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Electromagnetic nature of the nuclear forces and toroid structure of the deuteron and triton

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ABSTRACT

In this paper we model in a new way the nuclei of deuterium and tritium. We consider the nucleons as toroids that rotate at a constant angular velocity around a line perpendicular to their rotation plane and passing through the center of mass of the nuclei. Based on exact analytical formulas obtained by us for the electrostatic interaction between two spheres with arbitrary radii and charges, we obtain that the known binding energy of the deuteron and triton has an electromagnetic nature. We also obtain through these formulas the force of interaction inside these nuclei. Besides that, within the framework of the classical model we use, we calculate the volumes and mass densities of the nucleons. Throughout all that we use the experimentally obtained results for the radii and masses of the nucleons and nuclei under study. Through our toroid model we confirm the main experimental results obtained for the deuteron and triton not only for the binding energy but also for the magnetic moments, spins and stability.

Keywords: Deuteron; Triton; Strong Interactions; Binding Energy; Electrostatic Interactions

1. INTRODUCTION

In order for a complete theory of the atomic nucleus to be created, that theory has to be able to explain the structure of the nucleus and the available experimental data about its behavior [1-4]. The main difficulty here is the incomplete knowledge of the forces of interaction between nucleons inside the nuclei and their models.

In the field of elementary particles there are two leading models: *standard* and *helicon*.

The standard model [5-7] presents elementary particles as quantum objects that can be both wave and particle. As particles they have mass, charge, spin, magnetic moment, quadrupole moment. The elementary particles mainly are modelling with spheres.

The helicon model [8-11], or ring model is less well-known. According to that model the particles have ring spiral structure of charged filaments, one or more. The filaments are superconductors coiled around an imaginary ring. The helicon model is consistent with all the widely accepted and experimentally verified properties of elementary particles. This model implies the assumption that all known types of interactions (strong, electroweak, gravitational) should be electromagnetic in nature.

In [12] we introduce *a toroid model* of the nucleons that is to a certain degree in contradiction with the standard model, but it is in full agreement with the helicon model.

We consider the nucleons as tori, rotating with a constant angular velocity around an axis *z*, passing through their mass (geometrical) centre *O* and perpendicular to the plane of rotation of their central circle. From quantum mechanical point of view the nucleon is not a localized object in the three-dimensional physical space and therefore it cannot be consider a sphere or a torus [13]. We feel such a model is appropriate in the formal-heuristic sense of Niels Bohr. It is similar to the old quantum theory model of the electron in the hydrogen atom for which Bohr obtains good results for the description of its spectrums. Modern quantum theory confirms Bohr's results based on other concepts.

Formal approaches are widely used in physics. In classical mechanics for example a variety of formulations have been proposed by Lagrange, Hamilton and others. The best example in that sense is quantum mechanics, where one introduces the so-called wave function which allows for the theoretical derivation of a number of physical properties confirmed extremely well by experiment.

We consider nucleons within nuclei to be space dimensional objects—tori, within which the electrical charges can be redistributed. This assumption does not contradict the quark model. The latter enables us to determine the electrostatic interaction between them. Based on this model, we obtained that *the strong interactions are electro-*

magnetic in nature. To achieve this we used exact analytical formulas first obtained by us about the electrostatic interaction between two charged conducting spheres with arbitrary charges and radii [14].

In this paper we apply this method in order to obtain the electrostatic interaction between nucleons in the nuclei of deuterium and tritium.

As noted by Feynman [15], at distances under 10^{-15} m either Coulomb's law is not in force or the electrons and protons are not point charges. We consider the proton-neutron couples at distances under 10^{-15} m. Thus in this paper we determine that *the known binding energy between the nucleons in the deuteron and triton is obtained through electromagnetic interactions*! We also explain the other basic experimental data—*spin*, *magnetic moment*, *stability of the nuclei of deuterium and tritium*. Doing that, we use the experimentally obtained values of the radii and masses of the nucleons and the nuclei.

We obtain the *volumes and mass densities of the nucleons*; we also obtain the *force of interaction* within the nuclei under consideration—results obtained for the first time in nuclear physics.

2. METHOD FOR FINDING OUT ELECTROSTATIC INTERACTION BETWEEN TWO CHARGED CONDUSTIVE SPHERES

We will represent the part of the method presented by us in [10], necessary for performing the calculations for the nuclei of deuterium and tritium.

Let S_1 and S_2 be two isolated charged conductive spheres, with charges Q_1, Q_2 and radii r_1, r_2 respectively. Let's denote with R the distance between their centers O_1, O_2 in an inertial system J. Since charges Q_1 and Q_2 are evenly distributed on the surfaces of S_1 and S_2, it is assumed that before the interaction between the spheres they are concentrated in the centers O_1 and O_2 respectively.

