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Review Article

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Research in Strong Interactions of Protons and Deuterons

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Abstract

Investigations were made of the electric forces of interaction of two protons at distances comparable to the sizes of protons. The proton interaction force is calculated as a superposition of the interaction forces of the quarks of one proton with the quarks of another proton. The nature of the change in the electric force of the interaction of two protons, established by theoretical calculations, coincides with the nature of the change in the strong interaction measured experimentally.

Theoretical studies of the interaction force of two deuterons, which takes place during thermonuclear fusion, have been carried out. The change in the interaction force of two deuterons from the distance between them also coincides with the change in the strong interaction at small distances.

Based on theoretical studies, it was concluded that strong interaction reveals the electrical nature.

Preface

One of the four fundamental interactions is strong interaction. It manifests itself in the nuclei of atoms at small distances between nucleons. As stated in the literature [1], the binding energy consists of the energy of strong interaction and the energy of electrostatic repulsion. However, nowhere in the literature are there calculations of the electric forces of interaction of nucleons at small distances between them. Among experts, the opinion has been established that protons are positively charged, and they should always repel each other.

In fact, the proton is a triplet of quarks, the charges of which are distributed throughout the volume. The proton diameter is 0.84FM (1Fm= 15 10^{-15}m). When calculating the forces of interaction of protons at distances comparable to the sizes of protons, protons cannot be considered as point charges. The force of proton interaction should be considered as a superposition of the interaction forces of the quarks of both protons.

To have a correct idea of the nature and magnitude of the strong interaction, we need to know the contribution of the electric interaction forces to the strong interaction. In [2], neutron-neutron and neutron-proton interactions were studied. For a more complete study of the nuclear electric forces of interaction, it seems appropriate to study the electric forces of interaction of positively charged protons, as well as to study the interaction of two positively charged deuterons, which, when combined, form the nucleus of a helium atom. This is also relevant from the standpoint of studying processes in thermonuclear fusion.

Research results

First, we consider the interaction of two protons. Both protons contain two *u*-quarks with charges +2/3e and one *d*-quark with a charge of -1/3e. When the protons are at close range, the negatively charged quark of each proton attracts the positively charged quark of the opposite proton. In each proton there remains one more positively charged quark, and they repel each other. Through these interactions, all the quarks of two protons lie in the same plane, and they will look as shown in Figure 1. The force of proton interaction is equal to the superposition of the forces of interaction of each quark of one proton with each quark of another proton. We are interested in the force with which one proton can be torn from another. Therefore, we calculate the projection of all forces on the *x* axis.

