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Short-range action and long-range action of the electrostatic forces within atomic nuclei

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ABSTRACT

We study the interaction forces in atomic nuclei based on our expressions for the electrostatic interaction between spheres of arbitrary radii and charges. We prove that at small distances the proton-neutron electrostatic attraction forces are short-range-acting and the proton-proton electrostatic repulsion forces are long-range-acting. We obtain that these forces are commensurate with the nuclear forces. The proton-neutron electrostatic attraction forces and the proton-proton electrostatic repulsion forces at the same distance between nucleons differ in absolute value by about an order of magnitude. It follows that based on electromagnetic interactions the neutrons are the binding building blocks in nuclear structures.

Keywords: Nucleon; Electrostatic Force of Interaction; Strong Interaction; Long-Range-Acting Forces; Short-Range-Acting Forces

1. INTRODUCTION

Let q_1 and q_2 be two point electric charges and R be the distance between them. Then, according to Coulomb's law the magnitude of the interaction force between them in vacuum is $F = q_1 q_2 / 4\pi\varepsilon_0 R^2$ (ε_0 is the dielectric constant of vacuum). Thus the Coulomb forces are inversely proportional to R^2 $\left(F \sim 1/R^2\right)$ and decrease slowly with the increase of the distance R. Therefore they are so-called *long-range-acting* forces.

For dimensional objects however, it is possible that electrostatic forces be *short-range-acting*. A typical example in this regard is the attraction and repulsion force between molecules. These forces are electrostatic in nature and change very fast with distance. At small distances between molecules the attraction forces (van der Waals forces) are inversely proportional to the seventh power of distance $\left(F \sim 1/R^7\right)$, and the repulsion forces are inversely proportional to the thirteenth power $\left(F \sim 1/R^{13}\right)$. So the intermolecular forces are short-range-acting.

As is well known from numerous experiments, one of the main features of the forces acting inside the nucleus between protons and neutrons (so-called nuclear forces) is their short-range action. From various scattering experiments it has been determined that the radius of interaction between nucleons is of the order of 10^{-15} m. It is claimed that at such distances the nuclear forces are substantially bigger than electromagnetic forces. Moreover, inside the nucleus these forces are huge, but to its outside even in close proximity they are insignificant. With the increase of the distance between nucleons the nuclear forces decrease significantly faster than electromagnetic forces.

Back in 1956 Hofstadter [1] conducted experiments showing that protons and neutrons have a complex internal electric structure. Studies with fast electrons allowed uncovering distribution of the charges along the radius of nucleons [2]. The proton possesses an elementary positive charge $p = 1.6021764874 \times 10^{-19}$ C [3]. The neutron has both a positive and a negative charge, which cancel out so that the neutron can be considered as electrically neutral, *i.e.* has a charge of $n = 0$ C.

The structure of nucleons and the fact that they are located at very small distances between each other inside the nucleus presents a strong argument to model them as dimensional objects, whose charges can redistribute within their volumes when they interact with external charges. This assumption is completely natural if we assume that the charges of the proton and the neutron are made up of quarks.

In [4] using the method of image-charges we solve analytically the problem of electrostatic interaction between two charged conducting spheres with arbitrary charges q_1, q_2 and radii r_1, r_2. As a result, we derive in the most general way exact analytical expressions for the magnitude of the force and the binding energy of their interaction. We also determine the potential in an arbitrary point of the electromagnetic field created by the two spheres. These results can be applied with some approximation to non-spherical bodies with a single center of symmetry by modeling them with spheres of equivalent surface area [4].

Through the general formulas we have obtained, it is possible to determine for the first time the force and energy of interaction between two charged spheres located at a distance significantly smaller than their radii. In [5,6] we have used these results to determine the electrostatic interaction between nucleons in atomic nuclei.

At the root of intermolecular forces lies the electrostatic interaction, while the magnetic forces play an insignificant role. In our considerations, we can assume with some approximation that the magnetic force between the nucleons will not play a significant role, so that the electrostatic forces are dominant in the interaction. This assumption is justified by the results we have obtained in [5,6].

The experimentally measured radii of the proton and neutron are $r_p = 0.84184 \times 10^{-15}$ m [7] and $r_n = 1.1 \times 10^{-15}$ m [2], respectively. Therefore, we consider the nucleon couples at a distance of $\tau \le 10^{-15}$ m between their surfaces.