As a result of the electrostatic interaction between S_1 and S_2, on their surfaces appear induced charges $\tilde{Q}_1$ and $\tilde{Q}_2$, which are interrelated. Formally, we can consider that these charges are located on line segment O_1O_2. On the surfaces of S_1 and S_2 appear uniformly distributed charges $\overline{Q}_1$ and $\overline{Q}_2$, we can assume that they are concentrated in their canters O_1 and O_2.

From the law for preservation of electric charges are in power the equations:

$$O_1\overline{Q}_1 = Q_1 - \tilde{Q}_1 \quad \text{and} \quad \overline{Q}_2 = Q_2 - \tilde{Q}_2 . \qquad (1)$$

We will determine the charges $\tilde{Q}_1$, $\tilde{Q}_2$ and hence the charges $\overline{Q}_1$, $\overline{Q}_2$. Let as a consequence of Q_1 be generated image charges $Q_{1,j}$ (j = 1, 2, 3, ···). Because each charge $Q_{1,j}$ generates $Q_{1,j+1}$, the charges with an odd index $Q_{1,2m-1}$ (m = 1, 2, 3, ···) are located in the sphere S_2, and charges with an even index $Q_{1,2m}$—in the sphere S_1. Similarly are determined the image charges $Q_{2,j}$ (j = 1, 2, 3, ···), arising as a consequence from charge Q_2. The charges with an odd index $Q_{2,2m-1}$ (m = 1, 2, 3 ···) are located in the sphere S_1, and charges with an even index $Q_{2,2m}$—in the sphere S_2.

Let's denote $\delta_1 = r_1/R$ and $\delta_2 = r_2/R$. We introduce for j = 1, 2, 3, ··· the following denotations:

$$\begin{aligned} A_{1,j} &= 1+\sum_{k=1}^{j}(-1)^k \sum_{s=0}^{k}\binom{j-1-s}{k-s}\binom{j-k+s}{s}\delta_1^{2(k-s)}\delta_2^{2s} \\ A_{2,j} &= 1+\sum_{k=1}^{j}(-1)^k \sum_{s=0}^{k}\binom{j-1-s}{k-s}\binom{j-k+s}{s}\delta_1^{2s}\delta_2^{2(k-s)} \\ B_{1,j} &= 1+\sum_{k=1}^{j}(-1)^k \sum_{s=0}^{k}\binom{j-s}{k-s}\binom{j-k+s}{s}\delta_1^{2(k-s)}\delta_2^{2s} \\ B_{2,j} &= 1+\sum_{k=1}^{j}(-1)^k \sum_{s=0}^{k}\binom{j-s}{k-s}\binom{j-k+s}{s}\delta_1^{2s}\delta_2^{2(k-s)} \end{aligned} \qquad (2)$$

If $d_{i,j}$ $(i=1,2;\ j=1,2,3,\cdots)$ are the distances of image-charges $Q_{i,j}$, respectively to the centers of the spheres O_i, in [14] we obtain that:

$$\begin{aligned} d_{1,2m-1} &= \delta_2^2 R\frac{A_{1,m-1}}{B_{1,m-1}},\ d_{1,2m} = \delta_1^2 R\frac{B_{1,m-1}}{A_{1,m}} \\ d_{2,2m-1} &= \delta_1^2 R\frac{A_{2,m-1}}{B_{2,m-1}},\ d_{2,2m} = \delta_2^2 R\frac{B_{2,m-1}}{A_{2,m}} \end{aligned} \qquad (3)$$

We find also that:

$$\begin{aligned} Q_{1,2m-1} &= -\frac{\delta_1^{m-1}\delta_2^{m}}{B_{1,m-1}}\overline{Q}_1,\ Q_{1,2m} = \frac{\delta_1^{m}\delta_2^{m}}{A_{1,m}}\overline{Q}_1 \\ Q_{2,2m-1} &= -\frac{\delta_1^{m}\delta_2^{m-1}}{B_{2,m-1}}\overline{Q}_2,\ Q_{2,2m} = \frac{\delta_1^{m}\delta_2^{m}}{A_{2,m}}\overline{Q}_2 \end{aligned} \qquad (4)$$

Lets

$$\begin{aligned} X_1 &= \sum_{m=1}^{\infty}\frac{\delta_1^m\delta_2^m}{A_{1,m}},\ X_2 = \sum_{m=1}^{\infty}\frac{\delta_1^m\delta_2^m}{A_{2,m}} \\ Y_1 &= \sum_{m=1}^{\infty}\frac{\delta_1^{m-1}\delta_2^m}{B_{1,m-1}},\ Y_2 = \sum_{m=1}^{\infty}\frac{\delta_1^m\delta_2^{m-1}}{B_{2,m-1}} \end{aligned} \qquad (5)$$

where $\delta_i^0 = 1$ at $\delta_j = 0$ $(i = 1,2)$.