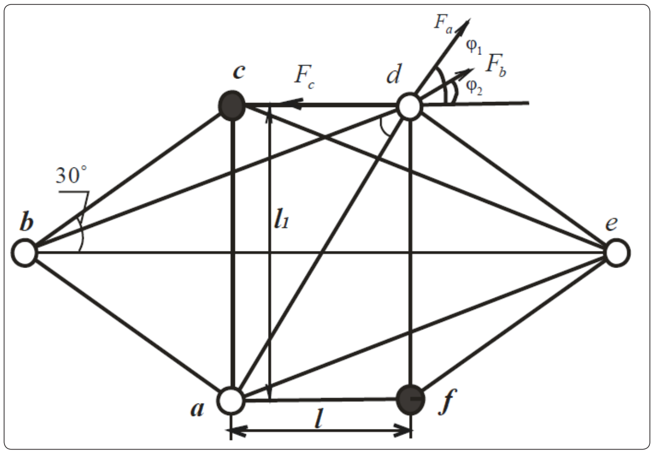

Figure 1: Doublet of two protons

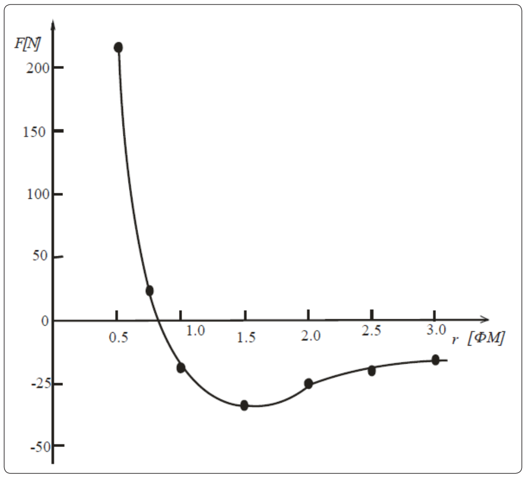

Figure 2: Dependence of the attraction force of protons on distance

The diameter of the protons is $D = 0.84Fm$. The side of an equilateral triangle inscribed in a circle is equal to $l_1 = D \cdot \frac{\sqrt{3}}{2} = 0.727Fm$. The minimum distance at which you can bring the neutrons closer is about $0.5Fm$.

The distances between any quarks are easily determined using exclusively the Pythagorean Theorem. The forces of interaction of quarks are calculated according to the Coulomb law. The strong interaction between nucleons has a sharper dependence on the distance between them than the Coulomb forces. Coulomb's law is valid for point charges, or the distance between charges must be significantly greater than the magnitude of these charges. In nucleons, the charges of the quarks are distributed in the volume, and the interaction force of the nucleons depends on the position of these quarks. This is especially noticeable at short distances, comparable with the size of nucleons. We show this by the example of the interaction of a quark *d* with quarks *a,b,c*. The force of interaction is

$$F_d = F_c - F_a .\cos\varphi_1 - F_b .\cos\varphi_2 \qquad (1)$$

where:
F_1, F_2, F_3 – Coulomb forces,
φ_1, φ_2– angles between forces F_a, F_b and x axis.

Forces F_a and F_b multiply by $\cos\varphi_1$ and $\cos\varphi_2$ to determine the projection of these forces on the x axis.
The Coulomb forces F_c, F_a and F_b decrease in inverse proportion to the square of the distance between the corresponding quarks, and at the same time, as the distance increases, the angles φ_1 and φ_2 decrease, but $\cos\varphi_1$ and $\cos\varphi_2$ increase. The repulsive forces $F_a.\cos\varphi_1$ and $F_b.\cos\varphi_2$ compensate the force of attraction F_c to a greater extent. The imposition of two factors gives a sharp decrease in the strength of interaction with increasing distance. At small distances, the theoretically calculated force of interaction of two protons coincides with the experimentally measured characteristic of the change in strong nuclear interaction. There is every reason to believe that the strong interaction is electric in nature.

Calculations show that with a minimum distance between quarks *a*, *f* and quarks *c*, *d* equal to $0.5Fm$, the proton attractive force (Figure 2) is $214N$ (Newton). When the distance is changed to $0.75Fm$, the attractive force sharply decreases to $23N$.

Most of the attractive force is formed by quarks *c*, *d* and quarks *a*, *f*, between which the smallest distance. Quarks *b*, *e* repels, but they are relatively far away and repel less. The superposition of all the interaction forces of quarks gives the dependence of the interaction force on distance, shown in Figure 2. Each proton has a predominantly positive charge. As the distance between them increases, the triplets of quarks seem to contract to a point, and the dominance of a positive charge affects the strength of the interaction. Already at $l=1F_m$, the interaction force changes sign, that is, protons begin to repel. At $l=1.5_{Fm}$, the repulsive force of protons reaches a maximum ($F=31N$).

When the distance between protons is much larger than their size, the interaction force will change according to a law close to the Coulomb law.

Now we consider the calculations of the interaction forces of two deuterons-doublets of a neutron and a proton. The doublet of the neutron and proton is the nucleus of the isotope of hydrogen - deuterium. An analysis of the electric forces of interaction between two doublets is of particular interest, since in a thermonuclear reaction two deuterium nuclei combine to form a helium nucleus. The electric forces of the interaction of quarks determine the orientation of the doublets relative to each other when they are combined.