We prove that in atomic nuclei authoritative are the short-range-acting proton-neutron electrostatic attraction forces as well as the long-range-acting proton-proton electrostatic repulsion forces. We also obtain that these forces are commensurate with the nuclear forces.

2. QUANTIFICATION OF THE ELECTROSTATIC INTERACTION FORCES BETWEEN NUCLEONS MODELED AS SPHERES

We consider the nucleons as spheres similar to their representation in the standard model [8-10]. Let us denote with S_p the sphere that models the proton and with S_n—the sphere modeling the neutron. Based on the assumption that the charges of the proton and the neutron can be redistributed within their volumes, we shall assume with some approximation that S_p and S_n are conducting spheres. Following the procedure outlined in [4], we find the interaction force $F\left(S_p^1, S_p^2\right)$ between the spheres S_p^1, S_p^2 (modeling two protons), and the force $F\left(S_p, S_n\right)$ between the spheres S_p, S_n (modeling a proton and a neutron) as a function of the distance between their centers *R*.

The results are presented on **Figure 1**. For the sake of demonstrability and clear comparison, we have also plotted the force $F(p, p)$ between two protons assumed as point charges according to Coulomb's law.

The curve representing interaction force for the proton-neutron system is displaced to the right along the *R* axis, because the radius $r_n = 1.1 \times 10^{-15}$ m and the radius $r_p = 0.84184 \times 10^{-15}$ m so $R > r_n + r_p$.

For better clarity in the comparison between the interaction forces we present on **Figure 2** the dependence of the forces $F\left(S_p^1, S_p^2\right)$ and $F\left(S_p, S_n\right)$ on the distance $\tau \in \left[1\times10^{-17}\ \text{m}; 1\times10^{-15}\ \text{m}\right]$ between the surfaces of the nucleon modeling spheres.

Close examination of the curves depicted in **Figures 1**

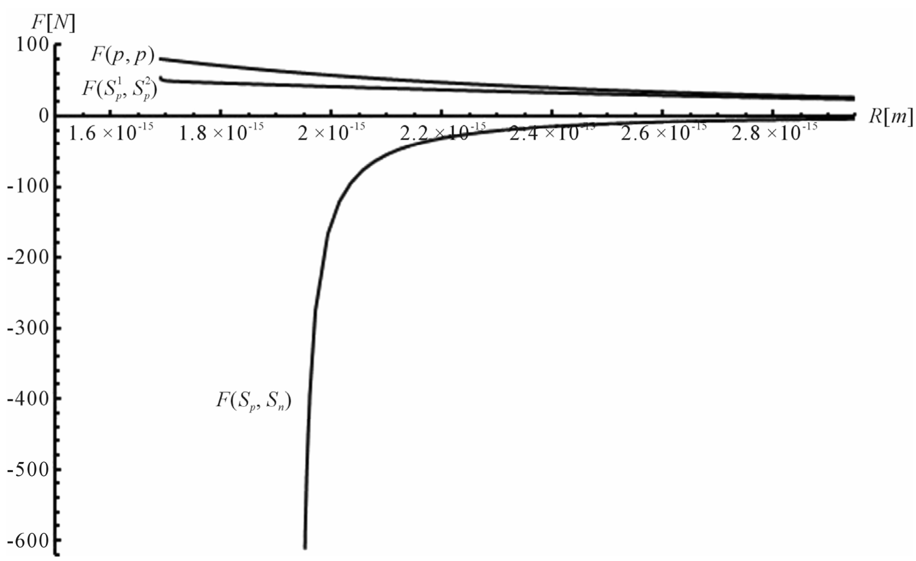

Figure 1. Example plot of the interaction forces $F(p, p)$, $F\left(S_p^1, S_p^2\right)$ and $F\left(S_p, S_n\right)$ depending on the distance *R* between: point charges *p*, *p*; the centers of spheres S_p^1, S_p^2; the centers of spheres S_p, S_n.

