The Electromagnetic Considerations of the Nuclear Force—PART II: The Determination of the Lowest Energy Configurations for Nuclei

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Abstract

This paper explores how the electromagnetic energies of the quarks within the atomic nucleus affect the behavior of the Nuclear Force. By examining the electromagnetic energies and forces, many questions about nuclear behavior can be answered, and many insights into the atomic nucleus can be gained. Previous theoretical models for the Nuclear Force include only the Coulomb electric force of the protons, but with little or no consideration of the electromagnetic characteristics of the quarks. By incorporating the electromagnetic energies and forces into nuclear theory, this model has been able to achieve predictions of binding energy better than any previous model, doing so by using only one parameter instead of the five parameters used in the semi-empirical Weizsäcker formula of the Liquid Drop Model. The Electromagnetic Model unifies the Nuclear Force to the Electromagnetic Force.

The Electromagnetic Model of the Nuclear Force includes the calculation of electromagnetics of the quarks, and by doing such, it is shown that the Nuclear Force is significantly influenced by the Electromagnetic Forces of the quarks. This paper, Part II of this series, illustrates the ground state configurations of the atomic nuclei, showing the basic segments of how the protons and neutrons cluster together, and how these segments bond to form larger atomic nuclei. A pattern emerges for the ground state configurations due to the uniformity of the electromagnetic laws. Diagrams are shown for this basic pattern, for both stable and radioactive atomic nuclei. By incorporating the electromagnetic energies and forces into nuclear theory, this model has been able to achieve not only excellent predictions of binding energy, but the ability to answer many other questions regarding the various behaviors of atomic nuclei.

Keywords—electromagnetics, Nuclear Force, quarks, nuclear molecules, clustering, nuclear diagrams, lowest energy state

1. Introduction

THE Nuclear Force is the force which binds the protons and neutrons together in the atomic nucleus. The Electromagnetic Model of the Nuclear Force states that the Nuclear Force is a direct result of the Electromagnetic Forces of the quarks within the nucleons. The model further answers and clarifies how this Electromagnetic Force is able to achieve nuclear bonding. Historical objections and misunderstandings regarding the Electromagnetic Force within atomic nuclei are answered and clarified in Part I of this series on the Electromagnetic Considerations of the Nuclear Force [1]. Thus, it is recommended that the first paper in this series is reviewed and understood, prior to continuing with this second paper.

In this second paper, the ground state configurations of the atomic nuclei are determined and illustrated, to show the basic segments of the clustered protons and neutrons and the bonding of the segments. The lowest energy configurations of the atomic nuclei are determined by using the laws of electromagnetics as applied to the quarks. Because thermodynamics insists that the configuration of the atomic nuclei are in their lowest energy states, a determination of these lowest energy states is necessary before a better understanding of the subsequent nuclear behavior can be achieved. Unless a Nuclear Force model describes the lowest energy configuration of nuclear structure, then the results for that model are irrelevant, and such approaches are not realistic for the proper consideration of binding energy and other nuclear behaviors. For a genuine and credible understanding of any structured atomic nucleus, the lowest energy configuration must first be determined. This lowest energy configuration is strongly dependent upon the forces and energies, and the associated equations, within the atomic nucleus. Thus, any type of nuclear behavior cannot be properly determined unless there is a mathematical formulation of these forces and energies internal to the atomic nucleus to determine the lowest energy. In this paper the lowest energy configuration of the structured atomic nucleus is determined by using the electromagnetic equations applied to the electromagnetic forces and energies of the quarks.

This Electromagnetic Model of the Nuclear Force assumes the laws of electromagnetics are valid inside an atomic nucleus, and that these laws should not be disregarded. This model asserts that the electromagnetic properties of the quarks are significantly responsible for holding the nucleons together in an atomic nucleus. The thermodynamics of the electromagnetic energies of the quarks cause the atomic nuclei to fall into the lowest energy state and configuration. Therefore, to understand nuclear behavior of the atomic nuclei, the lowest energy state must be known. The lowest energy configurations of the atomic nuclei are responsible for giving the atomic nuclei specific behaviors—such as the unique shape of the binding energy curve, the large quadrupole moments, excited states, and particle decay.

When taken into full account, rather than being disregarded and ignored, the Electromagnetic Forces of the quarks can explain much about nuclear behavior. The role of electromagnetics within the atomic nucleus is a field that deserves further research and serious analysis by theoretical nuclear physicists. This paper serves as further on-going theoretical investigations into the electromagnetic considerations of the Nuclear Force.

In this paper, the lowest energy state configurations of the atomic nuclei are determined and illustrated, showing the basic segments of how the protons and neutrons cluster together to form the larger atomic nuclei. The lowest energy configurations of the atomic nuclei are determined by using the laws of electromagnetics as applied to the quarks.

1.1. Definition, Explanation, and Clarification of Terms

The "Nuclear Force" is the force that binds together the protons and neutrons in an atomic nucleus. Historically, the Nuclear Force was called the "Strong Nuclear Force", and it was considered to be one of the four forces of nature—along with the Gravitational Force, the Electromagnetic Force and the Weak Nuclear Force. Soon after the discovery of quarks, a force called the "Chromodynamic Force" was used to describe that force which holds the quarks together inside a proton or neutron. The Chromodynamic Force is considered to be much stronger than the Nuclear Force. In the 1970's, the term "Chromodynamic Force" was changed to the term "Strong Nuclear Force". The "Strong Nuclear Force" is now used to describe the behavior and interactions of all sub-particles contained inside of a proton or neutron, such as quarks, gluons, and other partons. The name of the force that holds the protons and neutrons together in an atomic nucleus was also changed to the "Nuclear Force", also known as the Nucleon-Nucleon Force . Unfortunately, this series of name changes has caused much confusion.

Even more confusing, one model of the Nuclear Force is called the "Residual Strong Force", also known as the "Residual Chromodynamic Force". For clarity to the reader in this paper, the terms "Strong Force" and "Strong Nuclear Force" will not be used, since they are confusing and ambiguous terms. Rather the term "Quantum Chromodynamic Force" will be used to reference the force that holds together the quarks inside a proton or neutron. The term "Nuclear Force" will be used to describe the force that holds together the protons and neutrons in an atomic nucleus. The term "Residual Color Force" will be used to describe the one specific model of the Nuclear Force, which is also known as the "Residual Strong Force".

Linguistically, it is also unfortunate that the words "neutron", "nucleon", "nucleons", "nuclides", "nuclei", "nucleus", and "nuclear" are all so similar. This similarity makes it easy for a reader to misread them and misunderstand what is being communicated. To mitigate the confusion between these linguistic similarities terms, the term "protons and neutrons" will occasionally be used instead of "nucleons". Also, the terms "atomic nucleus" or "atomic nuclei" will be used instead of "nucleus", "nuclide", "nuclides" or "nuclei". (Other writers often use the word "isotopes" to mean "nuclides" in order to avoid this same confusion; however, since that is a misuse of the word "isotope", this will not be done for this paper.)

Another source of confusion is caused by the similarity of the terms "Chromodynamic Force", and the "Residual Chromodynamic Force". Thus, to prevent confusion, the terms "Residual Color Force", and "Quantum Chromodynamic Force" will be used to better distinguish these two different forces for the reader. The Quantum Chromodynamic Force is the force inside of the protons and neutrons, and it holds the quarks together in a proton or neutron. The Nuclear Force is outside of the protons and neutrons, and it holds the protons and neutrons together in an atomic nucleus. There are many models of the Nuclear Force, one of which is the Residual Color Force. It is related to the Quantum Chromodynamic Force, theorized to be caused by virtual pi-mesons going back and forth between the protons and neutrons. It is thought to be similar to the van der Waals force for molecules. The "Quantum Chromodynamic Force", which is the force that holds the quarks together inside of a proton or neutron.

