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Proton, Neutron, and Nuclei Models without Strong Nuclear Force

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Abstract

We show that for the particles that have both a charge and a magnetic moment, combining the electrostatic and the magnetic interactions between particles allows to build a consistent description of nuclear structures made of such particles, without introducing the concept of a strong nuclear force. In the modern nuclear physics, protons and neutrons are described as consisting of quarks, the particles that possess the charge and the spin magnetic moment properties. We show that combining the electrostatic and magnetic forces between quarks in nucleons, it is possible to achieve all the required interactions in the nucleons the strong nuclear force is assumed to deliver –to supply both the attraction and the repulsion between the quarks in a nucleon as well as between nucleons in a nucleus. The equilibrium state of the particles in nucleons can be achieved and the equilibrium distance between quarks can be determined using the electromagnetic forces without introducing any additional strong nuclear force. A balance between attraction and repulsion between quarks in an isolated nucleon determines the equilibrium distances between quarks where the net force on each quark is zero and the potential energy of a nucleon is negative and at minimum. We suggest that the combination of the electrostatic force and the force between magnetic moments will work for explaining any system consisting of particles with both electric charge and magnetic moment, including electron and positrons. In another paper, we have shown the electron-positron pairs can be a stable formation, and we suggested that free space might be a network of interacting electrons and positrons at some distances between them, not recombining without external intervention. We hope that comparing the prediction calculated with our models and experimental data on nuclear particles and systems will allow determining the constants related to the magnetic and electrostatic interactions between elementary particles with charge and spin magnetic moment.

1. Models of a proton and a neutron based on electrostatic and magnetic interactions between quarks

In the modern nuclear physics, a proton and a neutron are considered as composed of quarks. A proton is composed of three quarks - one d quark with the electric charge of -e/3 and two u quarks each of charge of +2e/3, so the total charge of a proton is +e where e = $1.6\text{x}10^{-19}$ Coulomb. Similarly, a neutron is composed of three quarks – one u quark with the charge of +2e/3 and two d quarks, each with the charge of -e/3, so the total charge of a neutron is 0. In a nucleus being a composition of positively charged protons and neutral neutrons, some additional force is required to overcome the electrostatic repelling between positively charges (protons), which, if not balanced, would push the protons out of the nucleus. At the time when protons and neutrons were considered as elementary particles, such additional force was introduced, with its properties unknown except that that force was attractive and was acting only at very short distances between nucleons, supplying kind of “glue” between them. After it was discovered that protons and neutrons had some internal structure and were not elementary particles, the quark models of a proton and a neutron were introduced. I was recognized that to properly describe protons and neutrons, the attraction and repulsion were both required between quarks. To satisfy that requirement, the assumed properties of the strong nuclear force were adjusted for it to supply not only the attraction but also the repulsion between the oppositely charged quarks. To correctly describe the quark models of protons and neutrons, that force was declared as being attractive at very short distances but turning to become repulsive at even shorter distances (<0.7 fm as stated in [1]).

As far as we know, however, nobody discussed how are the charged particles (quarks) positioned inside protons and neutrons. It worth to start with considering the electrostatic forces between three charges for the particular cases (quarks in protons and neutrons). It is expected that electrostatic forces between the three charges at rest, two positive and one negative, like in a proton, and two negative and one positive like in a neutron must cause them to align along a straight line, with one charge in the middle and two other charges of the opposite sign on both sides of the charge in the middle. A proton in such a model is a linear structure consisting of a d quark (-e/3) in the center and two u quarks (+2e/3) at both sides of the d quark. Similarly, the model of a neutron is also linear, with one u quark (+e/3) in the center and two d quarks(-e/3) on both sides. Having no other info on the shape and size of quarks, the positive and negative

quarks can be considered, in the 1^{st} approximation, as point charges that in equilibrium are held from each other at some distance D between their centers.
With such linear arrangement of three charges in mind, the models of a proton and a neutron can be considered as the ones shown in Fig. 1, where the u and d quarks are shown, for simplicity, as spheres of the same diameter D.

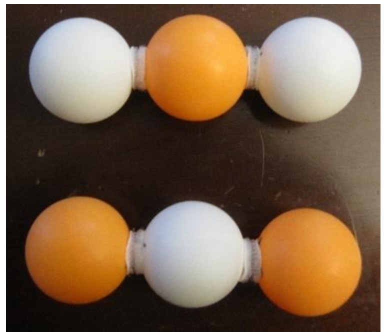


Fig. 1. In the models of a neutron (top) and a proton (bottom), the dark and light balls represent the u and d quarks, correspondingly.