Since charges $\tilde{Q}_1$ and $\tilde{Q}_2$ are sums of all image charges, located respectively in the spheres S_1 and S_2, then

$$\tilde{Q}_1 = \sum_{m=1}^{\infty}Q_{1,2m} + \sum_{m=1}^{\infty}Q_{2,2m-1}$$

and

$$\tilde{Q}_2 = \sum_{m=1}^{\infty}Q_{1,2m-1} + \sum_{m=1}^{\infty}Q_{2,2m}$$

From here and from (4) and (5) it follows that

$$\tilde{Q}_1 = \overline{Q}_1 X_1 - \overline{Q}_2 Y_2 \quad \text{and} \quad \tilde{Q}_2 = -\overline{Q}_1 Y_1 + \overline{Q}_2 X_2$$

Then, substituting these equations in (1), we get:

$$\overline{Q}_1 = \frac{Q_1(1+X_2)+Q_2Y_2}{(1+X_1)(1+X_2)-Y_1Y_2}$$
$$\overline{Q}_2 = \frac{Q_2(1+X_1)+Q_1Y_1}{(1+X_1)(1+X_2)-Y_1Y_2} \quad (6)$$

Lets denote the charges from formulas (4) and (6), which are located in the sphere S_1 as Q'_j, and those located in the sphere S_2 as Q''_j ($j = 0,1,2,\cdots$). Thus $Q_{1,0} = \overline{Q}_1 = Q'_0$ and $Q_{2,0} = \overline{Q}_2 = Q''_0$, and for $m = 1,2,3,\cdots$, $Q_{2,2m-1} = Q'_{2m-1}$, $Q_{1,2m} = Q'_{2m}$ and $Q_{1,2m-1} = Q''_{2m-1}$, $Q_{2,2m} = Q''_{2m}$. Their corresponding distances to the centers of the spheres, where they are situated, we denote with d'_j and d''_j ($j = 0,1,2,\cdots$), where $d'_0 = d''_0 = 0$.

If $\delta'_j = d'_j / R$, and $\delta''_j = d''_j / R$, then, according to Coulomb's law, for the magnitude F of the projection of the force of interaction on O_1O_2, acting on the spheres S_1 and S_2, we obtain

$$F = \frac{1}{4\pi\varepsilon_0 R^2} \sum_{j=0}^{\infty}\sum_{t=0}^{\infty} \frac{Q'_j Q''_t}{\left(1-\delta'_j-\delta''_t\right)^2} \quad (7)$$

The potential energy of interaction between the spheres S_1 and S_2, according to [16], is

$$W = \frac{1}{4\pi\varepsilon_0 R} \sum_{j=0}^{\infty}\sum_{t=0}^{\infty} \frac{Q'_j Q''_t}{1-\delta'_j-\delta''_t} \quad (8)$$

Let us point out that in (7) and (8) we do not take into consideration the interactions between the charges inside the spheres S_1 and S_2 as actually the interaction is external—between the charges on the surface of S_1 with the charges on the surface of S_2.

Let M be an arbitrary point in the electric field created by charges Q'_j and Q''_j ($j = 0,1,2,\cdots$). If M is at distances a_j and b_j from charges Q'_j and Q''_j respectively, then, using the metric relationships in a triangle, we can determine

$$a_j = \sqrt{\frac{\left(a_0^2 - Rd'_j\right)\left(R-d'_j\right)+b_0^2 d'_j}{R}}$$

and

$$b_j = \sqrt{\frac{\left(b_0^2 - Rd''_j\right)\left(R-d''_j\right)+a_0^2 d''_j}{R}}$$

Then based on the principle of linear superposition of states, the potential at point M will be the sum of the potentials of all charges in M [16]. Therefore

$$V(M) = \frac{1}{4\pi\varepsilon_0} \sum_{j=0}^{\infty} \left(\frac{Q'_j}{a_j} + \frac{Q''_j}{b_j}\right) \quad (9)$$

It is worthwhile to mention that using **Eqs.7-9** one can determine the interaction between two charged spheres for arbitrary small distances between them, which represents a result obtained for the first time.

3. TOROID MODEL OF NUCLEONS

Using the results from [14] in [12] we first consider the nucleons as spheres, as they are viewed in the standard model. In this case we show that at distances $\geq 10^{-16}$ m we can calculate with good approximation the binding energy and force of interaction between nucleons by modeling protons as point charges. But at distances $< 10^{-16}$ m the proton should not be considered as a point charge. We also found out that using the standard model the binding energy of triton cannot be obtained. Using this model it is difficult to explain the experimentally obtained magnetic moments of the nuclei relative to the magnetic moments of the comprising nucleons; it is also hard to explain the experimental results for the radii and stability of the nuclei.

For this reason we remodel the nucleons as tori [12]. At that they are rotating with a constant angular velocity around a straight axis *z*, passing through their mass (geometrical) center *O* and perpendicular to the plane of rotation of their central circle (**Figure 1**).

After that we study a system of proton and neutron in order to determine the electrostatic interaction between them.