This paper is about the Nuclear Force, the force that holds the protons and neutrons together inside an atomic nucleus.

This paper is not intended to be an overview, an explanation, or a tutorial of the Quantum Chromodynamic Force or of the Weak Nuclear Force. For a detailed review and explanation of the Quantum Chromodynamic Force model, see [2, 3]. For a review and explanation of the Weak Nuclear Force model, see [4].

1.2. The Electromagnetic Model of the Nuclear Force and the Intent of this Research

The Electromagnetic Forces cause the atomic nucleus to fall into the lowest energy state and lowest energy configuration. It is asserted that this electromagnetic energy, as well as the specific lowest energy configurations of the atomic nucleus, are the attributes that dictate the nuclear behaviors—such as binding energy, large quadrupole moments, excited states, and particle decay.

Rather than disregarding the Electromagnetic Forces of the quarks, when taken into full account and understanding, the Electromagnetic Forces inside an atomic nucleus can explain much about nuclear behavior. By applying this knowledge and insight, a better understanding and explanation of the nuclear behaviors can be gained through this model.

The role of electromagnetics within the atomic nucleus is a research field that deserves further analysis and serious consideration by theoretical nuclear physicists. This paper serves to advance the theoretical investigations into the electromagnetic considerations of the Nuclear Force.

For detailed calculations of the electromagnetic internucleon quark-to-quark energies, please refer to Part I of this series of papers on the Electromagnetic Considerations of the Nuclear Force. These detailed calculations will not be repeated in this paper. Rather only a brief review of the electromagnetic energies will be given here.

The intent of this paper, as well as for the series of papers about the Electromagnetic Considerations of the Nuclear Force, is to explore how much of nuclear behavior can be explained by the Electromagnetic Force. In other words, the goal is to explore what fraction of the Nuclear Behavior can be explained by the Electromagnetic Force.

It is not the intent of this paper to explore the Residual Color Force. Other theoretical research groups have explored the theoretical Residual Color force, with only minimal success in duplicating experimental data, as is discussed in the appendix. To repeat this extremely difficult task of exploring the Residual Color Force is not the intent of this paper. Rather, the intent is to explore how much of the nuclear behavior can be explained by the Electromagnetic Force. That is the intended endeavor this entire series of papers.

For that reason, the force between nucleons is assumed, from the onset, to be an internucleon quark-to-quark Electromagnetic Force. Using that assumption, the resulting predicted nuclear behavior is examined and compared with the actual experimental data. This is why the Residual Color Force Model—or any of the other numerous models of the Nuclear Force such as the Liquid Drop Model, the Shell Model, or the Effective Field Models—are not included in the calculations for the simulations in this paper. The intended endeavor of this series of papers about the Electromagnetic Considerations of the Nuclear Force is to learn what parts of nuclear behavior can be explained by the Electromagnetic Force.

1.3. A Clarification of Chromodynamic/Color Forces

A clarification should be made here. The topic of this paper is the Nuclear Force, that force which holds the protons and neutrons together in an atomic nucleus. The subject of this paper is the lowest energy configurations of atomic nuclei, as determined by the Electromagnetic Force. The information described in this paper is consistent with the current theories and models about the Quantum Chromodynamic Force, quark containment, the Standard Model, and the Weak Nuclear Force. Thus these topics are not reviewed in this paper; readers interested in these topics are referred to other scientific papers for more information on these ancillary topics.

A further clarification must be made regarding the Quantum Chromodynamic Force and the Residual Color Force. The Quantum Chromodynamic Force acts inside the protons and neutrons. It is believed, by current models, that the Quantum Chromodynamic Force also has a residual force, which is called the Residual Color Force in this paper. The Residual Color Force acts outside the protons and neutrons. The Quantum Chromodynamic Force and the Residual Color Force are related to each other, but they are not exactly the same force. The two forces are related because they are both associated with the color of the quarks; however, a distinction between these two forces should be made. The Quantum Chromodynamic Force is mediated by massless gluons, it is extremely strong, and it has a long range. The Residual Color Force is thought to be mediated by virtual pi-mesons, it is much weaker than the Quantum Chromodynamic Force, and it has a very short range. Although both forces are related to quark color, one force is inside the protons and neutrons and the other force is outside the protons and neutrons. Also, they have different strengths, ranges, and mediating particles.

1.4. A Brief Review of Quarks

In 1964, the existence of quarks was proposed independently by Gell-Mann and Zweig [5, 6, 7], changing the concept of the proton and neutron from homogeneously-charged particles to particles having electrical inhomogeneity. A proton is made up of three quarks, two up quarks and one down quark. A neutron is also made up of three quarks, two down quarks and one up quark. Up quarks have an electrical charge which is 2/3 of an elementary charge. Down quarks have a charge which is -1/3 of an elementary charge. The electrical charge and magnetic moments of a proton or neutron are confined to the quarks, rather than being homogeneously distributed.

Gell-Mann believed that quark charges could be localized, and Richard Feynman asserted that high energy experiments showed that quarks are indeed real particles. Feynman surmised the quarks have a distribution of position or momentum, like any other particle, and he correctly believed that the diffusion of quark momentum explained diffractive scattering. James Bjorken proposed that point-like partons would imply certain relations in deep inelastic scattering of electrons and protons, which were verified in experiments at SLAC in 1969. Thus, it is believed that the quarks have a distribution of position and momentum, due to uncertainty principles. However, when averaged over time, they can be modeled as point-like particles within those same distributions. This is an important concept to understand, and it is related to the Expectation Value of the position of the quarks, when the probability function of the quarks is analyzed and averaged over time. Stated again for clarity, there are quantum fluctuations, due to the uncertainty that is inherently involved; however, the position of the quarks can nonetheless be modeled as a point-like charge.

Quarks have both color and electric charge. (The word color does not mean an actual visual color, rather the word color is simply a quantum attribute of the quarks—either red, green, or blue.) The Quantum Chromodynamic Force controls the quarks and confines the quarks, and it is dependent upon the color of the quarks. The Quantum Chromodynamic Force is a very confining and powerful force, and it controls and confines the quarks. Outside of the proton and neutron, only a slight residual of the Quantum Chromodynamic Force remains; however, when that slight residual force is outside of the nucleon, it is called the "Residual Color Force". (To avoid confusion, the residual force should be thought of, conceptually, as a different force—one that is related to, but different from, the Quantum Chromodynamic Force. This is similar to the way the van der Waals force is conceptually different from the Electromagnetic Force.) Also outside of the proton and neutron, and also related to the quarks, is the electromagnetic force. The Electromagnetic Force is a long range force and it does not abruptly "turn itself off" or neutralized itself at the edge of the proton or neutron. Conversely, the Quantum Chromodynamic Force does essentially neutralized itself at the edge of the proton or neutron. To reiterate, the Quantum Chromodynamic Force abruptly changes to almost zero at the edge of the nucleon, but the Electromagnetic Force continues outside of the nucleon, unaffected by the edge of the nucleon.

It is important for the reader to understand that the quarks have both a color and an electric charge. Because the quarks inside the nucleons are in the three colors of red, green, and blue, this causes the protons and neutrons to be color neutral. Thus, the Quantum Chromodynamic Force, which is due to the color of the quarks, behaves with an abrupt step-like function near the edge of the nucleon, dropping suddenly to almost zero. In contrast to that, the Electromagnetic Force, and its associated electromagnetic field, are unaffected by the edge of the nucleon. The Electromagnetic Forces of the quarks, therefore, continue to be felt by all of the other quarks in the atomic nucleus, and these Electromagnetic Forces have an influence on the other quarks within the entire atomic nucleus.

