Unexplored ways the atomic nucleus may be bound

Peter Horst Rehm

Abstract

The first theories of atomic nuclear cohesion entailed electric forces binding together protons with a few electrons in the nucleus. The 1932 discovery of neutrons destroyed that line of thinking. The evidence suggested a new fundamental force of nature characterized by operation on both protons and electrically-neutral neutrons, with a very short range, and overpowering strength. Presented herein are novel and non-obvious structures that show these characteristics could nevertheless be manifestations of the electrical force. Protons and neutrons are now known to each securely contain fractional charges of both signs. If two oppositely-charged fractional charges in neighboring nucleons can get within 5% of a nucleon radius, Coulomb's law predicts they will form an electrical bond strong enough to explain nuclear cohesion. Ironically, such electrical bonds would be characterized by the very phenomena that were thought to rule out the electrical force: participation of neutrons, nucleon-contact distances, and more powerful than overall proton repulsion. Such bonding also predicts saturation at three bonds per nucleon, particularly stable 4-nucleon rings, limited 3D structures of nucleons, and more. If fractional charges had been known in 1932, scientists would have adapted their theories of an electrically-bound nucleus before assuming that they had discovered a new fundamental force of nature.

Keywords nuclear structure · nucleon structure · fractional charges · nuclear force · Coulomb's law · quarks · strong force · residual strong force

Coulomb Labs
Orem, Utah
peter.rehm@CoulombLabs.com

1 Introduction

The 1932 discovery of the neutron caused physicists to abandon their theories of electric cohesion of the atomic nucleus. They gave three compelling reasons why there must be a separate, non-electrical nuclear force holding the protons together. However, when it became clear that both protons and neutrons contained multiple fractional charges of both signs, their original three compelling reasons were never reevaluated. It is the purpose of this paper to reexamine the three main reasons for abandoning all theories of an electrically-bound nucleus and to establish limits on how broadly that abandonment should be applied.

It is shown that in light of the existence of fractional charges of both signs in all nucleon, each of the three main reasons is flawed. The 1932 rejection of the electrical force should thus be limited to whole protons and whole neutrons when treated as fundamental particles. The need for this limitation is pointed out by presenting a counterexample and by pointing out how the counterexample causes some additional issues fall in place as well.

1.1 Historical background of the nuclear force

1.1.1 An electrically-bound atomic nucleus (1911-1932)

In 1911, physicists were astonished by Ernest Rutherford's discovery that the positive charges in matter were concentrated in a tiny nucleus [1]. It was immediately apparent that something mysterious was overcoming the tremendous mutual repulsion of the protons in the nucleus. The only forces known at the time were the electromagnetic force and gravity.

For about two decades, theories of the atomic nucleus were based on electric attraction made possible by electrons that were thought to be in the nucleus [2]. It was known that atomic mass was about twice what would be expected for the amount of positive charge in the nucleus [3]. This invited speculation that there were additional protons in the nucleus, along with a matching number of nuclear electrons that both masked the additional protons' charges and somehow held the nucleus together.

These models were not working out very well. Then, in 1932, the final blow came with James Chadwick's discovery of the neutron [4]. Now scientists were faced with another nuclear particle that was electrically neutral and yet it was participating in the force that held the nucleus together. Also, these neutrons explained the extra mass, taking away the mass that was thought to be additional protons and electrons acting as glue.

1.1.2 It must be a new fundamental force of nature (1932 on)

In [5], Rudolf Peierls said "After 1932 things were different; we knew of the neutron and we had to find a new law of force." "[I]t was immediately accepted by everybody that a new, and very strong, force was required to hold the nucleus together. There was never any doubt that there was some new force at work."

This was the birth of the nuclear force as a separate fundamental force of nature. It was the direct result of the phenomena being so different from the familiar electrical force that reconciliation at that time was impossible.