The two tori—of the proton and neutron we denote correspondingly as T_p and T_n and their centers as O_p and O_n. We also assume that the central circles of T_p and T_n lie in parallel or coincident planes and rotate in the same or opposite directions with constant angular velocity around a the straight line *z* passing through O_p and O_n, and perpendicular to the plane of their rotation. Thus if $O_pO_n = h$, then $h \geq 0$ (**Figure 2**).

Let us denote by K_p and K_n the centers of the forming circles of the tori T_p and T_n, and with $R_p = O_pK_p$ and $R_n = O_nK_n$—the radii of the central circles of T_p and T_n. We assume that T_p and T_n are at a distance $0 < \tau < 10^{-15}\,m$ from each other.

According to experimental data the radius of the proton r_p is smaller than the radius of the neutron r_n. Because of that we consider $R_p < R_n$.

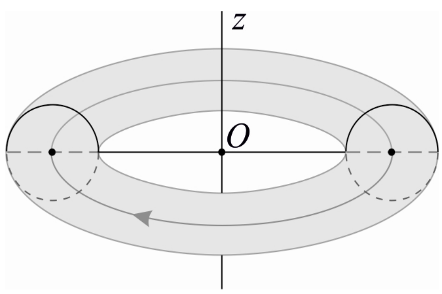

Figure 1. Toroid model of nucleon.

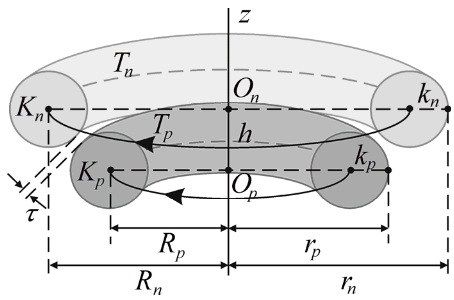

Figure 2. Cross section of a proton-neutron system.

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

$$R_p + k_p = r_p \text{ and } R_n + k_n = r_n \tag{10}$$

where r_p and r_n are the corresponding radii of the proton and neutron in this configuration. It should be noted that for different nuclei r_p, k_p, R_p and r_n, v, R_n may have different values.

From geometrical considerations for $O_pO_n = h$ will be fulfilled the equation

$$h^2 = \left(k_p + k_n + \tau\right)^2 - \left(R_n - R_p\right)^2 \tag{11}$$

It is clear that $0 \le h \le k_p + k_n + \tau$.

We assume that the volume mass densities of the proton and neutron are equal, *i.e.* $\rho_p = \rho_n$. The volumes of the tori T_p and T_n, according to [17], are correspondingly $V_p + 2\pi^2 k_p^2 R_p$ and $V_n + 2\pi^2 k_n^2 R_n$. Then if m_p and m_n are the corresponding masses of T_p and T_n, then from $\frac{m_p}{V_p} = \frac{m_n}{V_n}$ it follows that

$$k_n = k_p \sqrt{\frac{m_n R_p}{m_p R_n}} \tag{12}$$

In (12) we can substitute the experimentally measured masses of the proton and the neutron [18]

$m_p = 1.672621638 \times 10^{-27}$ kg, $m_n = 1.674927212 \times 10^{-27}$ kg.

Lets denote with $q > 0$ the radius of the empty part of the circle with a radius R_p. Then

$$q = r_p - 2k_p \tag{3}$$

Further let T_p and T_n from **Figure 2** be a proton-neutron couple bound in the nucleus of deuterium or tritium. If we denote with r_k the radius of the nucleus under consideration, then $r_n = r_k$.

In order to apply the results from Section 2 for spheres we will remodel the tori.

We will emphasize that the potential energy and the force of interaction between two spheres depend on the distance between image-charges, *i.e.* from the lengths of the line segments $d_{i,j}$ $\left(i = 1,2; j = 1,2,3,\cdots\right)$ from formula (3). These lengths in (3) are determined from the squares of the radii r_1 or r_2 of the spheres and from the length of their central line $R = r_1 + r_2 + \tau$, where τ is the smallest distance between their surfaces. For the square of the radii of each of the two spheres is fulfilled $r_i^2 = L_i / 4\pi$, $i = 1,2$, where L_i is the surface area of the corresponding sphere. Therefore, when we remodel the tori of the proton and the neutron we have to keep both their surface areas L_p and L_n and the distance τ between them.

Due to the central symmetry of the charge of the proton we can consider all of its charge p to be concentrated in the geometrical center O_p of the torus T_p.

Therefore *we remodel the proton as a sphere* S_p, with radius $\bar{r}_P$ and the same centre O_p on the straight line *z* and a surface area equivalent to the torus surface area, *i.e.* it has the same surface area as the torus T_p. At that S_p is charged with a charge p that is centrally symmetrical and can be redistributed.

