Could the Electrostatic Force Play a Role in Holding the Atomic Nucleus Together?

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Abstract

It is well known that the electrostatic force has infinite range, but an unheralded property of this force is that as the distance between charges approaches zero the force increases without bound. Applied to the atomic nucleus, if a positive fractional charge in one nucleon (proton or neutron) can get close enough to a negative fractional charge in a neighboring nucleon, the attractive force between them would bind these nucleons in an electrostatic bond. For example, at a distance of 5% of a nucleon radius they will experience an attractive force of -25 kN. This is orders of magnitude stronger than the repulsive force between whole protons in the nucleus. Contrary to what is normally expected from the electrostatic force, such a bond would have a short range, shorter than the radius of a nucleon. Ironically, this charge-based bond would match the nuclear force's characteristic of charge independence (affecting both neutrons and protons), because the required positive and negative fractional charges occur inside both neutrons and protons. This electrostatic bonding of fractional charges may therefore be an overlooked factor in the search for understanding the nuclear force and may shed light upon the structure of the nucleons and the atomic nucleus.

Introduction

The atomic nucleus is said to be held together by the nuclear force, a strong, short range, charge independent force that can overcome the electrostatic repulsion of the protons according to Coulomb's law. Understanding the nuclear force has been a challenge for over seven decades [1].

The atomic nucleus was discovered in 1911. Various models were proposed in which it was held together electrically by nuclear electrons [2]. However, the discovery of the neutron in 1932 and other issues caused the electric force theories to fall out of favor. Hans A Bethe explains in his 1953 article [3], "What Holds the Nucleus Together?" The subtitle answers: "Electrical forces bind the electron to the atom, but they cause the nuclear particles to fly apart. The powerful cohesion of protons and neutrons must be explained by a wholly different phenomenon." Within the article, Bethe speculated "even if the sign [of some charges] were changed so that they attracted one another, the electric force of attraction would be too small by a factor of 40 to account for the binding energy with which protons are held together in the nucleus."

Years later, in the 1960s, nuclear opposite charges were theorized by George Zweif and Murray Gell-Mann. The theorized particles had just a fraction of the charge of an electron or proton. This was hard to swallow, so fractional charges were considered to be mere mathematical fictions [4]. It took another decade before they were viewed as physical entities [5]. The nucleons (protons and neutrons) were probed and found to each contain three point-like electrostatic charges. Each proton has two $+{}^{2}/_{3}$ e and one $-{}^{1}/_{3}$ e charges, for a total charge of +1e. Each neutron has one $+{}^{2}/_{3}$ e and two $-{}^{1}/_{3}$ e charges, for a total charge of 0 [4]. Somehow, this discovery did not trigger a reconsideration of electric force's role in holding the nucleus together.

For an example of this lack of change, in 2004, in a brief review of the history of physics in [6], Frank Wilczek recounted that "the known forces, gravity and electromagnetism, were insufficient to bind protons and neutrons tightly together into objects as small as the observed nuclei. Physicists were confronted with a new force, the most powerful in Nature." This review included a discussion of these fractional charges but did not question the dismissal of the electrical force as possibly having a role in holding the nucleus together.

In 2014, Professor Ruprecht Machleidt put it this way in [1]: "After the discovery of the neutron by Chadwick in 1932 [citation omitted], it was clear that the atomic nucleus is made up from protons and neutrons. In such a system, electromagnetic forces cannot be the reason why the constituents of the nucleus are sticking together. Indeed, the repulsive electrical Coulomb force between the protons should blow the nucleus apart. Therefore, the concept of a new strong nuclear force was introduced."

The new force was called the nuclear force. According to [1-3] and innumerable other sources, it is a short range force that binds together neighboring protons and neutrons into atomic nuclei. Characteristics of the force include charge independence, meaning that it applies to proton-proton, proton-neutron and neutron-neutron interactions. It is sensitive to spin alignment. It has a maximum attractive force at a distance of about 1 fm (center to center) and becomes strongly repulsive at shorter distances. It is strong enough to overcome the collective electrostatic repulsion of the protons within the same nucleus, yet it is of such short range that at distances greater than about 2 fm only the long-range electrostatic force remains significant.