The Quantum Chromodynamic Forces is inside of the nucleon, and it is what controls and contains the position of the quarks, inside of the proton and neutron. The electromagnetic charges of the quarks do not contain and control the quarks inside the proton or neutron. However, the electromagnetic charges of the quarks are felt outside of the proton and neutron, whereas the Quantum Chromodynamic Force is not. The Electromagnetic Force of the quarks extend beyond of the edge of the nucleon, essentially unaffected by it. The Electromagnetic Forces, thereby, can electromagnetically attract or repulse the other quarks in the atomic nuclei. That attractive or repulsive force depends on the polarity of the associated electric charges and magnetic dipoles of the quarks.

As a result, a quark that is inside of one nucleon, feels the electromagnetic influences of a quark that is inside of another nucleon, in a quark-to-quark internucleon force. Those two quarks, which are in two different nucleons, are contained within their two different respective nucleons by the Quantum Chromodynamic Force, which acts inside of the nucleon. However, these two same quarks are influenced by each other due to the electromagnetic forces outside of their respective nucleons. Furthermore, that electromagnetic influence can be either attractive or repulsive.

1.5. Current Concepts Regarding the Quantum Chromodynamic Force

The Quantum Chromodynamic Force is thought to be much stronger than the Nuclear Force, by several orders of magnitude. However, an actual definitive measurement of the strength of the Quantum Chromodynamic Force has not been made because particle physicists have been not able to separate the quarks from inside a nucleon. Presently there are numerous theoretical models about what is inside a nucleon, which are not only quite complex, but also conflicting. Particle physicists believe that there might be several hundred non-valence quarks inside a nucleon. In this paper, only the three valence quarks are considered.

1.6. The Numerous Models for the Nuclear Force

Currently, there is no one theory of the Nuclear Force that can explain all of nuclear behavior [8, 9]. Rather, there are numerous models for the Nuclear Force, each one describing one or two specific aspects of nuclear behavior. Even with these numerous models, there are still many nuclear behaviors that remain unexplained. A brief review of the numerous other models of the Nuclear Force is given in Part I of this series on the Electromagnetic Considerations of the Nuclear Force, and will not be repeated here. Another excellent and comprehensive review of the numerous models of the Nuclear Force is given by Cook [10]. One of the many models of the Nuclear Force is the Residual Color Force Model.

1.7. The Residual Color Force Model

The Residual Color Force Model is based on the concept that the Nuclear Force is a residual of the Quantum Chromodynamic Force. The Residual Color Force Model is similar to the meson exchange model of 1935, in that the force is believed to be due to an exchange of virtual pi-mesons.

Of the numerous models of the Nuclear Force, the Residual Color Force Model is one of the few models that incorporates the concept of quarks, thereby making it consistent with the Standard Model. Unfortunately, there is no closed mathematical form for the Residual Color Force, and it is extremely difficult to calculate any type of nuclear behavior.

As described previously, the Quantum Chromodynamic Force is the force that holds the quarks together inside the proton or neutron, mediated by gluons. In contrast, the Residual Color Force occurs outside the protons and neutrons, mediated by virtual pi-mesons. The Residual Color Force Model theorizes that the Residual Color Force binds the protons and neutrons together via an internucleon quark-to-quark force based on the color of the quarks. In other words, in the Residual Color Force Model, the protons and neutrons are theorized to be held together by a bond that is formed between a quark in one nucleon binding to a different quark in another nucleon; this is what is meant by an internucleon quark-to-quark bond.

Because the Residual Color Force Model includes the concept of quarks, it is consistent with the Standard Model. However, due to its extreme mathematical complexity, the Residual Color Force Model cannot sufficiently explain nuclear behavior. For example, Residual Color Force Model cannot accurately predict binding energy or duplicate the binding energy curve. Also, it does not explain large quadrupole moments, excited states, radioactivity, or particle decay. Conceptually, the Residual Color Force Model, based on its internucleon quark-to-quark interaction, is an appealing theoretical concept to most particle physicists. However, as an applied theory, it has been relatively unsuccessful due its extreme difficulty and mathematical complexity.

The Residual Color Force Model is a very complicated mathematical problem, requiring brute computing power and using a discretized lattice of time and space. There are two difficulties with a derivation of Nuclear Forces from Quantum Chromodynamics. The first difficulty is that each proton or neutron consists of three quarks, turning even the simplest binding energy calculation, such as for deuteron, into a six-body problem. The second difficulty is that the Quantum Chromodynamic Force a very strong force compared to the Nuclear Force. This large difference in the strengths of these two forces makes it difficult for the iterative mathematical computer calculations to converge to a solution.

To solve the six-quark problem with brute computing power, the six-quark system is put into on a lattice of discrete points, with the three spatial dimensions and one temporal dimension, in a method known as lattice QCD. However, such calculations are computationally very expensive and cannot be used as a feasible nuclear physics tool. As a result, the Residual Color Force Model of the Nuclear Force has not been useful from a practical standpoint [11, 12, 13]. More details about the Residual Color Force Model are given in the appendix for the interested reader.

1.8. A Minor Change to the Residual Color Force Model

The Residual Color Force Model postulates that the Nuclear Force is a residual effect of the color forces between a quark in one proton or neutron with another quark in a different proton or neutron, and that the force is related to the color of the two quarks involved. The Residual Color Force Model is postulated to be due to an exchange of virtual pi-mesons between the quarks of the two different nucleons. However, one simple variation to this model makes a very interesting difference in the understanding of the forces involved within atomic nuclei.

If the Nuclear Force between the protons and neutrons is dependent upon the up and down flavor of the quarks, which then considers the positive and negative electric charge of quarks rather than only the color of the quarks, then this small change is able to answer many questions about nuclear behavior.

The concept here is that a negatively-charged down quark is electrically attracted to a positively-charged up quark, one that is in a different nucleon from itself. Similarly, a positively-charged up quark is attracted to down quark, one that is in a different nucleon. Up quarks and down quarks that are in two different nucleons are electrically attracted to each other. Up quarks are electrically repulsed by other up quarks in other nucleons, and down quarks are repulsed by other down quarks in other nucleons.

These attractive and repulsive Electromagnetic Forces are internucleon quark-to-quark forces that are outside of the protons and neutrons, where the term "internucleon" means it is between two nucleons. These electromagnetic internucleon quark-to-quark forces bind the protons and neutrons together in an atomic nucleus. An internucleon quark-to-quark force is <u>not</u> the Quantum Chromodynamic Force. (The Quantum Chromodynamic Force is the force that bonds confines the quarks together inside a proton or neutron.) Rather, these electromagnetic internucleon quark-to-quark forces are a <u>Nuclear Force</u>; they are a force that binds the protons and neutrons together to form an atomic nucleus. The bonding force between the nucleons is, quite simply, the attraction of the up quark in one nucleon to the down quark in another nucleon. When a bond is made between these two different quarks in two different nucleons, the two different nucleons are, therefore, similarly bonded. This force bonding these two different nucleons together is the Nuclear Force; it is not the Quantum Chromodynamic Force. This force bonding these two different nucleons together is an electromagnetic internucleon quark-to-quark attractive force.

This simple change of concept, that the Nuclear Force is dependent upon the electromagnetic charge of the quarks rather than the color of the quarks, easily explains why a system of 6 protons and 6 neutrons is at a lower overall energy (and thus at a higher binding energy) than 5 protons and 7 neutrons. It is because 6 protons and 6 neutrons can form one bond for every pair of up-down quarks. There are 18 up quarks and 18 down quarks in the system of 6 protons and 6 neutrons. Thus there could be 18 up-to-down quarks bonds. However, for 5 protons and 7 neutrons, there are 19 down quarks and 17 up quarks, thus only 17 bonds could be formed. The nucleus with 5 protons and 7 neutrons would be at a higher overall energy (and thus at a lower binding energy) than the system of 6 protons and 6 neutrons. With this simple change, it easily can be understood why a nucleon can only bond to its nearest neighbors. Specifically, a nucleon can only bond to three other nucleon, because there are only three quarks in every nucleon with which to bond. The internucleon quarks involved in the bonding must be of opposite electromagnetic polarity.