The surface area L_p of a torus T_p according to [17] is

$$L_p = 4\pi^2 k_p R_p \tag{14}$$

Then, as the surface areas of the torus T_p and the sphere S_p are equal, then from (14) it follows that the radius of S_p is

$$\bar{r}_P = \sqrt{\pi k_p R_p} \tag{15}$$

We remodel the neutron T_n *with a torus* T_N with an equivalent surface area. At that T_N has the same center O_n on *z* and its surface is at the same distance τ from the surface of S_p as in the case of T_n and T_p (**Figure 3**).

Let S_N be a sphere. Its central circle, is forming for the torus T_N. We denote the centre of S_N with K_N, at that $O_nK_N = R_N$ and with $\bar{r}_N$ —the radius of S_N. Thus if $O_pK_N = \bar{R}$ then $\bar{R} = \bar{r}_P + \bar{r}_N + \tau$ and from $O_pO_n = h$ it follows that $R_N{}^2 = \bar{R}^2 - h^2$, *i.e.*

$$R_N = \sqrt{\left(\bar{r}_P + \bar{r}_N + \tau\right)^2 - h^2} \tag{16}$$

It is clear that $\max R_N = \bar{r}_p + \bar{r}_N + \tau$ and $\min R_N = \bar{r}_N$.

From the equality of the surface areas L_N and L_n of the tori T_N and T_n, it follows that

$$\bar{r}_N = k_n \frac{R_n}{R_N} \tag{17}$$

For the number l of spheres S_N which have total surface area equal to the surface area of the torus T_N is fulfilled $l.4\pi\bar{r}_N^2 = 4\pi^2 R_N \bar{r}_N$. Therefore

$$l = \pi \frac{R_N}{\bar{r}_N} \tag{18}$$

We assume that the centre O_p is motionless relative to the inertial reference system *J*. We introduce a solid non-inertial reference system *G* that rotates with the constant angular velocity $\boldsymbol{\omega}$ of rotation of T_N relative to *J*. At that, the point O_p is the centre of the coordinate system $O_p xyz$, stationary connected with *G* and relative to which the spheres S_P and S_N are motionless to each other (**Figure 3**).

Then for the experimentally obtained value of $r_k = r_n$, giving values to *q*, from **Eqs.10-13** we calculate R_p, k_p, r_p, R_n and k_n. With those and formula (15) we obtain the radius $\overline{r}_P = \sqrt{\pi k_p R_p}$ of the surface-equivalent sphere S_P. Varying $0 < \tau < 10^{-15}$ m and $0 \le h \le k_p + k_n + \tau$, from formulas (16) and (17) we calculate the radius $\overline{r}_N$ of the forming sphere S_N.

Thus at $\overline{R} = \overline{r}_P + \overline{r}_N + \tau$, through formulas (7) and (8), we find the binding energy $W(S_P, S_N)$ and force of interaction $F(S_P, S_N)$. According to (18), the binding energy $W(T_p, T_n)$ and force of interaction $F(T_p, T_n)$ between a the proton and the neutron will be

$$W(T_p, T_n) = \pi \frac{R_N}{r_N} W(S_P, S_N)$$
$$F(T_p, T_n) = \pi \frac{R_N}{r_N} F(S_P, S_N) \qquad (19)$$

The **Eqs.19** are valid because the forming spheres of the torus T_N are situated symmetrically relative to the centre of the sphere S_P.

Moving on we will structure the nuclei of deuterium and tritium. The positioning of the nucleons in them must correspond to the principle of minimum potential energy. Due to the mass defect in the nucleus, the potential energy of the interaction in the atomic nuclei is calculated by the following formula [2]:

$$W_K = \left(N_p m_p + N_n m_n - m_K\right) c^2 \qquad (10)$$

Here N_p is the number of the protons, N_n – number of the neutrons; $m_p = 1.672621638 \times 10^{-27}$ kg and $m_n = 1.674927212 \times 10^{-27}$ kg are the masses of the proton and of the neutron, respectively [18] and m_K is the mass of the considered nucleus; $c = 2.99792458 \times 10^8$ $m \cdot s^{-1}$ is the velocity of the light in flat vacuum [18]. We will find the values of W_K according to our method with formula (8), comparing them with the values obtained through formula (20).

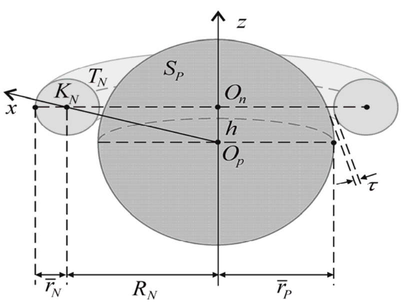

Figure 3. Cross section of reduced model of the proton-neutron system.

Let us consider the proton in a unbound state as a torus T_p^0. Its radius according to [19] is $r_p = 0.84184 \times 10^{-15}$ m. If K_p^0 is the center of the forming circle of T_p^0, then we denote as k_p^0 the radius of this circle and with $R_p^0 = OK_p^0$.