Note that in such one-dimensional models of isolated protons and neutrons, the nucleons do not have a spherical symmetry anymore. While this can lead to some changes in description of nuclei and atoms, we will not consider in this paper the role the symmetry might play in the description and interaction of nucleons.
If a neutron is placed next to a proton, the interaction of quarks of the neutron with the quarks of a proton should be considered. The electrostatic Coulomb's force attracts the oppositely charged quarks to each other, so in the result the proton and the neutron are attracted to each other and no additional force is needed that would add some "glue" to the proton and neutron pair. The strong nuclear force was introduced initially as some "glue" with the goal of explaining how the multiple protons in a composition of closely placed positively charged protons and neutral neutrons do not expel each other from the nucleus until just one proton remains in the nucleus. We think that such a special nuclear attractive force is not needed to supply the attraction between nucleons. The required "glue" is just the well-known electrostatic attractive force between the unlike charges.
While including some special "glue" as a strong nuclear attractive force might be not required anymore, it was understood that, in the quark models of nucleons, some other, repulsive force is needed to keep the quark charges from recombining with each other (kind of skin of a quark was needed). In order to get such a repulsive force, it was assumed that the same strong nuclear force can change from attractive to repulsive at a very small change of the distance between the particles. For example, as described in [1], the strong nuclear force should be attractive and strong at the distances between quarks of about $0.8 \cdot 10^{-15}$ m, but at the distances less than $0.7 \cdot 10^{-15}$ m it should be strongly repulsive. While such an adjustment of a single force allowed to explain the structure of nucleons, we think that combination of two different forces- one attractive and the other repulsive - could do the job. We think that the required combination of attractive and repulsive forces could be the attractive electrostatic force between the unlike charges of particles and the repulsive force between the spin magnetic moments of the quarks. It is known that the magnetic moments in a magnetic field tend to align in the direction of the magnetic field vector. Therefore the magnetic moments of quarks interacting with each other might tend to align in the same direction, and that would result in repulsive forces between quarks. A force between the magnetic moments increases as $1/r^4$ with decreasing the distance *r* between the magnetic moments while the attractive electrostatic force between unlike charges also increases with decreasing the distance between the charged particles but only as $1/r^2$. Hence, it is reasonable to expect that at some distance between the particles, the attractive electrostatic force between the oppositely charged particles can be balanced by the repulsive force between the magnetic moments of the particles.
Bernard Schaeffer [2] discussed the polarization of a neutron by a positively charged proton for getting it attracted to a proton, and they also considered the magnetic interaction between a proton and a polarized neutron to balance the electrostatic attractive force. In their paper, Bernard Schaeffer mentioned: "Bieler of the Rutherford laboratory imagined in 1924 a magnetic attraction equilibrating an electrostatic repulsion between the protons". We think that considering the combination of the repulsive magnetic spin interaction force and the attractive electrostatic force

between the charged particles with spin, such as quarks or electrons and positrons, can be used to explain the origin of the required attractive turned repulsive net force between the charged magnetic dipoles (quarks in nucleons). The magnetic interaction between particles with both a charge and a magnetic moment can set the limit on how close to each other the charged particles can come. The electromagnetic interaction of particles with both charge and spin magnetic moment provides attraction and repulsion between charged particles with spin considered in nuclear physics, the properties currently imposed on the strong nuclear force. We think that the role of strong nuclear force as a separate force in nature could be re-evaluated if not excluded, unless it would be impossible to explain some properties of nuclear systems using the known electromagnetic forces between particles possessing both charge and magnetic moment.

Using the Coulomb's Law and the equation for the force between magnetic moments, we can calculate the equilibrium distance between the quarks in isolated protons and neutrons from the condition that the net force on any selected quark is zero.

2. The forces and the equilibrium distance between quarks in the proton and neutron models.

The force between two magnetic moments of infinitely small size (point magnetic moments, or magnetic dipoles) is given by the following equation [4]

$$\vec{F} = \frac{3\mu_0}{4\pi r^4}((\vec{r}\times\vec{M}_1)\times\vec{M}_2 + ((\vec{r}\times\vec{M}_2)\times\vec{M}_1 - 2\vec{r}(\vec{M}_1\cdot\vec{M}_2) + 5\hat{r}(\vec{r}\times\vec{M}_1)\cdot(\vec{r}\times\vec{M}_2) \quad (1)$$

