, R_n and k_p, R_p, r_p for different values of the mass density ρ taken from **Table 1** of Section 3 and different values of the distance τ. The mass defect of the two protons and the neutron has been taken into account in **Eqs.3** and **4** accordingly to the mass proportions of the nucleons. According to **Eqs.7-9** we calculate $\bar{r}_P$, $\bar{r}_N$ and the distance $\bar{R}=\bar{r}_P+\bar{r}_N+\tau$ between the centers of the spheres S_P^i and S_N.

The experimentally established mass of the helion is $m_{{}^3_2He}=5.00641192\times10^{-27}$ kg [15]. According to **Eq.12** the binding energy of the helion is $W_{{}^3_2He}=-12.352\times10^{-13}$ J. Using the corresponding **Eq. 11**, we confirm this value for $W_{{}^3_2He}=2W\left(T_p^i,T_n\right)+W\left(p,p\right)$, where $i=1$ or $i=2$. By virtue of the same **Eq.11** we find the magnitude of the interaction force for the helion $F_{{}^3_2He}=2F\left(T_p^i,T_n\right)+F\left(p,p\right)$, where $i=1$ or $i=2$.

In **Table 2**, k_n and k_p denote the radii of the forming circles, while R_n and R_p are the radii of the central circles of the neutron and the proton tori in the helion, respectively. In addition, $F_{{}^3_2He}$ is the interaction force between the nucleons in the helion.

It is important to note that in order to obtain the value of $W_{{}^3_2He}$, we can vary h as well for different values of the distance τ, such that $k_p<h<k_p+k_n+\tau$ holds. This implies that the distance τ_p between the surfaces of the two protons will vary according to $0<\tau_p\le 2k_n+2\tau$.

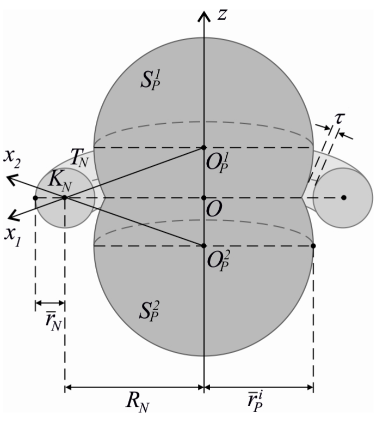

Figure 5. Cross section of the reduced model of the triton.

5. MODEL OF THE ALPHA PARTICLE

Structurally, *the alpha particle* is obtained by adding one neutron to the helion. We assume that the centres of the protons T_p^1, T_p^2 and the neutrons T_n^1, T_n^2 are symmetrically located with respect to the mass centre of the nucleus. The central circles of the tori lie in parallel planes. The distance between the tori T_p^i, T_n^i $(i=1,2)$ is the same $0<\tau<10^{-15}$ m, while the elongation between T_n^1, T_n^2 is some small distance (**Figure 6**).

From this configuration it follows the *stability of the alpha particle is* $T_{{}^4_2He}=\infty$.

The centres O_p^i and O_n^i $(i=1,2)$ of the tori T_p^i and T_n^i lie on one axis z perpendicular to the plane of rotation. The tori T_p^1 and T_n^1 rotate in the same direction around z with constant angular velocity $\boldsymbol{\omega}$, while T_p^2 and T_n^2 rotate with the same velocity in the opposite direction. It follows that both *the spin and the magnetic moment of the alpha particle* are zero, which is an experimentally established fact [15,16].

Moreover, the decrease of the centrifugal force as compared to the helion implies that *the radius of the*

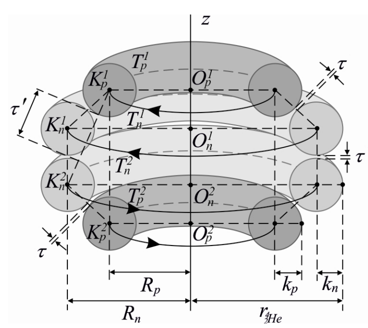

Figure 6. Cross section of the model of the alpha particle.

Table 2. Dimensions of nucleons and interaction force between them in the helion.