This single concept immediately explains the asymmetry term of the Weizsäcker formula, because the greatest number of bonds occurs when there are equal numbers of up quarks and down quarks, which in turn means an equal number of protons and neutrons. Also, this new concept–that the Nuclear Force is dependent upon the electromagnetic charge rather than the color of the quarks– clarifies the "constant" term of the Weizsäcker formula. It is because each nucleon has a limited number of bonds it can form with other nucleons. As will be clarified later when looking at the representations of the lowest energy configurations, the "surface" term applies to the unbonded quarks on the ends of the chain-like configuration, as well as the two unbonded quarks that are in the star segment. The Coulomb energy term of the Weizsäcker formula is also easily explained as being related to the electrical energy of the net positive charges. Without going into a long and detailed explanation, the pairing term can cursorily be explained as being related to the fact that there are two protons and two neutrons for each alpha segment, and that the alpha segments have no unbonded quarks. Thus the highest binding energy occurs when there are even numbers of protons and neutrons, and the most number of alpha segments. Thus, for this one simple change—that the internucleon quark-to-quark bond is related to electromagnetics rather than color—the Electromagnetic Model can explain all of the five terms of the semi-empirical Weizsäcker formula. This is indeed why it is able to duplicate the binding curve so accurately.

Quick calculations have been made to test this hypothesis [14]. These simple calculations show that this concept of electromagnetic internucleon up-to-down quark bond reproduces the binding energy curve surprisingly well, using only one variable—the strength of the bond. Such good replication, achieved with simple mathematics, strongly implies that this concept is correct. The quick calculation of this concept did not assume any particular type of force for the bond; it only assumed that a bond was formed between an up quark and a down quark. A more rigorous and detailed calculation follows when the Electromagnetic Force is used as the force between the up and down quarks, as was done in Part I of the Electromagnetic Considerations of the Nuclear Force [1]. The detailed calculations for the Electromagnetic Forces are found in Part I, and will not be repeated in this paper.

1.9. The Limitation of the Electromagnetic Force

Prior to the 1960's, the proton was incorrectly thought to be homogeneously charged and to have a radius of about 1.2 femto-meters. As a result, the strongest electrical energy between two such protons was thought to be 9.62×10^{-14} joules.

The experimental energy required to free a single nucleon from an atomic nucleus is much larger than 9.62×10^{-14} joules. For this reason, the Nuclear Force was believed to be much stronger than the Electromagnetic Force. As a result, this incorrect concept of a homogenously charged proton created an erroneous limitation of the Electromagnetic Force. Unfortunately, this incorrect concept is still often perpetuated.

If the minimum internucleon quark-to-quark distance (defined as the minimum distance of one quark in one nucleon to another quark in another nucleon) is 0.2111 femtometers, which is the parameter we use for the minimum internucleon quark-to-quark distance in our calculation, and if we include the magnetic force between the quarks into calculation, the value for the energy of an electromagnetic bond is 1.18014×10^{-12} joules, which is 7.36584 MeV.

Mathematically, in the limit as the distance goes to zero, the electromagnetic energy goes to infinity. Hence, the electromagnetic energy can be extremely large if the quarks are close enough to each other. Since the charge of the nucleons resides within the quarks, a quark from one nucleon can bond electromagnetically with a quark in another nucleon, and that resultant force between two such quarks can be extremely large—large enough, indeed, to be the Nuclear Force.

The Electromagnetic Model of the Nuclear Force assumes the laws of electromagnetics are valid inside an atomic nucleus, and that these laws should not be disregarded. This model asserts that is the electromagnetic properties of the quarks within the atomic nucleus are the forces that create the Nuclear Force. Thus, these Electromagnetic Forces are the actual Nuclear Forces that hold the protons and neutrons together in an atomic nucleus, a force that was previously thought to be a mysterious and complicated force.

2. The Electromagnetic Energies Inside the Atomic Nucleus

2.1. The Internucleon Quark-to-Quark Bond

The electric charges and magnetic dipole moments of the protons and neutrons are contained in the quarks, and this fact must be taken into consideration for any model of the Nuclear Force. The attractive Electromagnetic Force between an up quark and a down quark is strong enough to bond the nucleons together. No other force, different from the Electromagnetic Force, is needed to account for the strength of this bond. This electromagnetic bond is shown in Fig 1, along with the minimum internucleon quark-to-quark distance.

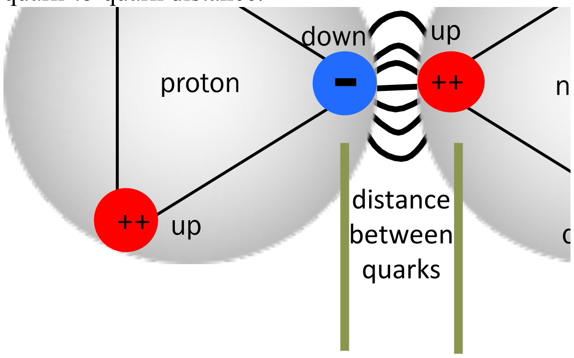


Fig. 1. The electromagnetic bond between quarks

The force binding the proton and neutron together need not be anything other than the Electromagnetic Forces between the internucleon quarks.

2.2. The Electric Energy

The electric energy [15, 16, 17] between two electrically charged particles is shown in Eq. (1):

$$U_{E12}=-\frac{q_1 q_2}{4\pi\epsilon_0 r_{12}} \qquad (1)$$

where: U_{E12} is the electric energy between particles 1 and 2, r_{12} is the distance between particles 1 and 2, and q_1 and q_2 are the electric charges on particles 1 and 2, respectively.

For additional charges, the electrical energies are simply summed for every pair of charges, as shown in Eq. (2).

$$U_{electric\_total}=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}-\frac{q_i q_j}{4\pi\epsilon_0 r_{ij}} \qquad (2)$$

This is the equation used to calculate the electric energy on a configuration of electric charges, in a three dimensional configuration.

2.3. The Magnetic Energy

The magnetic energy [18, 19, 20] between two magnets is more complicated than the electric energy because it has vector and position dependence. Given two magnets, with magnetic moments μ_1 and μ_2, the magnetic field of $magnet_1$ must first be determined at the position of the $magnet_2$, symbolized as B_{12}. This is shown in Eq. (3).

$$B_{12}=\frac{\mu_0}{4\pi}\frac{3(\mu_2\cdot r_{12})r_{21}-r_{21}^2\mu_2}{r_{21}^5} \qquad (3)$$

where r_{21} is the vector distance from $magnet_2$ to $magnet_1$, and similarly r_{12} is vector distance from $magnet_1$ to $magnet_2$.

The resultant energy, $U_{magnetic12}$, is the negative dot-product of the vector of the magnetic moment μ_2 with the vector of B_{12}, as shown in Eq. (4).

$$U_{magnetic\_12}=-\mu_2\cdot B_{12} \qquad (4)$$

For a collection of magnets, the total magnetic energy is the double summation over all magnet pairs, as shown in Eq. (5).

$$U_{magnetic\_total}=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}-\mu_i\cdot B_{ij} \qquad (5)$$

where B_{ij} is the vector magnetic field established by the i^{th} magnet at the location of the j^{th} magnet.

Combining equations 2, 3, and 5, the total electromagnetic energy of a distribution of charges and magnets is shown in Eq. (6):

$$U_{EM\ total}=\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\frac{q_i q_j}{4\pi\epsilon_0 r_{ij}}+\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\frac{\mu_0}{4\pi}\frac{3(\mu_j\cdot r_{ji})(\mu_i\cdot r_{ji})-r_{ji}^2\,\mu_i\cdot\mu_j}{r_{ji}^5} \qquad (6)$$

This is the equation used to calculate the total electromagnetic energy on a configuration of electric charges, in a three dimensional configuration.