The potential energy of two magnetic dipoles is given in [5] as

$$U = -\frac{\mu_0}{4\pi|r|^3}\left[3(\vec{M}_1\cdot\hat{r})(\vec{M}_2\cdot\hat{r}) - \vec{M}_1\cdot\vec{M}_2\right] - \mu_0\frac{2}{3}\vec{M}_1\cdot\vec{M}_2\delta(\vec{r}) \quad (2)$$

Here $\vec{M}_1$ and $\vec{M}_2$ are the two magnetic moments, $\hat{r}$ is a unit vector in direction from $\vec{M}_1$ to $\vec{M}_2$. To simplify the calculations and resulting equations, we can consider that $\vec{M}_1$ and $\vec{M}_2$ normal to $\hat{r}$. If $\vec{M}_1$ and $\vec{M}_2$ are parallel or antiparallel, the equation reduces to a simple formula. Direction of the force of $\vec{M}_1$ on $\vec{M}_2$ (repelling or attractive) depends on the moments being parallel or antiparallel. If the magnetic moments are parallel, the force between them is repulsive, as we need for our models, and the magnitude of the force is

$$F_M = \frac{3\mu_0}{4\pi r^4}(|M_1||M_2|) \quad (3)$$

In the models of isolated protons and neutrons, each consisting of three charged quark with spin, the net force on a selected quark includes the electrostatic and magnetic forces from the other two quarks. Because the isolated proton and neutron are the linear structures, the forces will be colinear. In equilibrium, F_E and F_M – the electrostatic and the magnetic forces - must be opposite, and the two oppositely directed forces must be of the same magnitude to have a zero net force. Because the distance r between the interacting particles is present in both equations - for the electrostatic and for the magnetic forces - we can solve the equation $F_M = F_E$ for r and determine the equilibrium distance r_0 between the two adjacent quarks.

But for quantitative calculations, first we need to know the magnetic moments of the u and d quarks.

The magnitudes of the magnetic moments of a proton and a neutron are known as M_p = 2.973 M_0 and M_n = 1.913 M_0, where the nuclear magneton $M_0 = \frac{e\hbar}{2m_p}$.

Because a proton and a neutron are formed out of 3 quarks each, the resulting proton and neutron magnetic moments can be considered as some combination of the magnetic moments of the quarks. While it is possible to write the magnetic moments of a proton and a neutron as the linear combinations of the magnetic moments of u and d quarks and solve these equations for the magnetic moments of the u and d quarks, the correct choice of the equations is not defined. For example, in [4] the author suggested the equations as

$$\frac{4}{3}M_u - \frac{1}{3}M_d = M_p \text{ and} \quad (4)$$

$$\frac{2}{3}M_u - \frac{2}{3}M_d = M_n \quad (5)$$

But some other equations might be used as well. If the magnetic moments of the u and d quarks were known, it would be feasible to calculate the equilibrium distances between the quarks, the potential energy of a proton and a neutron in our models, and the potential energies of different combinations of protons and neutrons. Because the magnetic moments of quarks are not known from experiments, we will not use the numerical values for the magnetic moments of the u and d quarks hoping that they will be found from comparison of experimental data with the calculations using our models of a proton and a neutron.

We want to note that while it is tempting to use the Coulomb's law equation and the equations (1) – (3) as they are, with the known values of the permittivity and permeability of free space, it is better to not assume that in general the permittivity and the permeability in these equations applied to the nuclear-size systems are known when considering the particles at such small distances from each other. The permittivity and permeability of free space were determined experimentally by the experiments on "macro" level, where the medium was considered as free of anything (pure vacuum). As we suggested in our paper on electron-positron pairs [5], the free space could be not a space free of anything but a network of interacting electrons and positrons. But with the free space assumed to be the network of interacting electrons and positrons, there would be nothing of that "free space" medium between the closely spaced quarks. That is why instead of using the macroscopic values of μ_0 and ε_0 in our calculations, we will use the unknown so far local permittivity and the permeability, ε and μ (the same symbols but without the subscripts). However, using the known values μ_0 and ε_0 values in the calculated results would not change the results in principle, but the quantitively the calculated quantities might be not what they really could be for the considered systems of particles.