Nevertheless, understanding the nuclear force has also been a challenge. In [6] and [7], Professor Ruprecht Machleidt recounts a history of the nuclear force that starts in 1935 and chronicles many decades of struggle with various nuclear force theories. From then until now, it appears that no one ever seriously questioned the soundness of the conjecture that it could not be the electrical force.

In 1953, Robert G. Sachs began chapter 2 of his book Nuclear Theory [3] with the statement, "Completely convincing evidence for the existence of nuclear forces is given by the existence of stable nuclei, since the nuclei would otherwise be shattered by the coulomb repulsion between protons."

The same year, Blatt and Weisskopf wrote in page 2 of their book, Theoretical Nuclear Physics [8], that "The forces which hold a nucleus together cannot be ordinary electrostatic forces, since the (electrically neutral) neutrons are bound in the nucleus. The 'nuclear forces,' unlike the forces which hold an atom together, have no analogy in classical physics."

Also in 1953, Hans A Bethe asks in the title of his article [9], "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."

The placement this concept near the beginning of the various writings shows how fundamental this unquestioned concept is.

1.1.3 A new source of negative charges in the nucleus (1960s on)

Years later, opposite electric charges in nucleons were theorized independently by George Zweig [10] and Murray Gell-Mann [11]. However, they were not researching bonding between nucleons. The fractional charges were helpful to another theory called the eightfold way [11, 10, 12] and they also helped make sense of hundreds of newly discovered particles that clearly could not all be fundamental [13].

The theorized partons had just a fraction of the fundamental charge e, the charge of a proton. This was hard to swallow, so fractional charges were initially presented and then treated as mere mathematical fictions [14]. Gell-Mann later explained that he believed from the beginning that quarks were permanently confined within nucleons and could not be removed for individual examination, so he called them mathematical to avoid arguments from critics [15].

It took another decade before the fractionally charged quarks were viewed as physical entities [12, 16]. The nucleons (protons and neutrons) were probed and found to each contain three point-like charges. Each proton was found to have two $^{+2}/_{3}\,e$ and one $^{-1}/_{3}\,e$

charges, for a total charge of +1e. Each neutron was found to have one $^{+2}/_{3}$ e and two $^{-1}/_{3}$ e charges, for a total charge of 0 [14].

1.1.4 No reconsideration of electrical bonding in the nucleus

Unfortunately, this discovery of fractional charges of opposite signs in the nucleons somehow failed to trigger a reconsideration of the conjecture in which the electric force was rejected as possibly playing a role in holding the nucleus together. Instead, it appears that this 1930s conjecture was implicitly assumed to apply to the new fractional charges as well, or it was implicitly assumed that Coulomb's law did not apply to the fractional charges in neighboring nucleons in a classical way.

For example, in 2004, in a brief review of the history of physics in [17], 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 contrast, Wilczek said "Quarks were supposed to hardly notice one another when they were close together. . . ."

In 2014, Professor Machleidt put it this way in [18]: "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."

1.2 Characteristics of the force holding the nucleus together

The new force was first called the nuclear force. According to the cited and innumerable other sources, it has the following properties: It binds together neighboring protons and neutrons into atomic nuclei, and typically it does this without reaching across a nucleus. It is of such short range that at distances greater than about 2 fm (center-center) only the long-range electrostatic force remains significant. It is strong enough to overcome the collective electrostatic repulsion of the protons within the same nucleus. It is charge independent, meaning that it applies to proton-proton, neutron-neutron, and proton-neutron interactions, although only the latter seem to be found in nature. 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 'saturated' or subject to saturation, meaning that "not all pairs of nucleons within a nucleus can exert attractive forces upon each other" [8] and that "on the average, a nucleon forms at most three bonds" [3] with other nucleons.

It was understandable that the early theories of the electrical force holding the nucleus together were rejected. In the 1930s, all the evidence seemed to point elsewhere. When this collective conjecture was made, the first clue needed to conceive of a structure involving fractional charges inside the nucleons was about three to four decades away.