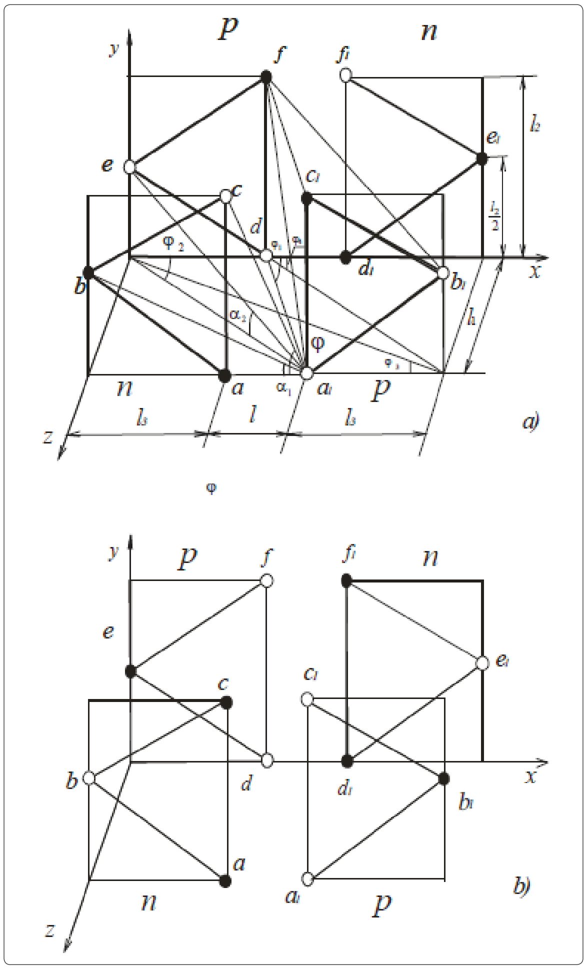

Figure 3: Two doublets: **a)** the first option, **b)** the second option

If the mutual orientation is unique for any two nucleons in the formation of a double, then when two doublets (in our case, two deuterons) are combined, the mutual orientation can be different. We will consider two such structures. At close range, if there is no other forces acting on the doublets, the quarks begin to interact and two doublets are attracted with a certain orientation relative to each other. What orientation will turn out depends on the initial state. Two variants of the structure of two deuterons are shown in Figure 3.

As can be seen from the figures, volumetric structures are similar. They differ only in the location of quarks. The second version of the structure can be obtained from the first version by rotating the left doublet 120° counterclockwise relative to the axis parallel to the *z* axis, and rotating the right doublet clockwise relative to the axis also parallel to the *z* axis.

To calculate the forces of interaction, we use the Coulomb law and multiply the force by the cosine of the corresponding angle to find the projection of the force on the *x* axis. The calculations were carried out in the computer mathematics system *Mathcad Prime* 3.1.

Letter *F* means force of interaction, and x means the projection of force on the *x* axis.

As can be seen from the results, the deuteron attractive force for the first variant with a distance between the nearest quarks of both deuterons equal to $r=0.5Fm$ is $560N$. With an increase in this distance to $1Fm$, the interaction force decreases to $40N$. This means that doubling the distance leads to a decrease in the interaction strength by 14 times. Such a sharp change in the strength of the interaction is similar to a strong nuclear interaction. An increase in the distance between doublets leads to a change even in the direction of action of the force. Already at a distance of $r=0.85Fm$, deuterons begin to repel each other. The repulsion force reaches a maximum at $r=1.4Fm$ and then decreases with increasing distance because of influence predominance of positive charge in each proton.

A proton is considered positively charged. There are positive and negative charges in the proton volume, but there are more positive charges. With increasing distance, the charge distributed in the volume contracts to a point and begins to affect the superiority of the positive charge in each proton. This contributes to the repulsion of doublets.

When the distance between doublets is much larger than the size of the doublet, they can be considered point charges and the strength of their interaction obeys the Coulomb law. In the second variant of the mutual arrangement of the doublets, the character of the change in the strength of their interaction is the same as in the first variant. The second option differs in that the interaction force changes somewhat more slowly and changes sign when the distance between the nearest quarks is $r=1.2Fm$.

Neutrons are electro-neutral particles in which the positive and negative charges are distributed in volume in equal amounts and balance each other. As studies [2] show, the neutron-neutron and neutron-proton interactions are also strong.