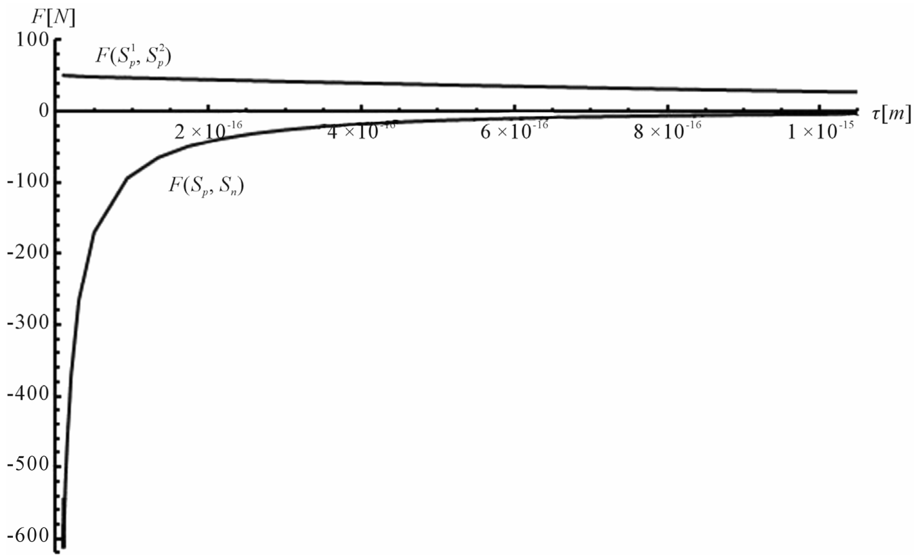

Figure 2. Plot of the forces between the spheres S_p^1, S_p^2 and S_p, S_n depending on the distance τ between their surfaces.

and **2** leads to some very interesting and quite unexpected conclusions about the electrostatic forces between nucleons (modeled as conducting spheres) within the nuclei:

1) The proton-proton repulsion force $F\left(S_p^1, S_p^2\right)$ is long-range-acting, with its plot lying even lower than the force $F(p, p)$ between protons assumed to be point charges (**Figure 1**);

2) The proton-neutron attraction force $F\left(S_p, S_n\right)$ is short-range-acting with characteristic radius of the order of 10^{-15} m between the centers of the spheres, and is practically zero at distances greater than this radius (**Figure 1**).

3) At small distances between the proton and the neutron the attraction force $F\left(S_p, S_n\right)$ rapidly increases in absolute value (**Figures 1** and **2**).

4) At the same small distances $\tau \approx 10^{-17}$ m between the surfaces of the interacting nucleons the proton-neutron attraction force $F\left(S_p, S_n\right)$ is one order of magnitude larger in absolute value than the proton-proton repulsion force $F\left(S_p^1, S_p^2\right)$ (**Figure 2**).

It is worthwhile to note that according to **Figure 1** one can assume (with some approximation) that the forces $F\left(S_p^1, S_p^2\right)$ and $F(p, p)$ are equal, *i.e.* for proton-proton interactions we can assume the proton charge to be point-like. However, when we calculate the interaction between a proton and a neutron, as we proved in [5], the proton should not be considered as a point charge.

For $\tau \in \left[10^{-17} \text{ m}, 10^{-15} \text{ m}\right]$, based on [4] as well as in [5], we can determine the potential energy of interaction $W\left(S_p^1, S_p^2\right)$ and $W\left(S_p, S_n\right)$ correspondingly between the spheres S_p^1, S_p^2 and the spheres S_p, S_n. The numeric values for the force and potential energy for different distances τ between the nucleon surfaces are presented in **Table 1**.

For $\tau < 10^{-17}$ m the force and interaction energy increase in absolute value.

Taking into account the shape of the curve for the proton-neutron attraction force $F\left(S_p, S_n\right)$ from **Figure 1**, we shall assume that

$$F\left(S_p, S_n\right) \sim \frac{1}{R^\lambda}, \text{ i.e. } F\left(S_p, S_n\right) = \frac{A}{R^\lambda},$$

where $A = \text{const}$. Then, if $F_1 = F_1\left(S_p, S_n\right) = A/R_1^\lambda$ and $F_2 = F_2\left(S_p, S_n\right) = A/R_2^\lambda$, it follows that $\frac{F_2}{F_1} = \left(\frac{R_1}{R_2}\right)^\lambda$, or equivalently $\lambda = \frac{\ln\left(F_2/F_1\right)}{\ln\left(R_1/R_2\right)}$.