However, regardless of how valid or useful this conjecture was at the time, in practice it was applied too broadly. In legal writing, the term "overbroad" is used to describe a law or other writings that is too sweeping in its wording or application. It is important that laws be narrowly tailored for their intended purposes. In the United States at least, if a law is overbroad, such as criminalizing Constitutionally protected behavior, the entire law is subject to being struck down by a court. By analogy, the idea that the electrical force has been ruled out as a possible explanation for nuclear cohesion must not be applied any broader than the evidence supports.

This paper will deliberately stay away from terms such as quark, strong force and residual strong force because these terms call forth theory that was developed in rejection of an electrically bound atomic nucleus. The fractional charges have been found by deep inelastic scattering and that is enough to move forward with the counterexample.

1.3 The three compelling reasons

Ever since the discovery of the neutron there have been three phenomena that had no electrical explanation. These quickly turned into three compelling reasons why nuclear cohesion could not be electrical. They were described differently by different writers, but in essence the three phenomena that were seen holding the atomic nucleus together were these properties:

(1) Short range; doesn't reach across the nucleus; contact force

(2) Overwhelming strength; orders of magnitude stronger than the electrical force that is pushing protons apart

(3) Charge independence; participation of electrically-neutral neutrons

2 A counterexample: Electrostatic bonding of fractional charges

A nuclear structure is proposed in which the composite nucleons are held together by the electric forces alone. This structure may also lead to explanations for additional characteristics of the atomic nucleus that go beyond the three compelling reasons. Presenting a complete theory would be beyond the scope of this paper. It is thought to be enough to present a toy model or counterexample to the conjecture that the nucleus could not be held together by electrical forces. It is hoped that this may spawn further development of hypotheses and theories, and even a few experiments.

2.1 Short Range

The electrostatic force operates according to Coulomb's law, which describes the force between two charges q_1 and q_2 separated by distance r,

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

For convenience when being used with nucleons, equation 1 can be adapted to accept the charges in units of the proton charge (in which the charge of a proton is 1) and distance in the unit of femtometers, by swapping out the constant k with k_n (k for nucleons):

$$k_n = 229.50 \, \frac{N(fm)^2}{protoncharges^2} \tag{2}$$

The resulting force is still given in Newtons.

For q_1 and q_2 of opposite sign, as distance r approaches zero, equation (1) predicts that attractive force increases without bound, so

$$\lim_{r \to 0} k \frac{q_1 q_2}{r^2} = -\infty \tag{3}$$

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 sum of the radii of these atoms. For example, for two carbon atoms this would be on the order of $1.4^{-11}m$. The obstructions are the electron clouds that give atoms their volume.

Deep inside an electron cloud of an atom is an atomic nucleus, smaller than one ten-thousandth the size of the atom. In this femtometer ($10^{-15}m$) scale world of protons and neutrons, the zero distance approached by equation (3) is not obstructed by this electron cloud.

However, there are still conceptual obstacles to seeing the practical effect of the attractive forces increasing without bound.

A first conceptual obstacle is the practice of using center-center distances to describe the distance between nucleons. While there are instances of reporting center-center distances less than the sum of two nucleon radii, these are for reporting that the nuclear force becomes strongly repulsive at such short distances.

This leads to the second conceptual obstacle. The nuclear force has been given credit for the hard core of the nucleons. This conflates what conceivably might merely be a resilience of the nucleon to compression with the force that causes nucleons to stick together. A nuclear force that is reported to be increasingly repulsive at closer distances obscures what might really be experienced by the fractional charges.

When considering nucleon center-center distances, it appears that the nucleons have a resilience to compression that keeps the distance above 1 fm, center-center. Typical graphs of the nuclear force show a repulsive force that goes off the chart, providing no data below 0.5 fm.