Due to the vector properties of this energy, the lowest energy configuration for two magnets is a stacked bond, in which the magnetic dipole moments of the magnets are aligned in a stacked orientation with respect to each other, and the magnets are as close as physically possible. Another way for two magnets to bond is a side-by-side bond, with the magnetic diole moments anti-parallel, and the magnets oriented side-by-side, as a close as physically possible. A bond that is in between a stacked and a side-by-side bond is an angled bond, and this will give intermediate results for its energy. The various orientations are shown in Fig. 2.

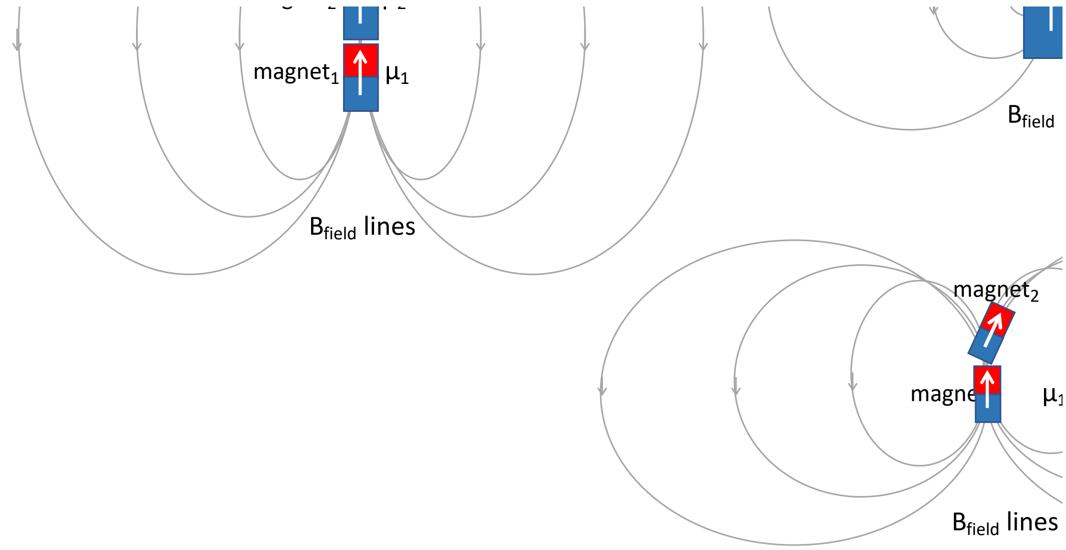


Fig. 2: Three orientations for magnetic bonds, stacked, side-by-side, and angled.

From quantum field theory, it is known that quarks behave as point-like Dirac particles, each having their own inherent magnetic moment [21, 22].

The calculated binding energy is the difference of the total energies of the configuration and the total energies of the isolated constituent parts. Although binding energy is considered to be positive, this binding energy is subtracted from the energy of the isolated constituent parts, resulting in the bound configuration being at a overall lower energy than the isolated parts. Unfortunately, this is often a source of confusion for many people, including some particle physicists.

To reiterate, the *higher* the binding energy, $U_{binding\ energy}$, of a bound configuration, the *lower* the overall total energy (and mass) of the configuration. In other words, binding energy of a bound configuration does not contribute to the mass of the bound configuration. Rather, a positive binding energy *reduces* the mass of the configuration compared to the mass of the isolated constituent parts. This is shown in Eq. (7).

$$Utotal\ of\ configuration = Utotal\ of\ isolated\ parts - Ubinding\ energy \qquad (7)$$

For nuclear binding energy, in this calculation, the mass of the electrons is taken into consideration, as is the binding energy of the electron to the atom. Any difference in the energy due to angular momentum must also be taken into consideration in this equation. For a stable configuration, the bond configuration will be at a lower total mass and lower total energy. This is true regardless of whether the energy is quantum energy or some other type of classical energy. Indeed, quantum energy is not different in this regard.

For the electromagnetic theory, it is assumed that no other energies, other than the electromagnetic energy and the angular momentum energy, contribute to the binding energy. Thus, the binding energy can be expressed as the difference in the electromagnetic energy, $\Delta U_{electromagnetic}$, plus the difference in the angular momentum energy, $\Delta U_{angular\ momentum}$, as shown in Eq. (8).

$$Ubinding\ energy = \Delta Uelectromagetic + \Delta Uangular\ momentum \qquad (8)$$

The electromagnetic energy of the quarks inside the individual protons and neutrons is taken into account as part of the electromagnetic energy of the individual constituent parts.

2.4. **Short-Range versus Long-Range Forces**

Historically, since there was no indication of a mysterious Nuclear Force at long-range distances, it was previously thought that the Nuclear Force must be a short-range force. Due to the misconception that protons were homogeneously charged, it was also thought that the Electromagnetic Force could not be same as the Nuclear Force. Thus, the existence of a force, different from the Electromagnetic Force, was postulated, and it was assumed to be some sort of a mysterious short-range force. Given the understanding that the Nuclear Force is electromagnetic, the presumed requirement of a short-range force is no longer necessary.

2.5. Electromagnetic Energies and the Schrödinger Equation

The Schrödinger equation is a useful tool and has been successful in many areas of quantum physics. The Schrödinger equation is a second-order differential equation that can only be solved for a given potential energy, kinetic energy, and initial boundary conditions. Previous nuclear models have modeled the nuclear potential as one large energy well, using different formulas for the Hamiltonian to obtain the probability function of the atomic nuclide in question.

However, if the Schrödinger equation is to be used properly for a quark-based Nuclear Force, the correct solution should have a Hamiltonian that is related to each individual quark within the atomic nuclide. Also, the proper potential energy well must take into account an energy that can be both attractive and repulsive, as well as any vector properties of the force. However, even without polarity and vector dependence, the quark-based solutions using the Schrödinger equation have proven to be extremely difficult, even for an atomic nucleus as simple ^{2}H, (as mentioned previously when discussing the Residual Color Force Model.) Thus using the Schrödinger equation with a quark-based model has proven to be almost intractable for larger atomic nuclei.

2.6. The Concept of a Nuclear Bond Is Similar to the Atomic Bond

For both the Residual Color Force Model and the Electromagnetic Model of the Nuclear Force, there is an energy well between the two internucleon quarks, and this energy well forms an internucleon quark-to-quark bond. (Recall, a nucleon is a proton or a neutron, and an "internucleon quark-to-quark bond" is a bond between a quark in one nucleon and another quark in a different nucleon.) For the Residual Color Force Model, the energy well is hypothesized to be between two quarks of two different colors, one quark from one nucleon and the other quark from another nucleon. For the Electromagnetic Model, the energy well is between the positively-charged up quark from one nucleon and the negatively-charged down quark of another nucleon. The energy of the Residual Color Force Model between quarks has no closed mathematical form, making it difficult to calculate. This is in contrast to the energy of the Electromagnetic Model, which is very easy to calculate.

Regardless of which energy or which force is used—the Residual Color Force or the Electromagnetic Force—the Nuclear Force is an internucleon quark-to-quark bond, which lowers the overall energy of the atomic nucleus.

This aspect, of lowering the of overall energy when a bond is formed, is similar to the electronic bonds that are formed between the atoms of a molecule. In the electronic bonding of atoms, one atom cannot bond to an indefinite number of other atoms. Rather the number of times that one atom can bond to another atom is limited by the number of valence electrons for that particular atom. Similarly, one proton or neutron cannot bond an indefinite number of times to other nucleons. Similar to the electronic bonding of atoms to form a molecule, the number of bonds that one proton or neutron can make with another proton or neutron is limited by the number of valence quarks available for bonding. The number of valence quarks available for bonding is three.