ρ $kg \cdot m^{-3} \times 10^{18}$	τ $m \times 10^{-17}$	k_n $m \times 10^{-15}$	R_n $m \times 10^{-15}$	k_p $m \times 10^{-15}$	R_p $m \times 10^{-15}$	$F_{^3_2He}$ N
1.78373	0.728856	0.16290	1.7877	0.17828	1.4905	−13415.87
2.25444	0.695851	0.14415	1.8065	0.15580	1.5441	−15321.68
3.02997	0.648141	0.12364	1.8270	0.13192	1.6025	−16853.54
4.43843	0.588400	0.10154	1.8491	0.10693	1.6650	−19439.99
7.42639	0.508946	0.078006	1.8726	0.08107	1.7313	−23415.29

Table 3. Dimensions of nucleons and the interaction force in the alpha particle.

ρ $kg \cdot m^{-3} \times 10^{18}$	τ $m \times 10^{-17}$	k_n $m \times 10^{-15}$	R_n $m \times 10^{-15}$	k_p $m \times 10^{-15}$	R_p $m \times 10^{-15}$	$F_{^4_2He}$ N
1.78373	1.582281	0.17769	1.4953	0.20746	1.0954	–60565.5
2.25444	1.421146	0.15697	1.5160	0.17881	1.1667	–72347.6
3.02997	0.793140	0.13440	1.5386	0.14916	1.2475	–84474.6
4.43843	0.313777	0.11018	1.5628	0.11934	1.3303	–100313.4
7.42639	0.246313	0.08449	1.5885	0.089552	1.4121	–139022.6

alpha particle $r_{^4_2He} = 1.673 \times 10^{-15}$ m [17] is smaller than the radius of the helion $r_{^3_2He} = 1.9506 \times 10^{-15}$ m.

Let K_p^i and K_n^i be the centres of the forming circles of T_p^i and T_n^i with radii $k_p = k_p^i$ and $k_n = k_n^i$ $(i = 1,2)$. For $i = 1,2$, we denote $R_p = O_p^i K_p^i$ and $R_n = O_n^i K_n^i$ (**Figure 6**).

The radius of the neutron is equal to the radius of the alpha particle, that is $r_n = r_{^4_2He}$ and $R_n = r_{^4_2He} - k_n$. From the isosceles trapezoid $K_n^1 K_n^2 K_p^2 K_p^1$ it follows that the distance τ' between the surfaces of the tori T_p^1 and T_n^2 is

$$\tau' = \sqrt{\left(2k_n + \tau + h\right)^2 + \left(R_n - R_p\right)^2} - \left(k_n + k_p\right). \quad (13)$$

We assume again that the proton charges are concentrated in their geometric centres O_p^i. Similar to Section 4, we model the protons as spheres S_P^i with centres O_p^i and radii $\overline{r}_P = \overline{r}_P^i$ $(i = 1,2)$, whose areas are equal to that of T_p^i. Moreover, the charge of S_P^i is p, which is spherically symmetric and can be redistributed.

With T_N^i $(i = 1,2)$, we denote the tori, whose areas are equal to the areas of T_n^i with the same centres O_n^i. The distance between the objects S_P^i and T_N^j is the same as the distance between T_p^i and T_n^j $(i = 1,2; j = 1,2)$. Let us denote: with S_N^i the sphere whose central circle is the forming circle of the torus T_N^i; with K_N^i the center of the sphere and with $\overline{r}_N = \overline{r}_N^i$ the radius of the sphere (**Figure 6**).

We further assume that the points O_p^i and O_n^i $(i = 1,2)$ are at rest with respect to an inertial reference frame J. In addition, four firm noninertial coordinate systems G_i^j $(i = 1,2; j = 1,2)$ are introduced rotating at constant angular velocity $\boldsymbol{\omega}$ (or $-\boldsymbol{\omega}$) equal to the angular velocity of rotation of the neutrons T_N^1 and T_N^2 with respect to J. Every point O_p^i is a centre of two coordinate systems $Ox_i^j y_i^j z^j$ $(j = 1,2)$ fixed firmly with the reference frames G_i^j with respect to which the spheres S_P^i and S_N^j are at rest.

Since the total charges of the tori T_N^1 and T_N^2 are zero it can be assumed with good approximation that there is no electrostatic interaction between them.

Due to the symmetry, it suffices to find the interaction between any of the spheres $S_P = S_P^i$ and the spheres S_N^j $(j = 1,2)$. We assume as we noted in Section 4 that the interaction between the spheres S_P^1 and S_P^2 is taken as point charges p, p, *i.e.* $W\left(S_p^1, S_p^2\right) = W\left(p, p\right)$ and $F\left(S_p^1, S_p^2\right) = F\left(p, p\right)$. For the sake of calculative simplicity it is assumed that the distance τ_p between the surfaces of the proton tori T_p^1 and T_p^2, as well as the distance τ_n between the surfaces of the neutron tori T_n^1 and T_n^2, is the same as the one between T_p^i and T_n^i $(i = 1,2)$, *i.e.* $\tau_p = \tau_n = \tau$.