Using formulas (10) and (13) for different values of the radius of the circle of the empty part *q* we find k_p^0, R_p^0, V_p^0 and ρ_p^0. We also find the volume V_n^0 of the neutron in a free state since we know its mass m_n^0 and we have assumed that $\rho_p^0 = \rho_n^0$. All the data are given in **Table 1**.

In **Table 1** we have denoted with k_p the radius of the forming circle of the torus of the proton and with R_p the radius of the central circle of the torus of the proton.

Due to the mass defect in atomic nuclei the volumes of the nucleons within them change. We will assume however that the volume mass densities of the proton and neutron do not change, *i.e.* $\rho_p^0 = \rho_n^0 = \rho = const$.

4. MODEL OF THE DEUTERON

We model the nucleus of deuterium as two concentric toroids inlaid one in the other. The internal torus T_p corresponds to the proton and the external one T_n corresponds to the neutron with T_p and T_n being at a distance $0 < \tau < 10^{-15}$ m. This configuration provides symmetry relative to the center of masses *O* of the deuteron placed in its geometrical center (**Figure 4**). From that follows the *stability of the deuteron* $T = \infty$.

We assume that both tori spin in the same direction with a constant angular velocity $\boldsymbol{\omega}$ around the line *z* going through their common center $O = O_p = O_n$ and perpendicular to their plane of rotation.

Table 1. Size, volume and mass density of the proton and neutron.

q m	k_p m $\times 10^{-15}$	R_p m $\times 10^{-15}$	V_p^0 m$^3 \times 10^{-45}$	V_n^0 m$^3 \times 10^{-45}$	$\rho_p^0 = \rho_n^0$ kg·m$^{-3} \times 10^{18}$
$0.3r_p$	0.29464	0.54720	0.93771	0.939001	1.78373
$0.4r_p$	0.25255	0.58929	0.74192	0.742946	2.25444
$0.5r_p$	0.21046	0.63138	0.55203	0.552787	3.02997
$0.6r_p$	0.16837	0.67347	0.37685	0.377369	4.43843
$0.7r_p$	0.12628	0.71556	0.22523	0.225537	7.42639

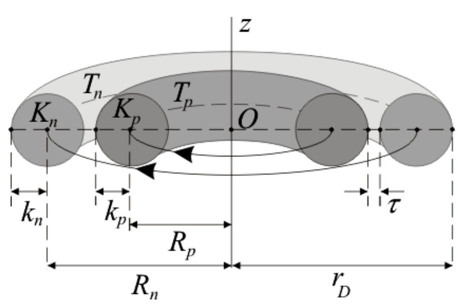

Figure 4. Cross-section of the model of the deuteron.

From this structure follows that the spin s_D of the deuteron will be a sum of the spins $s_p = s_n = 1/2$ of the proton and neutron, *i.e. the spin of the deuteron is* $s_D = 1$, which has been experimentally obtained.

The nucleons, binding to each other within the deuteron almost double their total mass relative to their separate masses and as a consequence the centrifugal force increases. From this follows that *the radius of the deuteron* is larger than the radii of the nucleons and as has been experimentally determined it is $r_D = 2.14\times10^{-15}$ m [18].

Let us assume that the charge of each of the nucleons is distributed parallel along a circle with a center *O*. Then a circular current appears and the magnetic moments of the nucleons are proportional to the magnitude of the charges and their angular velocity but also to the square of their distance from the center of rotation. The inlaying of the proton within the neutron increases the radius of the neutron more relative to the increased radius of the proton. This explains why the sum of the magnetic moments of the proton $\mu_p = 1.4106\times10^{-26}$ JT^{-1} and neutron $\mu_n = -0.9662\times10^{-26}$ JT^{-1} is larger than *the magnetic moment of the deuteron*

$\mu_D = 0.4331\times10^{-26}$ JT^{-1} [18].

Let K_p and K_n be the centers of the forming circles of T_p and T_n and let the radii of those circles be k_p and k_n correspondingly. We denote as $R_p = OK_p$ and $R_n = OK_n$ the radii of the central circles of the tori T_p and T_n (**Figure 4**).

In this case $O_p = O_n = O$ and $h = O_pO_n = 0$, also $R_n = r_D - k_n$ and $R_p = r_D - 2k_n - k_p - \tau$. Based on the method we described in Section 3 using mass volume density ρ of the nucleons from **Table 1** we find k_n, R_n, k_p and R_p. In formula (12) we consider the mass defect, proportionally for the masses of the proton and neutron. The experimentally obtained mass of the deuteron is $m_D = 3.3436\times10^{-27}$ kg [18]. Then, according to formula (20), the binding energy of the deuteron is $W_D = -3.5642\times10^{-13}$ J.

This value we confirm at different values of the distance τ between the tori (**Table 2**) for $W(T_p, T_n)$ with the corresponding formula from (19). From (19) we also obtain the force of interaction $F(T_p, T_n)$ for the deuteron.