Thus each nucleon, having only three valence quarks each, can only bond a maximum of three times to other nucleons. Also note that two quarks, one from each of the two different nucleons, are needed for one bond.

2.7. The Assumed Shape of the Protons and Neutrons

In order for the energy of the internucleon quark-to-quark bond to be calculated, the distance between the quarks must be determined. To make this determination, the general intrinsic shape of the proton must be known. However, the intrinsic shape, unfortunately, is not experimentally or theoretically known. As a result, some assumptions about the shape are necessary in order to proceed. For this paper, these assumptions will be as few as possible and as simple as possible.

Experimental and theoretical particle physicists do not know the intrinsic shape of the proton or neutron. There are many conflicting concepts about the nucleon shape, but the overall consensus is that protons and neutrons are not spherical. The most likely shape is an oblate ellipsoidal shape [23, 24, 25].

There is a quantum probability function associated with the quarks, depending on their Hamiltonian and potential energy wells. To the extent that the quarks vibrate at speeds in accordance with uncertainty principles, the Expectation Value of their location is defined by this probability function. The vibrational speed of the quarks depends on variables in quantum physics that are unknown—variables such as the quark mass, the correlation of the movement, and the distortion from a spherical shape of the quarks' three-dimensional potential energy well. Another unknown is which uncertainty principle should be appropriately applied to the quarks. The Robertson-Schrödinger uncertainty principle [26, 27] should be applied if there is a strong correlation in the movement of the quarks, and such correlation could very well exist. Other physicists even go so far as to suggest that uncertainty principles should not apply, since quarks are not isolated particles.

These same unknown variables in quantum physics are problematic with the Residual Color Force Model as well. To avoid this problem, the calculations for the Residual Color Force Model use an artificially inflated rest mass for the quarks, a rest mass that is overly large by several orders of magnitude. The calculations are done at several different values of these artificially large masses, followed by an extrapolation down to estimated the value for the smaller quark mass [28, 29, 30, 31]. This procedure is done to assist in the convergence of the computer simulations; however, this procedure also conveniently sidesteps the uncertainty principle problems. Thus, the complicated and difficult issue of the uncertainty of the quark position and momentum is essentially sidestepped for the calculations of the Residual Color Force Model.

Fortunately there is some justification for sidestepping this problem. As mentioned previously, the quark has a distribution in position and momentum, which averaged over time is similar to a point-like particle, wherein the location in three-dimensional space is the position of the Expectation Value of its probability function. Even though this probability function and the resulting Expectation Value depend on the exact shape of the potential energy well, the result is a point location in three-dimensional space. Thus, even with the various unknowns, quantum fluctuations, and uncertainties, the result is nevertheless similar to a point-like a particle at a specific location, when averaged over time. In other words, regardless of its extreme vibrational velocity and regardless of its positional uncertainty, the quark's location, when averaged over time, can be understood as the Expectation Value of its positional probability function.

This concept correlates to the concept that the quark is a point source of electric charge and a point-like magnetic dipole moment. Confined inside a proton or neutron by the Quantum Chromodynamic Force and the gluon field, the quarks vibrate within a potential energy well, at very high speeds. At any given instant in time, the quark has an uncertainty in its momentum, position, and energy. Also, the uncertainty in the quark position can extend outside of the mathematically defined radius of the nucleon, which is exactly what gives the Quantum Chromodynamic Force a residual force. The assumption that the Residual Color Force is several orders of magnitude smaller than the Quantum Chromodynamic Force implies that the probability function of the quarks is very tightly contained in three-dimensional space of the nucleon. Thus, when averaged over time, the Expectation Value for the location of the quark looks like a point source of charge and magnetism.

To review, each quark has an associated electric field and magnet field. When averaged over time, that electric field can be modeled as the field from a point-like electric charge. Similarly, when averaged over time, the magnet field can be modeled as the field from a point-like magnetic dipole. In actuality, the quarks do indeed move, and they have an extended probability function in three-dimensional space due to their vibrations, movements, fluctuations, and uncertainty. Experimentally, it is known that the quarks are tightly confined by the energy well of the Quantum Chromodynamic Force. However, the shape of that energy well for the Quantum Chromodynamic Force is not currently known, nor can this energy well be represented in a closed mathematical form. However, it is known experimentally that the energy well of the Quantum Chromodynamic Force is very strongly and tightly confining. When averaged over time, the Expectation Value for the position of quarks will give the quarks a characteristic that is similar to a point-like particle of charge and magnetism. All of these concepts are similar to those currently implied within the calculations of the Residual Color Force Model.

2.8. The Minimum Assumptions Possible

Consistent with what is observed experimentally, an oblate ellipsoid shape for the proton and neutron is assumed, with the quarks in an equilateral triangle inside that ellipsoid. This is shown in Fig. 3.

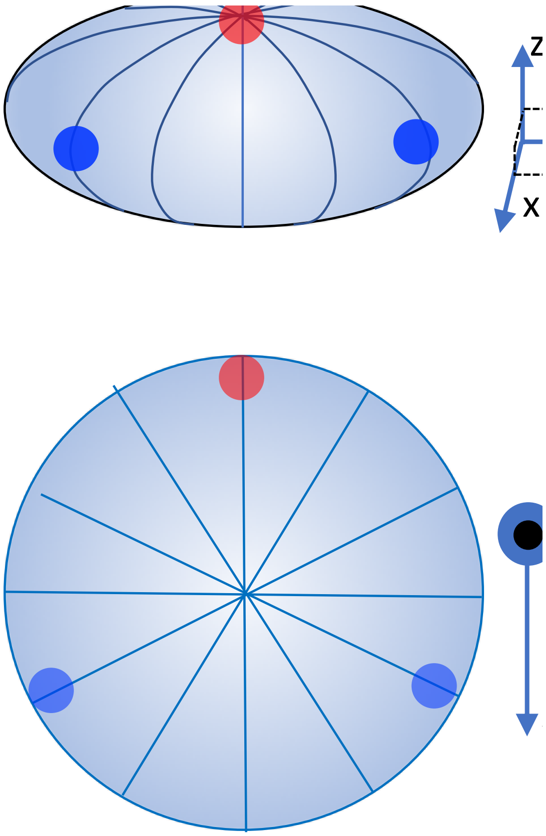


Fig. 3. An oblate ellipsoidal proton, with three quarks in an equilateral triangle.

A different kind of triangle could be assumed, like an isosceles triangle or a scalene triangle; however, those are not a reflection of the simplest assumption, involving more variables for the shape. If a different sort of triangle were assumed, it would change some of the binding energy values of the smallest atomic nuclei, but it would have an overall minor effect on the other nuclear properties. Thus, a different type of triangle would not cause a significant alteration of the overall results, but it would unfortunately include more variables. Should it be determined, in the future, that the Expectation Value of the positional probability function of the quarks are arranged in a different type of triangle, it would cause only minor variations in the binding energy curve. In this paper, an equilateral triangle is used, to reduce the number and complexity of assumptions.

No other assumptions are made concerning the intrinsic shape of the protons and neutrons.

2.9. Nuclear Bonds and the Quantum Hard-core Repulsion

The Pauli Exclusion principle states that nucleons cannot overlap in their physical dimensions; this is also known as the hard-core repulsion. For this reason, a pair of double-bonded nucleons, defined as two nucleons bonded twice to each other, is not allowed. Similarly a triple-quark bond, defined as three quarks attempting to bond together, is not allowed. These conditions are illustrated in Fig. 4.