Such graphs are similar in appearance to graphs that show chemical bond length settling at a distance with the lowest energy, with increasing energy at both longer and shorter distances. However, there is no evidence that nucleons behave like atoms in this manner. Deep inelastic scattering tests can be interpreted to suggest that nucleons have a hard core [12].

Typical nuclear force charts also make it difficult to appreciate a concept that could be shown on graphs of the electrical force if they extended closer to zero distance. When a graph of the electrostatic force extends closer to this unobstructed zero distance, at some point they should take a 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). Nucleon contact distances occur on the other (unfamiliar) side of that knee.

It is only at these close distances, well under the radius of a nucleon, that the electrical force starts to take on this unappreciated characteristic that appears to match the attractive portion of the known two-body nuclear force.

2.2 Overwhelming strength

The familiar part of the electrical force, according to Coulomb's law, always follows the horizontal asymptote as shown in Fig. 1. It is characterized by theoretically infinite range. The part of the electrical force that more closely follows the vertical asymptote is entirely unfamiliar. It is characterized by theoretically infinite strength.

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

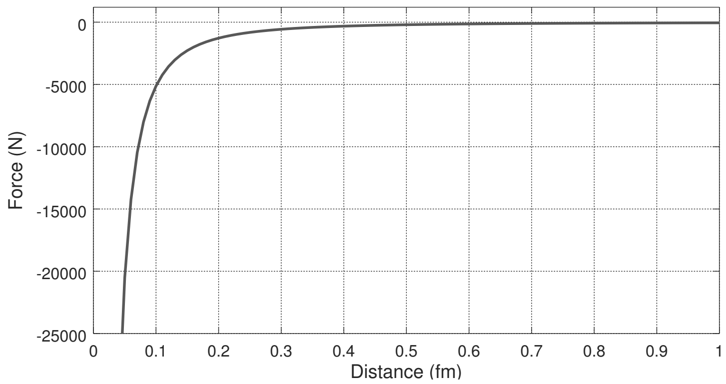

Fig. 1 The attractive electrostatic force between a $+\frac{2}{3}e$ charge in one nucleon and a $-\frac{1}{3}e$ charge in a neighboring nucleon as a function of distance. The Coulomb force grows quadratically as distance is reduced. At all familiar distances it follows the horizontal asymptote, but at nucleon contact distances it more prominently follows the vertical asymptote.

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 (with opposite signs) compared to the force that wants to blow it apart (with same signs).

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 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). At nucleon contact distances, according to the equations (1) and (3), 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

Table 1 Calculated repulsive (positive) force between whole protons based on traditional center charges and center-center distances.

Charges	Distance	Coulomb Force
Two protons	2.5 fm	37 N
Two protons	2.0 fm	58 N
Two protons	1.74 fm (two nucleon radii)	76 N

Table 2 Calculated forces between fractional charges at finer distances. Negative forces are attractive.

Charges	Distance	Coulomb Force
Two $^{-}\frac{1}{3}e$ charges	0.87 fm (one nucleon radius)	34 N
Two $^{+}\frac{2}{3}e$ charges	0.87 fm (one nucleon radius)	135 N
$^{+}\frac{2}{3}e$ and $^{-}\frac{1}{3}e$ charges	0.87 fm (one nucleon radius)	-68 N
$^{+}\frac{2}{3}e$ and $^{-}\frac{1}{3}e$ charges	0.2 fm	-1300 N
$^{+}\frac{2}{3}e$ and $^{-}\frac{1}{3}e$ charges	0.1 fm	-5100 N
$^{+}\frac{2}{3}e$ and $^{-}\frac{1}{3}e$ charges	0.087 fm (10% of nucleon radius)	-6800 N
$^{+}\frac{2}{3}e$ and $^{-}\frac{1}{3}e$ charges	0.045 fm (5% of nucleon radius)	-25000 N

that would generate the needed or observed force can be determined by solving the equation (1) for the distance r:

$$r = \sqrt{k\frac{q_1 q_2}{F}} \tag{4}$$

For example, if the observed binding force is 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 [19], when nuclear fission was discovered it could also be described in an essentially classical way.