In reviewing how the atomic nucleus is held together, I did not find any mention of a mathematical property that inverse square law forces have at extremely small distances, and which could potentially play a role in the cohesion that became known as the nuclear force. I also did not find any reconsideration of the reasons for rejecting the electrical force, even after it was discovered that both protons and neutrons contain fractional charges of both signs. Therefore, it is the purpose of this paper to reconsider the rejection of inverse square law forces as playing a role in holding the nucleus together.

Electrical Bonding of Fractional Charges

The electrostatic force operates according to Coulomb's law, which describes the force between two charges at distance r,

$$F = k \frac{q_1 q_2}{r^2} \qquad where \;\; k = 8.98755 \times 10^9 \frac{Nm^2}{C^2} \tag{1}$$

As distance r approaches zero, equation (1) predicts that force increases without bound, so

$$\lim_{r \to 0} k \frac{q_1 q_2}{r^2} = \infty \tag{2}$$

The meaning of distance r approaching zero can be easily misunderstood. In our macroscopic world, zero distance does not occur in a way that is meaningful to the inverse square law forces.

When physical objects are said to touch they are actually responding to forces that hold the nuclei of their atoms apart by at least the radii of these atoms. For example, for two carbon atoms this would be on the order of 1.4×10^{-11} m. The obstructions are the electron clouds that give atoms their volume.

However, in the femtometer-scale (10^{-15} m) world of protons and neutrons, zero distance has no such obstructions. The atomic nucleus is a tiny speck deep inside that cloud of electrons. It is smaller than one ten-thousandth the size of the atom. When a graph of the electrostatic force extends down to this unobstructed zero distance, at some point it appears to take a sudden turn like a bent knee, where the line gradually transitions from more predominately following a horizontal asymptote to more predominately following a vertical asymptote (Fig. 1).

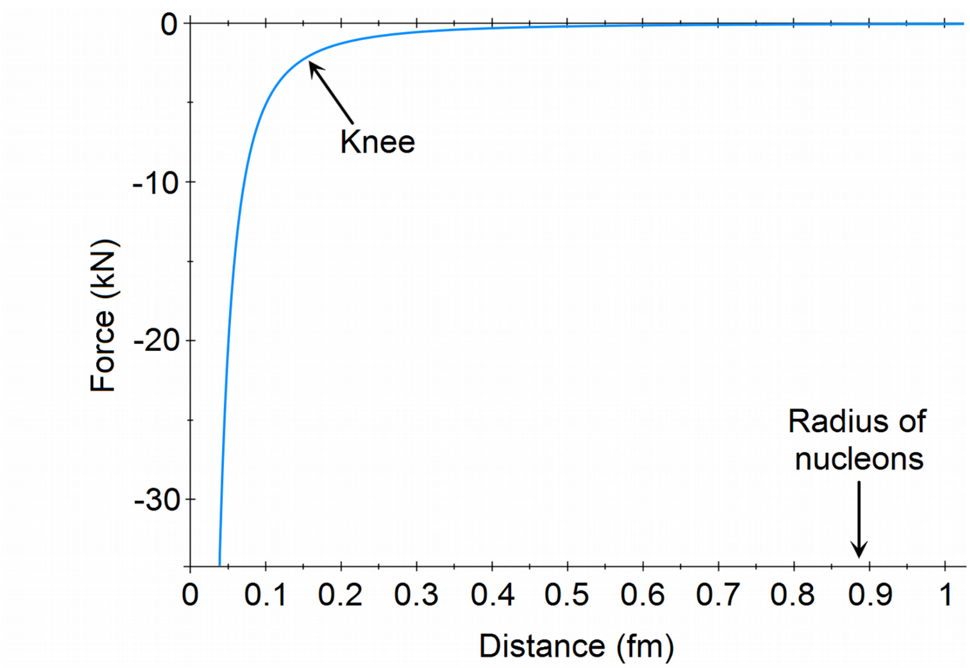

Fig. 1. *The electrostatic binding force between +2/3 e charge in one nucleon and -1/3 e charge in a neighboring nucleon grows dramatically as the effective distance between the charges is reduced.*

Where it takes this turn depends on the strength of the charges and the scales of distance and force chosen, but it has to happen somewhere. Regardless of how it is drawn, according to the inverse square law, reducing the distance down to 10% causes the force to increase by a factor of 100. Therein is the potential for orders of magnitude greater strength of the force that holds everything together compared to the force that wants to blow it apart. Both forces can be the same electric force. It is a matter of the true distances between the true charges and their signs. In other words, it is a matter of structure.