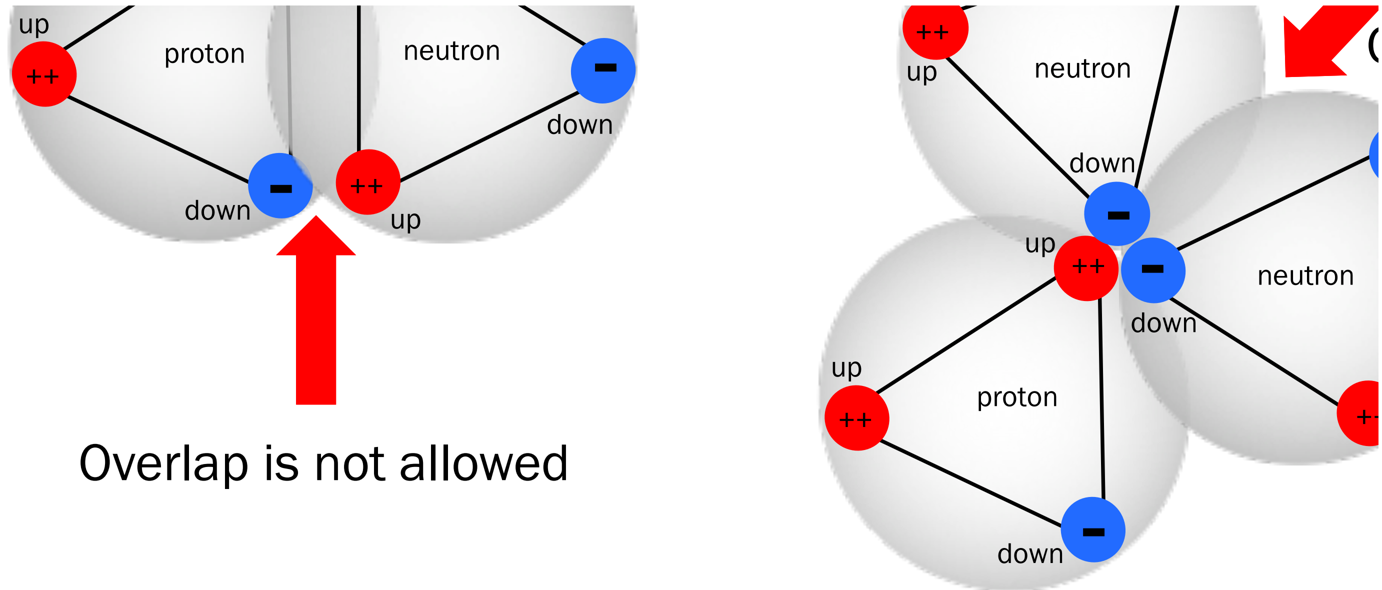


Fig. 4. Left is an illustration of a proton double-bonded to a neutron. Right, is an illustration of a triple-quark bond.

Double-bonded nucleons and triple-quark bonds are not allowed by quantum physics due to the overlapping that would result. As discussed above, it is assumed that the proton and neutron are disk-shaped, with a finite thickness that prevents the double-bonded quarks and the stacking one on top of another.

2.10. Simplified Representations of Protons and Neutrons

Given the considerations above, a representation of an atomic nucleus can be made for its lowest energy configuration. These representations of the atomic nuclei are not intended to be detailed physically accurate representations, but rather short-hand simplified graphics. In this first representation, the simplest atomic nuclei are shown, the individual proton and neutron. Fig. 5 illustrates four representations of the proton and neutron. The leftmost graphic shows the disk shape of the proton and neutron, with the symbols ++ and - for the up and down quarks. The up quarks are red and the down quarks are blue. (These colors are not related in any way to the colors of the Quantum Chromodynamic Force Model.) The next representation is more simplified, showing only the triangle for the nucleons, with the quarks as red and blue dots. (The dots are sized not meant to be the actual relative quark size; rather the dots are sized to be easily viewed.) The next representation is even more simplified red-and-blue diagram of the proton and neutron, with an implied quark at each corner. The rightmost illustration shows a black and white short-hand simplified representation.

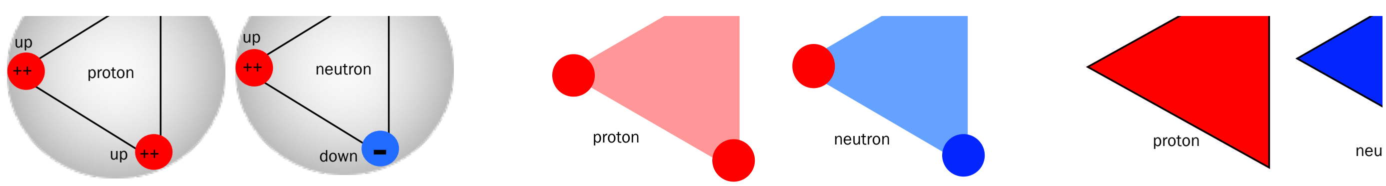


Fig. 5. Four short-hand simplified representations of protons and neutrons

For every atomic nucleus in this paper, the position of each quark is defined in a matrix with an xyz spatial coordinate and electric charge value of either -1/3 or +2/3 of an elementary charge. The value and vector direction of the magnetic moment are also included in the matrix for every quark. This matrix file is used to calculate electromagnetic energy and the kinetic energy of the quantum angular momentum, using the equations above. The result is then used to calculate the nuclear binding energy.

2.11. Summary of the Electromagnetic Force within the Atomic Nucleus

The following is a review of the basic concepts for the Electromagnetic Model of the Nuclear Force.

- The Electromagnetic Force is valid inside the atomic nucleus.
- The electric charge and the magnetic moment of the nucleons are contained within the quarks.

- There are three possible bonds per nucleon, one for each of the three valence quarks. After forming three inter-nucleon quark-to-quark bonds, the nucleon cannot bond to a fourth nucleon.
- A pair of quarks, one from each of the two different nucleons, is needed for one bond.

All of the above considerations are used in this Electromagnetic Model, along with the following quantum considerations:

- The kinetic energy of the quantum angular momentum of the nucleus is properly taken into account.
- There is a minimum distance between two quarks of two different nucleons, consistent with the Pauli Exclusion principle and the hard core repulsion.
- The hard core repulsion of the nucleons prevents a nucleon from bonding more than once to another same nucleon. Any nucleon that attempts to bond twice to another same nucleon is involved in a double-nucleon bond. A double-nucleon bond is not allowed.
- The hard core repulsion of the nucleons prevents a quark from bonding to more than one other internucleon quark. Any quark that attempts to bond to two other internucleon quarks is involved in a triple-quark bond. A triple-quark bond is not allowed.
- Inside the protons and neutrons, the quarks have a spatial quantum probability distribution determined by the Expectation Value of their time averaged probability function. (An equilateral triangle is assumed for simplicity.)

3. The Quantum Angular Momentum Energy

The calculations for the change in the angular momentum of the configuration are also properly considered in this model. The change in the angular momentum energy is due to the overall change in the quantum angular momentum of the atomic nucleus as compared to the component parts.

The energy for the quantum angular momentum [32, 33] of spinning nucleus is shown in Eq. (9):

$$U_{angular\ momentum} = \frac{\hbar^2}{2I} J(J+1) \tag{9}$$

where J is the angular momentum quantum number and I is the total moment of inertia for the object. The quantity $U_{angular\ momentum}$ represents the total energy due to the total quantum angular momentum of the nucleus. The angular momentum quantum number J is the number found in the nuclear tables for nuclear spin, and it represents the total angular momentum of the atomic nucleus, both intrinsic and orbital, for all the particles within the atomic nucleus.

For a non-spherical object, the calculation of the moment of inertia I is slightly complicated. Specifically, the moment of inertia must not be oversimplified by approximating its shape as a sphere. However, this is what previous calculations and models in the past have done. Previous calculations and models have erroneously assumed a spherical shape when determining the nuclear moment of inertia, simply to make the calculations easier. An overly simplified calculation of the moment of inertia for an atomic nucleus causes errors in the angular momentum energy, and these errors have resulted in conundrums and erroneous conclusions, specifically with regard to the collective motion of the nucleus. By using a more accurate calculation for the moment of inertia, much of the previous historical confusion regarding collective motion can be explained and better understood.