2.3 Charge Independence

According to [18] [9] and others, 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 the neutron was first discovered, it was immediately apparent that neutrons participated in the force that was holding the nucleus together. The deuteron provided direct evidence of a n-p force. There was no such direct evidence of an attractive p-p or n-n force, so it was initially assumed that the nuclear force was a neutron-proton force only [5]. It took a few more years to discover the charge independence property of the nuclear force.

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 that knows only the net charges of nucleons, it seems that all of the electrostatic forces that are present 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.

However, many decades later, 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 [14]. 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.

In Fig. 2, configurations (a) and (b) show PN bonds that potentially might occur in nature. It should be possible to devise an experiment to distinguish them because the fractional charges are distributed quite differently. During formation of such a bond between a free proton and a free neutron that are approaching each other, there would have to be wide ranges of velocity and distance at which the overall positive charge of the proton would cause the neutron to rotate to present a negative fractional charge for bonding. This would in turn rotate the proton to match it. Thus, configuration (a) might be the most common or even the exclusive

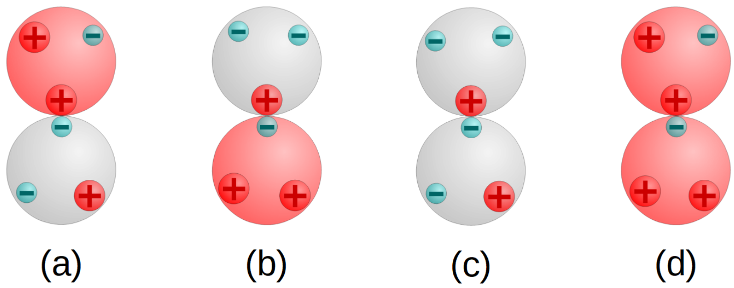

Fig. 2 Schematic diagram showing that there are four distinct configurations of two nucleons experiencing electrostatic binding between fractional charges. The bonds are where the nucleons touch. Protons are shaded in red. The $^{+2}\!/_{3}\,e$ charges are shown larger than the $^{-1}\!/_{3}\,e$ charges only to represent greater charge, not to imply an actual size or shape. This schematic ignores spin.

configuration found in natural deuterium nuclei. Nevertheless, if deuterons were formed outside that wide range of velocities or can be constructed artificially under extreme conditions, perhaps it is possible find or create PN bonds of configuration (b), making it possible to confirm the existence of both types. Configurations (c) and (d) have been tested but do not occur in nature.

3 Additional issues that fall into place or are food for thought

The following issues were not among the three compelling reasons for rejecting the electrical force, but they are worthy of consideration either because they explain more phenomena or are otherwise worthy of discussion.

3.1 Saturation

It has been known for a long time that a nucleon has a limited number of bonds that it can form. This is known as the saturation property. In [3], Sachs says that the average number of bonds per nucleon is the same as that in the alpha particle, and that on the average a nucleon forms at most three bonds with other nucleons.

Electrostatic bonding of fractional charges is consistent with the saturation property because there are three fractional charges in each nucleon. Each nucleon therefore could potentially be bonded in this manner with up to three other nucleons. One can imagine that this can result in various structures that may or may not be found in nature.

3.2 The alpha particle and its stability

If two protons and two neutrons can form a ring, it could be expected to be exceptionally stable because every nucleon is bound at two points. This would be an alpha particle. The ring as a whole would have four unused bonding sites left over, always two $+2/_3\,e$ charges and two $-1/_3\,e$ charges.