At the distances where the line in Fig. 1 is more prominently vertical, a very small change in distance corresponds to an enormous change in force. The following tables show how computations of the repulsive (positive) force between whole protons using traditional center forces and center-center distances can be overwhelmed by attractive (negative) force of fractional charges that are an order of magnitude closer. The distances in the table were chosen for illustrative purposes only. The forces were calculated using equation (1).

Table 1. Traditional distances and forces

Traditional Whole Charges and Center-Center Distances	**Coulomb Force**
Two protons, 2.5 fm	37 N
Two protons, 2 fm	58 N
Two protons, 1.74 fm (two nucleon radii)	76 N

Table 2. Forces between fractional charges and finer distances

Fractional Charges and Some Shorter Presumed Distances	**Coulomb Force**
Two -1/3 e charges, 0.87 fm (one nucleon radius)	34 N
Two +2/3 e charges, 0.87 fm (one nucleon radius)	135 N
+2/3 and -1/3 charges, 0.87 fm (one nucleon radius)	-67 N
+2/3 and -1/3 charges, 0.2 fm	-1300 N
+2/3 and -1/3 charges, 0.087 fm (10% of nucleon radius)	-6800 N
+2/3 and -1/3 charges, 0.045 fm (5% of nucleon radius)	-25000 N

At nucleon contact distances, according to the equations (1) and (2), the electrostatic force between opposite fractional charges is capable of any attractive force needed to hold the nucleus together. If a force is theorized or known from experiment, then the effective distance that would generate the needed force can be determined by solving the equation (1) for the distance r:

$$r = \sqrt{k \frac{q_1 q_2}{F}} \qquad (3)$$

For example, if the goal is a binding force of 25,000 N, and using the known +2/3 e and -1/3 e fractional charges that are available, and assuming favorable spin alignment (but otherwise ignoring its effect), the effective distance r comes out to be 0.045 fm.

This is not the first time a nuclear phenomenon could be explained in an essentially classical way. According to [7], when nuclear fission was discovered it could also be described in an essentially classical way.

Charge Independence

According to [1-3], another property of the nucleon-nucleon force is charge independence, meaning that it affects neutrons and protons alike even though protons have a charge and neutrons do not. The traditional nucleon-nucleon interaction has been found in proton-neutron (P-N), neutron-neutron (N-N) and proton-proton (P-P) bindings. In proton-proton bindings the force matches after compensating for the electrostatic repulsion of the protons.

When viewing the protons and neutrons as having whole number positive charge and no charge, respectively, the nuclear force does seem to be independent of charge. In this historically early view of net charges of nucleons, it seems that the only electrostatic forces in question are repulsive, that there has to be some entirely different kind of force that is overpowering the electrostatic force to hold the nucleus together, and that this entirely different kind of force does not care whether the nucleons have an electrostatic charge or not [1-3].

However, looking closer into the nucleons (as shown in Fig. 2) we see that both protons and neutrons have $+^2/_3$ e and $-^1/_3$ e charges in them [4]. We see that while each neutron has no net charge, it is not electrostatically neutral at close distances. We see opposite charges available for electrostatic forces in the attractive direction, and we see that the neutron is not an idle player but has fractional charges that should be considered capable of playing an important role.