For the quark-based model of a proton shown in Fig 1, the electrostatic and magnetic forces on the right quark the sums of the forces applied by the central and the left quark all laying on the same straight line (on the x-axis, drawn from the left quark toward the right quark):

$$F_E = \frac{1}{4\pi\varepsilon}\frac{\left(-\frac{e}{3}\right)\left(+\frac{2e}{3}\right)}{r^2} + \frac{1}{4\pi\varepsilon}\frac{\left(+\frac{2e}{3}\right)\left(+\frac{2e}{3}\right)}{(2r)^2} = -\frac{1}{9}\frac{1}{4\pi\varepsilon}\cdot\frac{e^2}{r^2} \qquad (6)$$

$$F_M = \frac{3\mu}{4\pi r^4}(|M_u||M_d|) + \frac{3\mu}{4\pi(2r)^4}(|M_u||M_u|) \qquad (7)$$

From the similar calculations for the right quark in the model of a neutron,

$$F_E = 2\frac{1}{4\pi\varepsilon}\frac{\left(-\frac{e}{3}\right)\left(+\frac{2e}{3}\right)}{r^2} + \frac{1}{4\pi\varepsilon}\frac{\left(-\frac{e}{3}\right)\left(-\frac{e}{3}\right)}{(2r)^2} = -\frac{1.75}{4\pi\varepsilon}\cdot\frac{e^2}{9r^2} \qquad (8)$$

$$F_M = \frac{3\mu}{4\pi r^4}(|M_u||M_d|) + \frac{3\mu}{4\pi(2r)^4}(|M_d||M_d|) \qquad (9)$$

From $F_M = F_E$, we could determine the equilibrium distance r_0 between d and u quarks in a proton and in a neutron. Using that equilibrium distance, the potential energies of the proton, neutron, and their combinations can be calculated.

But In view of uncertainty about the local values of the permittivity and permeability, as well as the absence of the reliable values for the magnitudes of the magnetic moments of the quarks, we will proceed with such calculations only in the equation forms, without using the numeric values for the permittivity, permeability, and the magnetic spin moments of the quarks. What is important at this time, however, is to conclude that the combination of the electrostatic force between charged particles and the magnetic force between particles with magnetic moment makes it possible to qualitatively explain the structure of nucleus, without introducing the strong nuclear force.

3. Binding energies of a proton and a neutron

Using the symbol r_0 as the equilibrium distance(s) between the centers of the quarks in our proton and neutron models, we can estimate the binding energies for a proton and a neutron. As a continuation of this approach, it would be possible to estimate the binding energies of some simple models of structures (nuclei) made of protons and neutrons. The potential energy of such structures in equilibrium can be easily as the sum of the electrostatic and magnetic potential energies for all the interacting pair of particles (quarks). We will use the linear models for a proton and a neutron where the quarks are located along a straight line, with the distance r_0 between the adjacent quarks and the distance $2r_0$ between the two quarks on both sides of the quark in the middle. Using Das the distance between the centers of the u and d quarks, the electrostatic potential energy in our proton model is

$$U_{Ep} = 2\frac{1}{4\pi\varepsilon}\frac{\left(\frac{+2e}{3}\right)\left(\frac{-e}{3}\right)}{r_0} + \frac{1}{4\pi\varepsilon}\frac{\left(\frac{+2e}{3}\right)\left(\frac{+2e}{3}\right)}{2r_0} = \frac{1}{4\pi\varepsilon}\frac{e^2}{r_0}\left(\frac{-2}{9}\right) \tag{10}$$

Similarly, for the neutron,

$$U_{En} = 2\frac{1}{4\pi\varepsilon}\frac{\left(\frac{+2e}{3}\right)\left(\frac{-e}{3}\right)}{r_0} + \frac{1}{4\pi\varepsilon}\frac{\left(\frac{-e}{3}\right)\left(\frac{-e}{3}\right)}{2r_0} = \frac{1}{4\pi\varepsilon}\frac{e^2}{Dr_0}\left(\frac{-3.5}{9}\right) \tag{11}$$

The magnetic potential energy, related to the magnetic moment interaction, for the proton and neutron models are

$$U_{Mp} = 2\frac{\mu}{4\pi r_0^3}(M_u M_d) + \frac{\mu}{4\pi(2r_0)^3}(M_u M_u) \tag{12}$$

$$U_{Mn} = 2\frac{\mu}{4\pi r_0^3}(M_u M_d) + \frac{\mu}{4\pi(2r_0)^3}(M_d M_d) \tag{13}$$

The total potential energies for the proton model the neutron models are:

$$U_p = U_{Ep} + U_{Mp} = \frac{1}{4\pi\varepsilon}\frac{e^2}{r_0}\left(\frac{-2}{9}\right) + 2\frac{\mu}{4\pi r_0^3}(M_u M_d) + \frac{\mu}{4\pi(2r_0)^3}(M_u M_u) \tag{14}$$