We have $O_p^1 O_p^2 = 2k_p + \tau$ and $O_n^1 O_n^2 = 2k_n + \tau$. Therefore, $O_p^i O_n^i = h = k_p - k_n$. Taking into account the mass density ρ of the nucleons from **Table 1** of Section 3 and using **Eqs.1-5** from Section 2 for different values τ all parameters k_n, R_n and k_p, R_p, r_p can be found. In **Eqs.3** and **4** the corresponding mass defect for the two protons and the two neutrons has been taken into account.

According to **Eqs.7-9** we calculate $\overline{r}_P$, $\overline{r}_N$ and the distances $\overline{R}_1 = O_P^1 K_N^1 = \overline{r}_P + \overline{r}_N^1 + \tau$ and $\overline{R}_2 = O_P^1 K_N^2 = \overline{r}_P + \overline{r}_N^2 + \tau'$ between the centres of the spheres S_P^1, S_N^1 and S_P^1, S_N^2, where τ' is given by **Eq.13**.

The experimentally established mass of the alpha particle is $m_{{}^4_2He} = 6.64465620 \times 10^{-27}$ kg [15]. According to **Eq.12** the binding energy for the alpha particle $W_{{}^4_2He} = -32.9232 \times 10^{-13}$ J. Using the corresponding **Eq. 11** we confirm this value for

$W_{{}^4_2He} = 2W\left(T_p^i, T_n^1\right) + 2W\left(T_p^i, T_n^2\right) + W\left(p, p\right)$, where $i = 1$ or $i = 2$. By virtue of the same **Eq.11** we find the magnitude of the interaction force for the alpha particle $F_{{}^4_2He} = 2F\left(T_p^i, T_n^1\right) + 2F\left(T_p^i, T_n^2\right) + F\left(p, p\right)$, where $i = 1$ or $i = 2$.

The quantities k_n and k_p in **Table 3** denote the radii of the forming circles of the tori, R_n and R_p are the radii of the central circles of the neutron and proton tori, respectively and $F_{{}^4_2He}$ is the interaction force between the nucleons in the alpha particle.

We would like to note that in order to obtain the value of $W_{{}^4_2He}$, the quantity h for different values of the distance τ can be varied as well, such that $0 < h \le k_p + k_n + \tau$. It follows that the distance τ_p between the proton surfaces will vary $0 < \tau_p \le 4k_n + 3\tau$. According to **Eq.13** the distance τ' will vary, too.

6. DISCUSSION

Describing the nucleons as tori, we calculate in [8] the potential energy and the interaction force between the nucleon couples. This approach is based on recently derived for the first time analytical expressions describing the electrostatic interaction between two charged spheres in the most general case [10]. According to the above mentioned formulae one can determine the electrostatic interaction between spheres at distances much less than their radii.

Based on this method, we find that strong interactions in atomic nuclei are electromagnetic in origin. Additional finding is the fact that the electrostatic interactions between the couples proton-neutron are short range (attracting forces), while the interactions between the couples proton-proton are long range ones (repelling forces) [18].

In [9] the basic experimental results for the deuteron and the triton such as binding energy, radii, spins and magnetic moments have been explained.

In the present paper, we extend this investigation for the nuclei of helium-3 and helium-4 and confirm that our model is capable to explain all essential experimental results for the basic simple nuclei. We find new results—the volumes and the mass densities of the nuclei, as well as the force of interaction in the considered nuclei.

7. CONCLUSIONS

The presented here model can be applied for the more complicated atomic nuclei. The electrostatic interaction between nucleons changes their electric structure. Thus, all nucleons enter to various extents in interactions, which compensate each other.

Let us also note that the electromagnetic forces between nucleons depend on whether they rotate in the same or different directions that is they depend on the orientation of their spins.

Based on our research, we are confident that all available experimental data about atomic nuclei can be explained by the model proposed. Other new properties of atomic nuclei can also be found.

It is essential that we obtain the basic nuclear characteristic—the binding energy in all of the considered nuclei, using only electromagnetic interactions. The most significant conclusion from our studies is that nuclear forces are electromagnetic in origin.

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