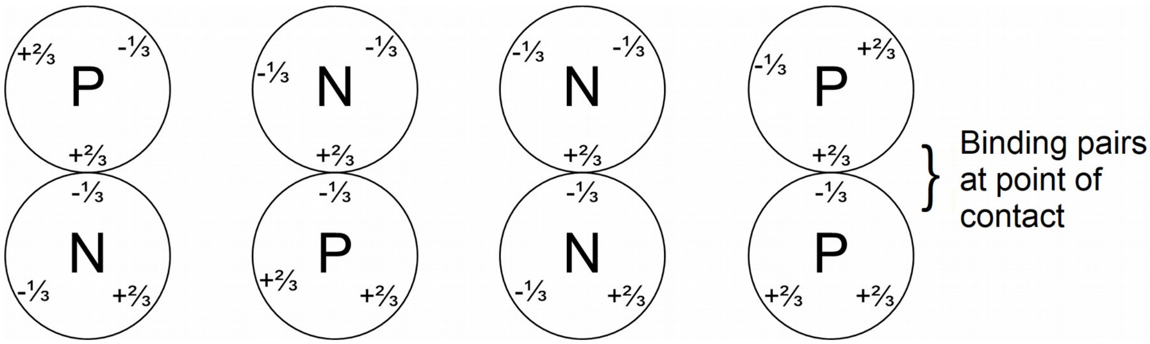

Fig. 2. Schematic diagram showing that there are four distinct combinations of two nucleons experiencing electrostatic binding between fractional charges. Protons are labeled with a large P and neutron are labeled with a large N.

Every binding pair will include both a $+^2/_3$ e charge and a $-^1/_3$ e charge. Therefore, every binding pair has a net charge of $+^1/_3$ e. This net $+^1/_3$ e charge that is leftover from a binding will repel unbound $+^2/_3$ e charges, if any, as well as other net $+^1/_3$ e charges that are leftover from other bindings. These latter two types of repulsion should be expected to occur at distances significantly farther apart than the distances that form the binding pairs. Because of the difference in these distances, the binding pairs as a whole would experience much smaller forces from other bound or unbound fractional charges than they would experience in their formation as a binding pair.

Because there are three fractional charges in each nucleon, each nucleon could potentially be bonded in this manner with up to three other nucleons. Three bonding points is not very conducive to building three-dimensional structures. However, if two protons and two neutrons can form a ring (that would be an alpha particle), the ring as a whole would have four unused bonding points left over. A structure with four bonding points would be more amenable to building three-dimensional structures. A small ring of four nucleons could also be expected to be exceptionally stable because every nucleon is bound at two points.

This analysis is presented to challenge the early 1930s reasoning that led to the rejection of the electric force as the force that is holding the nucleus together. It is presented according to current scientific understanding that protons and neutrons having well-contained $+^{2}/_{3}$ e and $-^{1}/_{3}$ e charges, something that scientists had no idea of in the 1930s. However, this analysis does not depend upon those particular fractional charges being present or being the only ones that exist. The concept of electrostatic bonding of fractional charges is broader than that. It extends to include other fractions of charges that might be present in nucleons or other particles. It also extends to the possibility that the currently-observed fractional charges might actually be net charges of electrostatically bound charges of unknown composition. It further extends to the possibility of perfectly-matched bound pairs, meaning the pair has a net charge of 0. Bound pairs with a net charge of zero would not be visible under normal conditions, and so the deep inelastic scattering tests that found evidence of fractional charges might not have been able to detected them. While perfectly-matched pairs are probably not binding nucleons to each other, they might be providing structure within the nucleons. The visible fractional charges could merely be loose ends that are unbound or that are not perfectly matched within each nucleon. So whatever fractional charges and structures may be found in the future, the analysis above could be modified accordingly.

Table 3 summarizes and compares the traditional nuclear force with electrostatic binding of fractional charges.

<u>The question of gravity</u>

Gravity is also an inverse-square law force. The question of whether gravitation could play a role in holding the nucleus together was raised and dismissed by [3] as “completely hopeless” and “too small to explain their attraction by a factor of 10^{37}.” However, this analysis was clearly based on the gravitational attraction between whole nucleons at whole nucleon distances.

I did not find any consideration of partons that are not separated by whole nucleon distances, so that possibility will be considered here. The force equation for gravity is:

$$F = G\frac{M_1 M_2}{r^2} \qquad where\ G = 6.67384\times10^{-11}\frac{m^3}{kg\,s^2} \tag{4}$$

It takes the same form as equation (1), Coulomb's law, so it is easily seen that the force of gravity may also increase without bound as the distance r approaches zero. All that is required is two masses that are compact enough to get close enough and for the law of gravity to still hold at those distances. For each pair of masses, the knee in the curve will occur at a different distance depending on the size of the product of the masses.