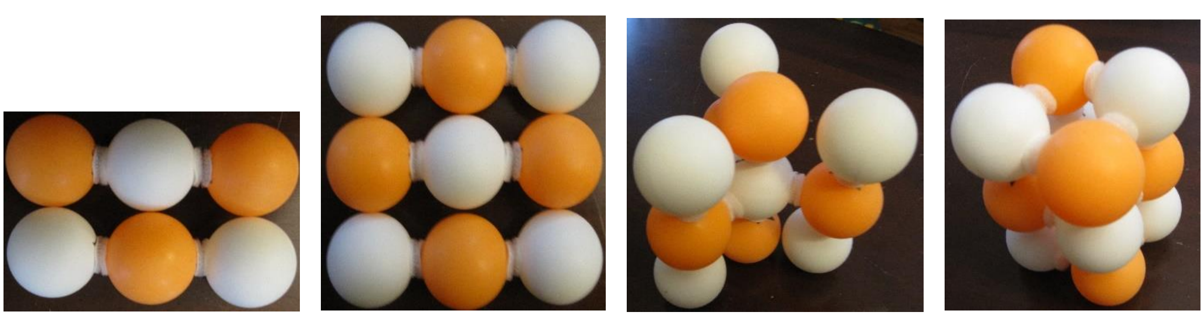
$$U_n = U_{En} + U_{Mn} = \frac{1}{4\pi\varepsilon}\frac{e^2}{r_0}\left(\frac{-3.5}{9}\right) + 2\frac{\mu}{4\pi r_0^3}(M_u M_d) + \frac{\mu}{4\pi(2r_0)^3}(M_d M_d) \tag{15}$$

The electrostatic and the magnetic forces are changing differently with the distance between the quarks ($1/r^2$ vs $1/r^4$), so they might be equal in magnitude and opposite in the direction at some equilibrium distance r_0 between the quarks. That could result in an equilibrium status of the system. The quarks might be at rest or in a motion, for example vibrating near the equilibrium position.

From the condition for the potential energy be at minimum (or, equivalently, the net force on any particle be zero), the equilibrium distance r_0 between the u and d quarks in an isolated nucleon and the potential energy of a free proton and a free neutron can be calculated.

4. On the model structures of nuclei made of proton and neutrons

Using the models of a proton and a neutron, we can combine them in simple structures for the nuclei of Hydrogen and Helium. The potential energies of such structures could be calculated and evaluated quantitively for the known or assumed values of the local permittivity, permeability, and the magnetic moments of the particles composing protons and neutrons. The suggested structures are shown in Fig. 2 where the proton and neutron models are still shown as one-dimensional structure while they might not be such due to interactions between the quarks other than the ones in individual protons and neutrons.



(a) (b) (c) (d)

Fig.2. Some model nuclei made of our models of nucleons: ${}_1^2H$ (a), ${}_1^3H$ (b), ${}_1^4H$ (c), and ${}_2^4He$ (d).

Some more speculations in favor of the nucleus models built of our proton and neutron models: (a) The nuclei, just as protons and neutrons, are not spherically symmetrical, and taking this into account might predict some new observations; (b) In the three-dimensional models of Hydrogen isotopes, there would be no place to add more than 6 neutrons around one proton, and that is in agreement with the fact that Hydrogen isotopes with the number of nucleons only ≤ 7 are considered (some being unstable); (c) Going further with the geometric arrangement in our models and adding to one ${}^4_2He$ 4 more ${}^4_2He$ at each side of the rectangle construction shown in Fig. 2d, the resulting structure would have 20 protons and 20 neutrons, which fits the experimentally found doubly magic numbers 2, 4, 16, 20… determined in studies of radioactive decays if different nuclei.

4. Conclusion

The suggested models of a proton and a neutron as linear structures of quarks interacting with each other via electrostatic forces between quark's charges and magnetic forces between their magnetic spin moments allow explaining qualitatively the binding the u and d quarks in the nucleons without invoking a concept of a strong nuclear force. This also can explains qualitatively binding nucleons to each other in nuclei. The role of interaction between magnetic moments of particles that have both electric charge and magnetic spin moment is important in interpretations of experiments in the field of nuclear physics. This might lead to re-evaluating the role of the strong nuclear force. As we have shown, binding quarks in nucleons and nucleons to each other can be explained without using the concept of strong nuclear force if the interaction between magnetic spin moments is taken into account. It might happen that using the known electromagnetic forces will be sufficient to explain the experiments with the particles that have both properties – electric charge and magnetic moment.

5. References

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