Conclusion

Due to the interaction of the quark charges, the protons are attracted with a certain orientation relative to each other, in which the positive and negative charges of both protons are at a small distance and are strongly attracted. The remaining positive charges are at a relatively large distance and their repulsive force is negligible, despite the fact that in each proton there is more positive charge +e. Protons are attracted strongly at a distance between the nearest quarks equal to $0.5Fm$, and repel at a distance greater than $1Fm$.

If there is no external influence, two deuterons are attracted with a force of about $500N$, and form a very stable multiplet of four nucleons. This can explain the stability of helium atoms.

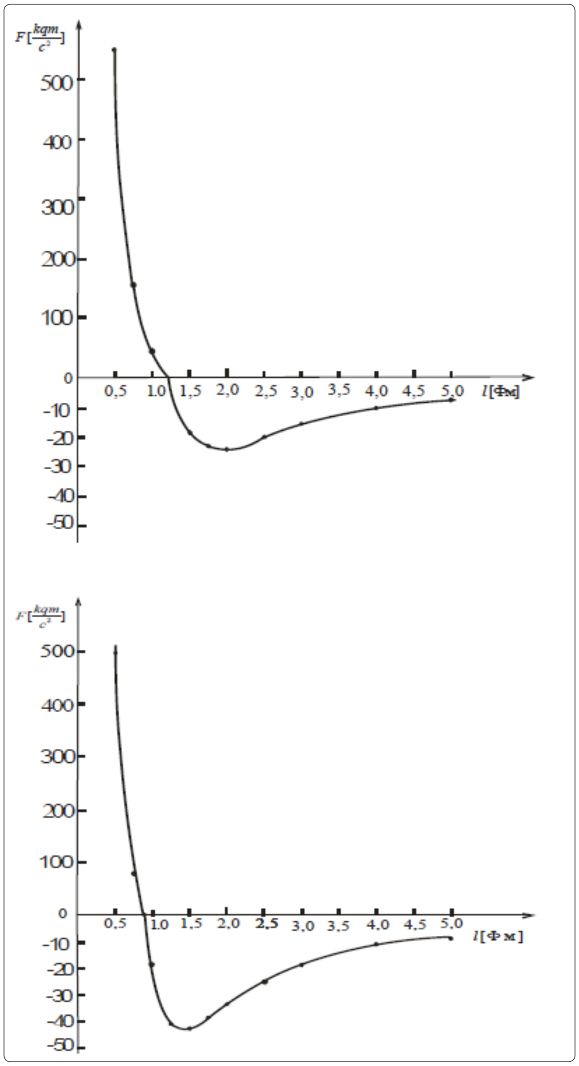

Figure 4: Dependence of the interaction force of doublets on distance: a) the first option, b) the second option

The nucleus of any atom is a combination of singlets, doublets, triplets and multiplets. Their packing can be different even for atoms with the same mass number; this explains the existence of isomers.

There is a weak interaction between stable multiplets in the nucleus. The reason for the weak interaction is an unsuccessful mutual orientation, or the structures of the multiplets are such that their strong interaction is impossible.

Doublets of neutron and proton are highly probable due to the fact that the interaction of neutron quarks with proton quarks orient them properly [2]. Similarly, deuteron doublets interact, which are also orientated and combined by a strong interaction through the interaction of quarks. For such a multiplet to form, there must be some freedom of movement, and therefore such multiplets can form on the surface of the nucleus, but not in the center of the nucleus. The probability of the existence of such multiplets on the surface of the nucleus is also high.

The interaction strength of the multiplet of two deuterons with the nucleus can be different and it depends on the structure of the nucleus as a whole. Atoms in which such a binding is very weak have the property of radioactivity and emit helium nuclei in the form of alpha particles.

Thus, theoretical calculations of the interaction strength of nucleons and deuterons depending on the distance between them coincide with the nature of the change in the strong interaction.

Based on the foregoing, we can draw a conclusion: ***strong and weak interactions are electric in nature***.

The fact that gravity is also electric in nature is said in [2]. Thus, the task of the Great Association, on which Einstein worked for 30 years, becomes solvable.

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