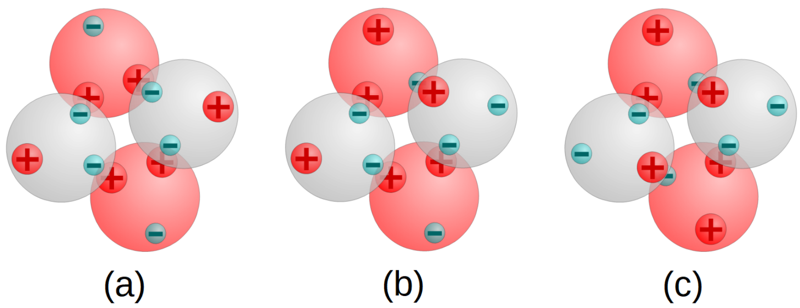

Fig. 3 Schematic diagram showing three distinct ways that an alpha particle may be bound in a ring. Configuration (a) seems the most normal because both protons are bound with their positive charges. In (b) one of the protons is oddly bound with its negative charge and in (c) both protons are oddly bound with their negative charges.

In Fig. 3, there is no suggestion that all of these configurations are found in nature. As with the deuteron, nature may favor a particular arrangement. Because of the differences in the locations of the fractional charges it should be possible to devise an experiment that can distinguish them from one another. It should be used to test alpha particles from many kinds of alpha-emitting sources as well as naturally-occurring sources of helium. If a variety does exist in nature, it would be interesting to determine the ratios that the configurations come in, and to see if there is consistency in the ratios among the various sources of alpha particles. Perhaps this could even provide clues about the formation of our various reserves of natural helium.

3.3 Formation and stability of larger structures

Depending on how the four bonding points of an alpha particle are arranged, they might be more amenable to building three-dimensional structures than a structure with only three bonding points, such as a bare nucleon. Four points don't have to lie in a plane.

A fifth nucleon bound to only one of these four remaining bonding sites would not enjoy the same stability because it is not part of the ring.

A sixth nucleon could also be bound elsewhere at only one point. However, if four nucleons can make a ring, it is feasible to suppose that a sixth nucleon that is bonded on another one of the ring's four remaining bonds in some cases might also be able to bond to the fifth nucleon as well, forming a second ring and enjoying increased stability.

If this continues at higher numbers of nucleons, it might shed some light on the superior stability of nuclei with an even number of nucleons and certain other magic numbers of nucleons.

It is even possible to imagine that in some nuclei that a nucleon could be bound on only one place, flopping around in a way that results in the ability to "walk around" by forming a new bond just as it breaks an old one. If the old bond can only break as a new bond is being formed, the nucleus would be stable even as its structure changes. If such behavior is common, it would make the nucleus behave like a liquid drop in at least some ways.

These bonds may be expected to provide some of the properties of a lattice structure, such as rigidity. However, known lattice structures have coordination numbers that represent the number places that a member touches another member, and these coordination numbers range from 6 to 12. Fractional charge bonding provides only 3 bonding sites, with no facility for sharing, so if the nucleons are proximate or "touch" in more places they would do so without additional bonds. This situation may shed some light on the discrepancy described by Norman Cook in [20] between what is known of two body nucleon-nucleon forces and the properties of larger nuclei.

Thus we can predict that fractional charge bonding would provide some of the characteristics of a lattice and some of the characteristics of a liquid drop, without providing all of the characteristics of either of them.

3.4 Spin

The foregoing has ignored spin even though spin certainly plays a role in the strength of the bonds between fractional charges. It can be expected that some of the strength of a bond arises from favorable spin alignment. Where spin alignment is not favorable the bond would be weaker or not commonly found in nature or maybe even not possible at all.

If favorable spin alignment can only be found in proton-neutron bonds, it might explain why it was difficult to find evidence of proton-proton and neutron-neutron bonds and why these are not seen in nature.

3.5 Ratio of protons to neutrons

Since fractional charge bonding consumes positive and negative fractional charges in pairs, it follows that in larger nuclei the ratio of positive to negative fractional charges is limited in how far it can depart from 1, unless there is some other effect in play.