Since $R_1 = r_p + r_n + \tau_1$ and $R_2 = r_p + r_n + \tau_2$, then according to **Table 1** for $\tau \in \left[10^{-17} \text{ m}; 10^{-16} \text{ m}\right]$ we obtain that $\lambda \approx 76$, *i.e.* $F \sim 1/R^{76}$. This perfectly proves that at small enough distances the proton-neutron electrostatic attraction force is strongly short-range-acting.

In [5] we have shown that the interaction energy $W\left(S_p^1, S_p^2\right) \approx W(p, p)$. We have also found that the binding energy $W\left(S_p, S_n\right)$ between the spheres S_p and S_n can take values within the range of the known binding energy of the deuteron $W_{^2_1\text{H}} = -3.5642 \times 10^{-13}$ J. However, based on the standard model it is not possible to obtain the larger binding energies of the triton, hellion, α-particle, etc. It is hard to explain by means of interaction between spheres other known results for nuclei such as stability, radii, magnetic moments, etc. That is why in [5,6] we introduce the toroidal model of nucleons which

Table 1. Force and interaction energy between the spheres S_p^1, S_p^2 and S_p, S_n.

τ m	$F(S_p^1,S_p^2)$ N	$F(S_p,S_n)$ N	$W(S_p^1,S_p^2)$ J	$W(S_p,S_n)$ J
10^{-17}	51.7264	−610.6788	1.1310	−1.7097
10^{-16}	47.2967	−88.1231	1.0680	−0.53086
10^{-15}	27.9881	−3.7940	0.80694	−0.050642

explains all the basic experimental results.

3. DETERMINING THE ELECTROSTATIC INTERACTION FORCES BETWEEN NUCLEONS MODELED AS TORI

We consider the nucleons as tori spinning with constant angular velocity around an axis z, passing through their center of masses (geometrical center) O and perpendicular to their plane of rotation (**Figure 3**).

Denote by T_p^1, T_p^2 the tori of the two protons and assume that the force $F(T_p^1,T_p^2) \approx F(p,p)$ and the energy $W(T_p^1,T_p^2) \approx W(p,p)$, that is in the case of proton-proton interactions we assume their charges as point-like situated in the centers of the tori.

Let the proton and neutron be two tori T_p and T_n, respectively, where the charge of T_p is p and the charge of T_n is 0. The centers of the tori we denote as O_p and O_n. Moreover, we assume that the central circles of T_p and T_n with corresponding radii R_p and R_n lie in parallel or coinciding planes and spin in the same or opposite direction with constant angular velocities $\boldsymbol{\omega}$ around an axis z, passing through O_p and O_n and perpendicular to their plane of rotation. If $O_pO_n = h$, then $h \geq 0$ (**Figure 4**).

The radii of the proton T_p and the neutron T_n are correspondingly $r_p = 0.84184 \times 10^{-15}$ m and $r_n = 1.1 \times 10^{-15}$ m. Let us denote with $q_p > 0$ the radius of the circle of the empty part of the torus T_p of the proton, *i.e.* $q_p = 2R_p - r_p$.

We remodel the proton T_p with a sphere S_p, and the neutron T_n with a torus T_N, equivalent in area. In addition, S_P and T_N have the same centers and stand at the same distance τ as in the case of T_p and T_n (**Figure 5**).

We apply a similar reasoning [5] for the interaction between conducting spheres. Therefore, for different values of the radius q_p of the empty part of T_p and the distance τ between the surfaces of the nucleons, we obtain the following results for the forces and interaction energies between nucleons, which are presented in **Table 2**.

For $q_p > 0.6r_p$, or $\tau < 10^{-17}$ m the force and binding

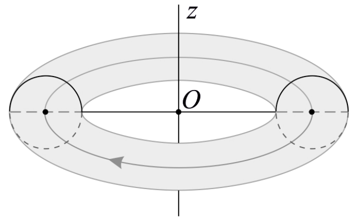

Figure 3. Toroidal model of a nucleon.