For gravity to have this effect, a point mass must not merely be the mathematical center of a diffuse mass. The entire mass should be significantly smaller than the effective distance. If the mass is too diffuse, using the mathematical center would obscure the fact that the parts that are closer would experience far more attraction than the parts that are farther.

Even if the entire mass of a proton were a point mass, obtaining a gravitational force of -25 kN between two such point masses would require an effective distance of no more than 9 x 10^{-35} meters, according to equation (4). Thus, for gravitation to play a significant role, the supposed point masses would have to be on the order of a Planck length (1.6 x 10^{-35} m) apart. This suggests that any gravitational features would have to be roughly 20 orders of magnitude smaller than a nucleon. With no theory to span 20 orders of magnitude, gravitation in the nucleus appears to be no more than a mere mathematical curiosity.

Conclusion

This essentially classical, structural explanation for how the atomic nucleus may be held together challenges the three frequently-cited reasons for why the electric force can not be what holds the nucleus together. (1) As for insufficient strength, it was shown that an unheralded property of this inverse square law force is that as distance approaches zero the force increases without bound. This makes an electrostatic bond of any strength a theoretical possibility if oppositely signed fractional charges of neighboring nucleons can get close enough. (2) As to charge independence (and especially the participation of neutrons), these electrostatic bonds can form between any two nucleons because the necessary positive and negative fractional charges are now known to exist in both protons and neutrons. (3) As to the short range of the nuclear force, the same electric force that is commonly characterized by theoretically infinite range can also be characterized by theoretically infinite strength, but only at nucleon contact distances. When an electrostatic bond of fractional charges is broken the attractive force drops off so rapidly that the mutually-repulsive overall-forces predominate by the time the formerly bonded charges are about a nucleon radius apart.

Having thus shown that the electric force is capable of providing and explaining these three pivotal characteristics of the nuclear force, it follows that none of these three reasons for rejecting the electric force was as valid as first supposed. It appears then that the electrostatic force may in fact play a paradoxical dual role: (1) It urges the nucleus to blow apart where distances exceed contact distances and (2) it holds the nucleus together with electrostatic bonding of fractional charges at select points of nucleon contact. While the early nuclear electron models were flawed and needed to be rejected, had the early scientists thought of electrostatic bonding of fractional charges in 1932, they certainly would have looked into it before taking the drastic action of inventing a new fundamental force of nature.

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Table 3. Comparison of traditional nuclear force to electrostatic bonding of fractional charges.

Characteristic	**Traditional Nuclear Force**	**Electrostatic Bonding of Fractional Charges**
Description	A phenomenon entirely different from any known force; a short-range force; not an inverse-square law force.	An unappreciated property of the electrostatic force; an inverse square law force has a vertical asymptote too.
Strength	For example, 25,000 N	Can be whatever is needed, including 25,000 N
Distance corresponding to 25,000 N	About 1 fm	0.045 fm (between fractional charges).
When closer than maximum force distance	Becomes extremely repulsive. Is given credit for incompressibility of the nucleons.	Nucleons have a hard core. Something else must be making the nucleons resilient so this is not really part of the nucleon-nucleon force.
When farther than maximum force distance	Measured force drops off rapidly so that by about 2 fm (center-center) it becomes insignificant.	Computed force drops off rapidly so that by 1 fm (between fractional charges) it becomes insignificant. (1 fm between nearest fractional charges is very close to 2 fm center-center.)
Charge independence	Applies to P-P, P-N and N-N interactions because it seems to be charge-agnostic.	Applies to P-P, P-N and N-N interactions because in every one of those cases it is possible to find the necessary +2/3 e and -1/3 e fractional charges, even in neutrons.
Spin	Is sensitive to spin alignment.	Is sensitive to spin alignment.
Dual action of one force	Traditional nuclear force is deemed responsible for both attraction farther than about 0.8 fm and more intense repulsion nearer than about 0.8 fm, center to center.	The electrostatic force is capable of both net repulsion farther than about 0.15 fm and overwhelmingly intense attraction between fractional charges when closer than about 0.15 fm.
Effect of dual action	The same traditional nuclear force is deemed responsible for both holding the nucleus together and giving the nucleus its volume.	The same electrostatic force is responsible for both making the nucleus want to fly apart and for bonding neighboring nucleons together.