When the number of protons matches the number of neutrons in a nucleus, the total number of positive fractional charges matches the total number of negative fractional charges. Many of these would be bound and some would be unbound sites. This is the tendency for nuclei up to about 20 protons (Z=20).

For nuclei with more than 20 protons, the tendency is for there to be more neutrons than protons. One possible reason might be the total positive charge of the nucleus starts to favor neutrons because they do not add stress to the total.

A second reason might be a call to reevaluate the possibility of electrons being trapped in an overwhelmingly positive nucleus, making it appear that the ratio is off further than it really is.

While the pre-1932 theories of many extra proton-electron pairs in the nucleus have been thoroughly falsified, this is a different issue. Even valid falsifications should be construed narrowly so they are not inadvertently extended to apply to a different phenomenon. The overwhelmingly positive charge of a proton-rich nucleus may be strong enough to have another electrical mechanism to capture an electron. This might happen with or without bonding it to any particular fractional charge(s). Such an electron in the nucleus would offset the charge of a proton and would thus be difficult to distinguish from a neutron or from the conversion of a proton into a neutron.

3.6 Other types of bonds or failure to bond

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 have 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 any fractions of charges that might someday be theorized or discovered to exist in nucleons or other particles.

The probing of the neutron could only be performed by probing neutrons that were bound to protons and subtracting out what was found from probing the protons alone [12]. Thus, there is the possibility that fractional charge bonding hid some of the charges. So the concept of fractional charge bonding also extends to the possibility that the currently-observed fractional charges might actually be net charges of electrostatically bound charges of unknown composition.

If for some reason two charges cannot get close enough, they would be unable to bond. This would then be seen as not participating in the strong nuclear force.

The series of inelastic scattering experiments that provided evidence of the three fractional charge quarks (the valence quarks) also provided evidence of a "sea of quark-antiquark pairs". This sea was common to both protons and neutrons. Because the fractional charges of these pairs added up to zero, they were treated as not interacting electrically [12].

According to fractional charge bonding, such pairs of equal and opposite charges should not be treated as electrically neutral up close. It raises the question of whether they are bound to each other electrically, or whether they are bound together by some other means that makes them come in pairs. If the latter, then does this mean they have fractional charges available to form chains of such pairs? Such chains of perfectly-matched pairs would be virtually invisible, except that the ends of the chains would have visible (valence) charges. This might what provides structure within nucleons. Thus, the total absolute value sum of the charges present in a proton or neutron could be significantly greater than what is now known from only the valence charges, which is already greater than their net charge.

If a sea of perfectly-matched pairs are hit with enough energy to separate them, then the individual fractional charges would become detectable, appearing to come out of nowhere.

4 Discussion

What is presented here is thought to be at least a prima facia case or toy model that a potentially viable explanation for nuclear cohesion has been left unexplored. It is entirely understandable that it would be missed. There was no evidence of fractional charges in the 1930s.

Instead, generations of other theories have been explored. They have not fared very well at all. In [6], Professor Machleidt called the "nuclear force problem" a history of "hope, error, and desperation." Theories were "judged as failures" and at times "attempts to derive the nuclear force started all over again."

A generation or two after the discovery of the neutron, the memory of an electromagnetic nucleus was so distant that purely mathematical suggestions of fractional charges did not trigger reconsideration of the electrical force nuclear theories of the 1920s.

Electromagnetic bonding of fractional charges can be expected to be incompatible with the various generations of nuclear force theory that developed after the discovery of the neutron. This is why fractional charges are not referred to herein as quarks. The term quarks certainly carries with it too much incompatible theory. Just the fact that fractional charges of both signs have been detected in actual experiments is enough for this paper. Even the exact number or sign or strength of them is not necessary for the prima facia case to be made.

Fractional Charge Bonding can be compared to the nuclear strong force in the following ways:

Description

The nuclear force was described as “A phenomenon entirely different from any known force,” “a short-range force,” and “not an inverse-square law force.”