In **Table 2** we have denoted with k_n and k_p respectively the radius of the forming circle of the torus of the neutron and the proton, with R_n and R_p respecttively the radius of the central circle of the torus of the neutron and the proton and with F_D the force of interaction between the nucleons in the deuteron.

5. MODEL OF THE TRITON

The triton is obtained structurally from the deuteron by adding one more neutron. The second neutron tries to take over the place of the first one.

The neutron, although it can be assumed electrically neutral, *i.e.* with a common charge *n* = 0, has an internal electric structure, its negative charge, as opposed to the positive one is distributed primarily at its surface [20,21].

Then because of the repulsion between the tori T_n^1 and T_n^2 the central circles of the nucleons will be situated symmetrically in two planes parallel to the plane in which the central circle of proton torus T_p is situated. At that T_n^1 and T_n^2 will be at the same distance $0 < \tau < 10^{-15}$ m from T_p. This configuration provides symmetry relative to the center of masses (geometrical center) *O* of the triton (**Figure 5**). From this follows the *relative stability of the triton* $T = 12.262\,y$.

Let us denote as O_n^i the centers of the tori T_n^i $(i = 1,2)$ and as O_p —the center of T_p. Then the center $O = O_p$ and the points O_n^i are on the same line *z*, perpendicular to their plane of rotation.

The tori T_p and T_n^1 rotate around *z* with a constant angular velocity $\boldsymbol{\omega}$ in the same direction (e.g. clockwise) and T_n^2 will rotate with the same velocity in the opposite direction (counterclockwise), *i.e.* with a velocity $-\boldsymbol{\omega}$. Thus we obtain that the *spin of the triton* is $s_T = 1/2$ which is experimentally confirmed.

Table 2. Size of the nucleons and force of interaction in the deuteron.

ρ kg·m$^{-3}\times10^{18}$	τ m$\times10^{-17}$	k_n m$\times10^{-15}$	R_n m$\times10^{-15}$	k_p m$\times10^{-15}$	R_p m$\times10^{-15}$	F_D N
1.78373	2.30200	0.15489	1.9851	0.17047	1.6367	−1 962
2.25444	2.28778	0.13717	2.0028	0.14906	1.6937	−2 045
3.02997	2.27329	0.11775	2.0223	0.12629	1.7555	−2 147
4.43843	2.25592	0.096787	2.0432	0.10244	1.8214	−2 284
7.42639	2.23334	0.074418	2.0656	0.077722	1.8911	−2 479

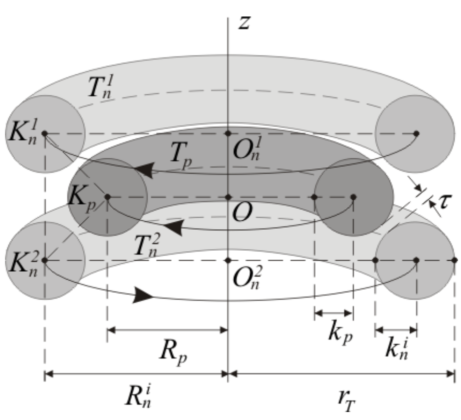

Figure 5. Cross-section of the model of the triton.

The neutron that rotates in an opposite direction will decrease the centrifugal force caused by the nucleons rotating in the same direction. Therefore *the radius of the triton* $r_T < r_D$. According to experiments $r_T = 1.6 \times 10^{-15}$ m [22].

The magnetic moments caused by the redistributed charges in the neutrons cancel each other out. Thus the magnetic moment of the triton is caused only by the charge of the proton. As a consequence of the increased radius of the proton relative to the free state *the magnetic moment of the triton* $\mu_T = 1.5046 \times 10^{-26}$ JT^{-1} is larger than the magnetic moment of the proton $\mu_p = 1.4106 \times 10^{-26}$ JT^{-1}, as shown by experimental data [18].

Let K_p and K_n^i be the centers of the forming circles respectively of T_p and T_n^i with corresponding radii k_p and k_n^i $(i = 1, 2)$. We denote $OK_p = R_p$ and for $i = 1, 2$, $O_n^i K_n^i = R_n^i$.

In this case $h = OO_n^i$ and if r_T is the radius of the triton, then $R_n^i = r_T - k_n^i$.

Due to the central symmetry of the charge of the proton we can assume that all of its charge $p > 0$ is concentrated in the geometrical center *O*. Because of that we model the proton as a sphere S_P with a center *O* and radius $\overline{r}_P$, equivalent in surface are to T_p. At that S_p is charged with a charge p, which is centrally symmetrical and can be redistributed.

With T_N^i ($i = 1, 2$) we denote the tori that are equivalent in surface to T_n^i with centers O_n^i and centers of the forming circles K_N^i (**Figure 6**). At that S_P and T_N^i have the same distance τ between them as T_p and T_n^i. With S_N^i $(i = 1, 2)$ we denoted the forming sphere of T_N^i.