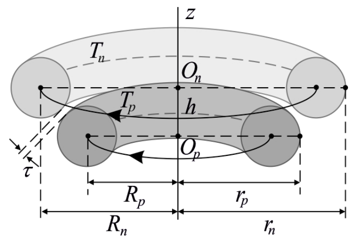

Figure 4. Cross-section of a proton-neutron system.

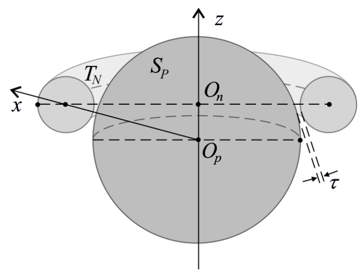

Figure 5. Cross-section of the reduced model of a proton-neutron system.

Table 2. Force and interaction energy between the tori T_p^1, T_p^2 and T_p, T_n, remodeled respectively as point charges p, p and surface-equivalent sphere S_P, torus T_N.

q_p	τ m	$F(T_p^1,T_p^2)$ N	$F(T_p,T_n)$ N	$W(T_p^1,T_p^2)$ J	$W(T_p,T_n)$ J
	10^{-17}	869.51	−6486.05	4.4789	−7.7951
$0.4r_p$	10^{-16}	630.09	−251.04	3.8127	−0.7769
	10^{-15}	101.84	−2.06	1.5328	−0.0188
	10^{-17}	1242.42	−7120.70	5.3538	−7.9408
$0.5r_p$	10^{-16}	850.20	−252.18	4.4289	−0.7480
	10^{-15}	114.27	−1.85	1.6237	−0.0163
	10^{-17}	1918.95	−7772.87	6.6537	−8.1703
$0.6r_p$	10^{-16}	1209.55	−253.98	5.2825	−0.7151
	10^{-15}	129.11	−1.61	1.7259	−0.0137

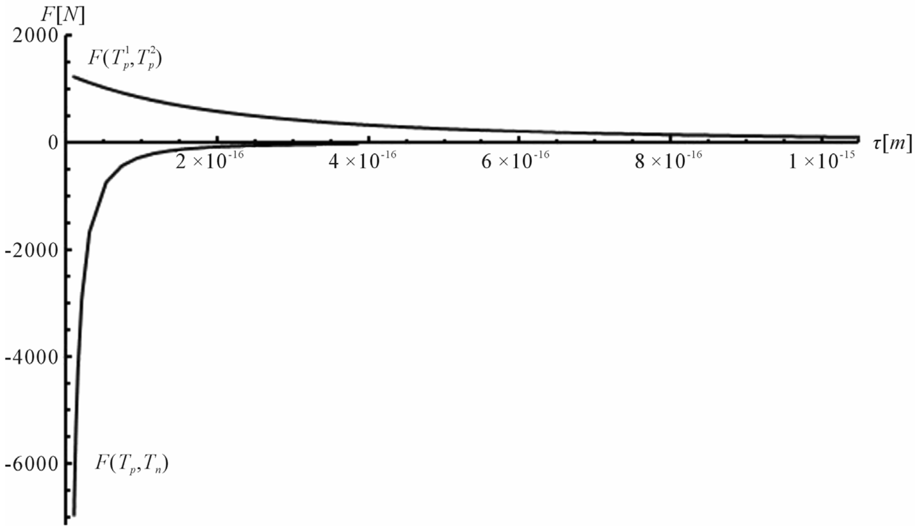

Figure 6. Plot of the interaction forces between the tori T_p^1, T_p^2 and T_p, T_n, remodeled correspondingly as point charges p, p and surface equivalent sphere S_P, torus T_N depending on the distance τ between the tori for $q_p = 0.5r_p$.

energy increase in absolute value.

For $q_p = 0.5r_p$ and $\tau \in \left[1\times10^{-17}\text{ m}; 1\times10^{-15}\text{ m}\right]$ on **Figure 6** are presented the curves of $F\left(T_p, T_n\right)$ and $F\left(T_p^1, T_p^2\right) \approx F\left(p, p\right)$ as a function of the distance between the objects.

From the curves plotted on **Figure 6** can be drawn conclusions for the short-range scope of the electrostatic force of interaction F between a proton and a neutron modeled as tori, which are similar to those when modeled as spheres (see **Figure 2**). For τ in the order of 10^{-17} m, according to **Tables 1** and **2**, the absolute value of F in the *toroidal model* is an order of magnitude larger than that in the *standard model*.