Fractional charge bonding could be described as an unappreciated property of the electric force, because an inverse square law force has a vertical asymptote too. This mathematically predictable vertical asymptote has not been adequately explored.

Strength

Binding energies are typically given in MeV. When converted to Newtons the force can be as much as 25,000 N. The nuclear force has been described as 40 to 100 times stronger than the electrical force pushing protons apart[9].

Fractional charge bonding can theoretically produce whatever attractive force is necessary. If the force can be determined experimentally then this sheds light on the distance between fractional charges.

Distance

With the nuclear force, the distance between nucleons is usually given as center-center distances. Sometimes this results in center-center distances somewhat less than the sum of two radii. In any case, at these distances the behavior of the electrical force below 0.15 fm is hidden.

Fractional charge bonding is based on distances between fractional charges, so the distances can be much shorter than center-center distances. This brings the full behavior of the electric force into play.

Incompressible nucleus

The nuclear force was given credit for the incompressibility of the nucleus. It was said that the nuclear force became strongly repulsive at distances below about 0.7 fm.

In contrast, fractional charge bonding returns to the early notion that the nucleons have a rigid or hard core that is independent of the force that holds nucleons together [12].

Short range

It was known that the nucleus operates between neighboring nucleons and does not reach across the nucleus. Sources vary on just how far it reaches.

With fractional charge bonding it is possible to compute the force according to Coulomb's law. For static fractional charges, it loses its overwhelming significance with even one nucleon radius of separation.

Participation of neutrons

To this day, the participation of electrically-neutral neutrons is used to show that the electrical force cannot be what holds the atomic nucleus together and that it must be the work of a some other force of nature.

For fractional charge bonding, the electrical participation of neutrons is a natural result of bonding at proximities where the total charge of a nucleon is irrelevant. Neutrons are not electrically neutral at contact proximities.

Charge independence

The nuclear force affects both protons and neutrons the same when compensating for electric charge. There is evidence the nuclear force can be seen in n-n interactions and (after compensating for proton repulsion) p-p interactions.

Fractional charge bonding can explain this property by ignoring the net charge of the nucleons and focusing on tiny but intense bonds between oppositely charged fractional charges that are found in both protons and neutrons.

Spin

Both the nuclear force and fractional charge bonding are sensitive to spin alignment. It is possible to theorize rules of proton and neutron spin alignment that would explain why proton-proton and neutron-neutron bonds are not found in nature.

Dual action of one force

The 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.

In contrast, 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 traditional nuclear force is deemed responsible for both holding the nucleus together and giving the nucleus its volume.

In fractional charge bonding, the same electrostatic force is responsible for both making the nucleus want to fly apart and for bonding neighboring nucleons together.

5 Conclusion

It is not the purpose of this paper to present a new, fully-formed theory of nuclear cohesion. It is thought to be enough to call into question the 1930s falsification of an electrically-bound nucleus and also to call into question the reasons given for why the nuclear force was thought to be a separate fundamental force of nature.

This classical-leaning, structural explanation for how the atomic nucleus may be held together challenges the 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 participation of neutrons, both protons and neutrons contain both positive and negative fractional charges. The sum of the charges of a nucleon should not be expected to be controlling. (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 dominate 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.

Electrostatic bonding of fractional charges can also explain additional characteristics of the nuclear force such as charge independence and saturation at three bonds per nucleon. It appears then that the electrostatic force may in fact play a paradoxical dual role: (1) to urge the nucleus to blow apart because of overall excess positive charge and (2) hold the nucleus together with electrostatic bonding of oppositely-signed fractional charges at select points of nucleon contact.

The early (pre-1932) electrical models of the nucleus were flawed and needed to be rejected. But if in 1932 scientists had thought of electrostatic bonding of fractional charges, they certainly would have looked into it and written about it before taking the drastic action of inventing a new fundamental force of nature.

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