We assume the point *O* to be stationary relative to the inertial reference frame *J*. We introduce two solid non-inertial reference systems G_1 and G_2, that rotate with the constant angular velocities $\boldsymbol{\omega}$ and $-\boldsymbol{\omega}$ respectively of T_N^1 and T_N^2 relative to *J*.

The point *O* is a center of the coordinate system $Ox_i y_i z$ stationary connected with the reference system G_i $(i = 1, 2)$ relative to which the spheres S_P and S_N^i are stationary to each other (**Figure 6**).

The two tori T_N^1 and T_N^2 are symmetrical relative to the sphere S_P. Then it is enough to study the electrostatic interaction only between one of them and S_P. We assume with some approximation that between T_N^1 and T_N^2 there is no electrostatic interaction since their total charges are zero. Besides that, to simplify the calculations, we assume that the distance between the surfaces of each of the tori is the same and equal to τ. Then the distance $h = k_n + \tau/2$.

Since $r_n = r_T$, using the model we revealed in Section 3, with the volume mass density ρ of the nucleons from **Table 1** we find k_n^i, R_n^i and k_p, R_p. In formula (12) we consider the mass defect proportionally for the masses of the proton and two neutrons. The experimenttally obtained mass of the triton is $m_T = 5.00735588 \times 10^{-27}$ kg [18].

Then, according to formula (20) the binding energy of the triton is $W_T = -13.5895 \times 10^{-13}$ J. This value we confirm for different values of the distance τ between the tori (**Table 3**) for $W_T = 2W\left(T_p, T_n^i\right)$, $i = 1$ or $i = 2$ using the corresponding formula from (19). From (19) we also obtain the force of interaction for the triton $F_T = 2F\left(T_p, T_n^i\right)$ for $i = 1$ or $i = 2$.

In **Table 3** we have denoted with k_n and k_p respectively the radius of the forming circle of the torus of the neutron and the proton, with R_n and R_p respectively the radius of the central circle of the torus of the neutron and the proton and with F_T the force of interaction between the nucleons in the triton.

We should note that by determining the value of W_T, we can also vary *h*, where in this case is fulfilled $k_n < h \le k_p + k_n + \tau$.

6. DISCUSSION

In [12] considering the nucleons as tori we theoreticcally determine the potential energy and the force of interaction in the systems: proton-neutron, proton-proton and proton-neutron-proton, which we derive using experimentally obtained results for the radii and the masses of the nucleons in unbound condition.

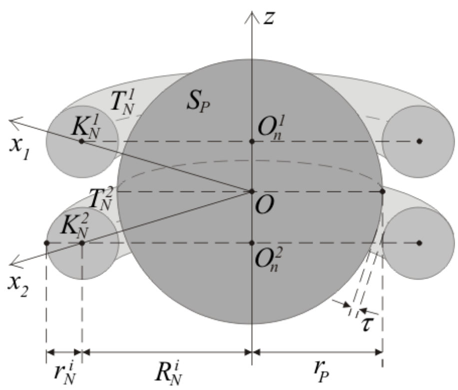

Figure 6. Cross-section of the reduced model of the triton.

Table 3. Size of the nucleons and force of interaction in the triton.

ρ	τ	k_n	R_n	k_p	R_p	F_T
$kg \cdot m^{-3} \times 10^{18}$	$m \times 10^{-17}$	$m \times 10^{-15}$	$m \times 10^{-15}$	$m \times 10^{-15}$	$m \times 10^{-15}$	N
1.78373	1.17113	0.18353	1.4165	0.21248	1.0554	−9 979
2.25444	1.16356	0.16203	1.4380	0.18322	1.1230	−10 393
3.02997	1.16033	0.13864	1.4614	0.15324	1.1944	−11 045
4.43843	1.15927	0.11358	1.4864	0.12284	1.2690	−11 649
7.42639	1.15838	0.08703	1.5130	0.092201	1.3462	−12 933

Using our method, we have shown that the electromagnetic forces for the proton-neutron pair are quite strong (in the order of the nuclear forces) an short-ranged. This suggests that *the binding energy of the nucleons have electromagnetic nature*. We can also explain other basic experimental data like stability, radius, magnetic moment and spin of the nuclei.

In this paper, we concretize the general results obtained in [12] for the nuclei of deuterium and tritium.

7. CONCLUSIONS

Nuclear physics bases its knowledge on experiments and has numerous different contradicting models. Considering nucleons as tori and modeling the deuteron and triton, we obtain and explain their basic experimentally obtained characteristics and also obtain new characteristics of these nuclei.

Our model can also be applied for more complicated atomic nuclei. Based on particular charge and current configurations to it can be considered the interaction betweennucleons in electrodynamic aspect; to be find analytical expressions for the magnetic moments, to determine the angular velocity of nucleons, the linear velocity at particular points on their surface, etc.; to explain excited states of the nuclei; to be find out the potential of the electromagnetic field generated by atomic nuclei and to calculate their quadrupole moments for the deuteron and the other nuclei.

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