From the values of the binding energy and the interaction force between the proton and neutron modeled as tori it follows that *the nuclear interactions may have an electromagnetic nature.*

4. DISCUSSION

Atomic nuclei are characterized by *short-range-acting proton-neutron electrostatic attraction forces* as well as *long-range-acting proton-proton electrostatic repulsion forces*.

The presence of a proton in immediate proximity to a neutron disrupts its neutral electrical structure. Due to its charge redistribution, it also interacts with other neutrons. Thus, the entire nucleus acts as a unified complexly interacting electrostatic system. But the short-range-acting nature and the large values of the attraction forces show that the *neutrons are the binding particles in nuclear structures*!

As is well known, with the exception of protium, all nuclei are made up of protons and neutrons. According to the Segre diagram [11], if A is the mass number of the nucleus, then the stability of the nucleus depends on the parameter $\left(A - N_p\right)/N_p = N_n/N_p$, that is the ratio between the number of neutrons N_n and the number of protons N_p. The light nuclei for which $N_n/N_p = 1$ are the most stable. With the increase of the mass number A the multiplication of the electrostatic repulsion between the protons is ever more manifested and the area of stability is shifted to values $N_n/N_p > 1$. For the heaviest nuclei, the parameter $N_n/N_p \approx 1.5$. The latter once again underlines the huge role of the neutrons for the stability of atomic nuclei.

As can be seen from the plots on **Figures 1** and **3** the proton-neutron forces of attraction are short-range-acting on distances of the order of 10^{-15} m. This interval covers the experimentally observed interval for short-range action of nuclear forces which is commonly accepted.

When kernels of proton and neutron penetrate each other, a huge force of repulsion occurs between them. This force can also be explained on the basis of our theory, taking into account the complex distribution of the internal charge in the nucleons. This will be done by us in the next article.

It is also interesting to note that in the standard model of the nucleus the role of the Coulomb repulsion between protons is considered as destabilizing factor for the nucleus and the "nuclear attraction forces" between protons are not taken into account. According to contemporary nuclear physics the nuclear forces are huge and significantly surpass the Coulomb repulsion forces, from which it follows that there should be no problem with nucleus stability. Since the electrostatic repulsion forces are long-range-acting they permeate the entire volume of the nucleus. Thus every proton in the nucleus interacts with all other protons and the repulsion force is multiplied as opposed to the attraction force. It turns out that the long-range action between protons is very effective. Because of that in heavy nuclei the number of neutrons is larger than the number of protons.

In more complicated nuclei very indicatively is being observed the action of the universal law of unity and struggle of opposites. Balance between the opposing forces—of attraction (short-range-acting) and repulsion (long-range-acting) leads to the unity—the presence of nuclei of chemical elements.

It is hardly the case that in the nucleus the short-range-acting electrostatic forces of attraction are combined with short-range-acting forces of a completely different nature —the so-called nuclear forces.

5. CONCLUSIONS

Based on our results for the short-range-acting character of the proton-neutron electrostatic forces the basic properties of nuclear forces can be explained. Eloquent example is the property of "saturation of nuclear forces". It is important to mention that the electromagnetic forces between two nucleons depend on whether they spin in the same or opposite directions, that is on the orientation of their spins.

The binding energies for the nuclei of deuterium—$W_{^{1}_{2}\mathrm{H}} = -3.5642 \times 10^{-13}$, tritium—$W_{^{1}_{3}\mathrm{H}} = -13.5895 \times 10^{-13}\ \mathrm{J}$, helium-3—$W_{^{2}_{3}\mathrm{He}} = -12.352 \times 10^{-13}\ \mathrm{J}$ and helium-4—$W_{^{2}_{4}\mathrm{He}} = -32.9232 \times 10^{-13}\ \mathrm{J}$, obtained in [6] are known and commonly accepted values. The binding energy—one of the most important nuclear characteristics has been obtained from solely electrostatic considerations. We believe this fact cannot be due to an insignificant coincidence.

In conclusion, we can assume that *the nuclear forces have an electromagnetic nature*.

6. ACKNOWLEDGEMENTS

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