A detailed explanation to show the calculations of the quantum angular momentum is done in Part I of this series [1], and it will not be repeated here. Calculating the correct quantum angular momentum of a non-spherical object is more complicated for a non-spherical object. In order to determine the proper moment of inertia, the calculation must include the position and mass of each proton and neutron, the center of mass for the configuration, and the axis of the spin. This calculation requires a computer, especially for the larger atomic nuclei. However, the effect of the change in the binding energy due to the quantum angular momentum is more pronounced for the smaller atomic nuclei, since it is a much larger percentage of the overall energy.

4. Brief Review of the Cluster Model and Nuclear Bonds

4.1. Introduction

Recent research regarding the clustering model of nuclear physics has shown that clustering-type structures do indeed exist experimentally within atomic nuclei [34, 35, 36], confirming that the concept of structure inside an atomic nucleus. Clustering is observed as general phenomena at high excitation energies in light alpha-like atomic nuclei. Also, clustering is a general feature not only observed in light atomic nuclei, but also in less common systems, such as ^{11}Li and ^{14}Be. The Alpha Cluster Model has recently been extended beyond the alpha-only atomic nuclei, with much study and research in the field of cluster structure and of "nuclear molecules". These nuclear molecules can be thought of as being built from building blocks, called segments, linked together to form the nuclear molecules. These nuclear molecules are illustrated graphically in Cluster Model diagrams [37]. This recent research in the clustering structure of the atomic nucleus further corroborates the experimentally-observed collective motion of atomic nuclei, strongly indicating that protons and neutrons do not move independently inside an atomic nucleus. A sample of Cluster Model diagrams are shown in Fig. 6, to familiarize the reader with this type of diagram for nuclear structure.

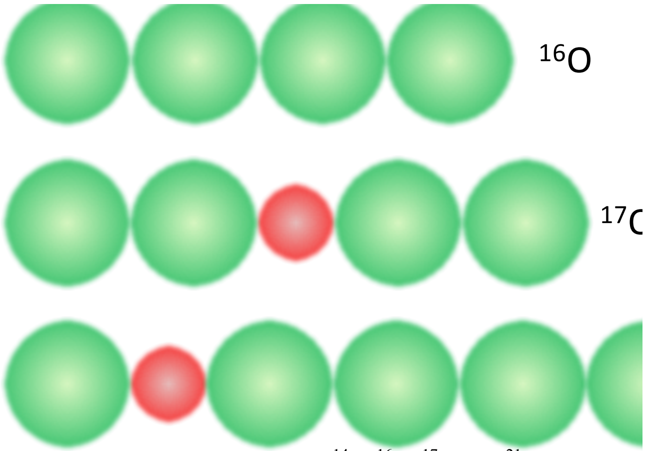


Fig. 6. Cluster Model diagrams of ^{14}C, ^{16}O, ^{17}O, and ^{21}Ne.

As can be seen from the diagrams, the nuclear segments form chain-like configurations, to create the atomic nucleus. Again, this long chain-like shape is verified both experimentally and theoretically within the Cluster Model. (It is possible that this chain-like shape curls up to form a more compact overall shape, like a curve or a helix.) The Cluster Model claims that protons and neutrons cluster into various types of segments. Alpha segments predominate as the most common type of segment. These segments then link together to form a chain-like structure.

The Electromagnetic Model also claims that protons and neutrons cluster into segments; there are, however, a few differences. The Electromagnetic Model takes into consideration the electric dipole moments of the clusters, and how the segments bind to each other. Also, there are more types of segments in the Electromagnetic model. However, the most important difference is that the Electromagnetic Model explains why clustering occurs and why the alpha segment is predominant.

4.2. Explaining Why Clustering Occurs.

Clustering is caused by the Electromagnetic Force putting the atomic nucleus in its lowest energy configuration. The lowest energy configuration is one that:

- maximizes the number of quark-to-quark bonds. The Electromagnetic Forces within the nucleus will attempt to make as many bonds as possible and allowable.
- spreads out the net positive charge as far as possible, while still maintaining the bonds. This will reduce the Coulomb energy.
- situates any negative charge, such as an unbonded down quark, in a position what would otherwise be the highest concentration of positive charge. Again, this will reduce the Coulomb energy.

When these three factors are taken into account, the resulting nuclear shape is a chain-like structure of nuclear segments. This is because a chain-like structure utilizes the maximum number of allowed quark-to-quark bonds, and also allows the charge to be spread out as much as possible while maintaining the bonds. The negative charges can be inserted into the chain-like structure where they are most needed to mitigate and spread out the net positive charge. On the other hand, a spherical shape violates all three of these electromagnetic considerations. A spherical shape does not maximize the number of bonds that can be made, since there would be a significantly large number of unbonded quarks around the periphery of the sphere. A spherical shape does not spread out the charge, but rather it compresses it into the tightest possible package, which is the exact opposite of what is needed for the lowest energy. Also spherical configuration does not utilize the negative charge in such a way as to mitigate the strong electric field of the net positive charge.

4.3. Explaining Why Alpha Segments Predominate

The nuclear bond is a bond between nucleons. For the Electromagnetic Model, it is a bond between quarks from two different nucleons, an internucleon quark-to-quark bond. This bond can be conceptualized as an energy well formed between the up quark and the down quark of two different nucleons. Alternatively, it can be conceptualized as an attractive electromagnetic force between the up quark in one nucleon and the down quark in another nucleon. Regardless of how it is conceptualized, this bond lowers the overall energy of the atomic nucleus, similar to the way that chemical bonds between the atoms lower the overall energy of a molecule. The number of times that an atom can bond to another atom is limited by the number of valence electrons available for bonding. Similarly, the number of bonds for each nucleon is limited by the number of valence quarks available for bonding. Thus with only three valance quarks, each nucleon can only bond three times. Two quarks, one from each of the two nucleons, are needed to form one bond. Thus, if every nucleon were fully bonded in an atomic nucleus, there would be three bonds for every two nucleons.

The alpha segment is predominant because there are only three bonds for each nucleon. The Electromagnetic Model claims that each nucleon can bond a maximum of three times, and this causes the nucleons to cluster into alpha segments. If there were only two bonds within each nucleon, they would simply string together as shown in the top illustration of Fig. 7a. As can be seen in that illustration, each hypothetical proton and neutron can bond only twice. A structure similar to a string of beads results. With three bonds allowed for each nucleon, the protons and neutrons form alphas segments, linked together, as shown in middle illustration of Fig. 7b. This results in clusters of alpha segments, linked together in a chain-like structure. If there were more bonds within each proton or neutron, the predominant cluster would be something larger than the alpha segment. For example, with five possible bonds per nucleon, the predominant structure inside such a hypothetical atomic nucleus would be ^{6}Li, as seen in the bottom illustration of Fig. 7c.

Experimentally, however, it is known that other unusual segments such as a ^{6}Li segment, are not indicated as being the predominant structure of atomic nuclei. This can be seen in the scallop-like pattern of the curve of binding energy per nucleon vs. A. This curve shows that there is a peak for every atomic nuclide made only alpha segments, this peak being more apparent for the smaller atomic nuclei. Also, radioactive alpha decay implies that the alpha segments are pre-formed within the atomic nucleus. Also, the binding energy and separation energies of ^{4}He is the largest for any stable atomic nucleus. This implies that the alpha particle is energetically unique. Other segments, like ^{6}Li, do not appear as common types of particle decay; however, alpha particles do. Thus, the predominant structure is the alpha segment, with two protons and two neutrons. This experimental evidence strongly implies that there are three bonds within each proton and neutron, exactly as might be expected with three quarks.

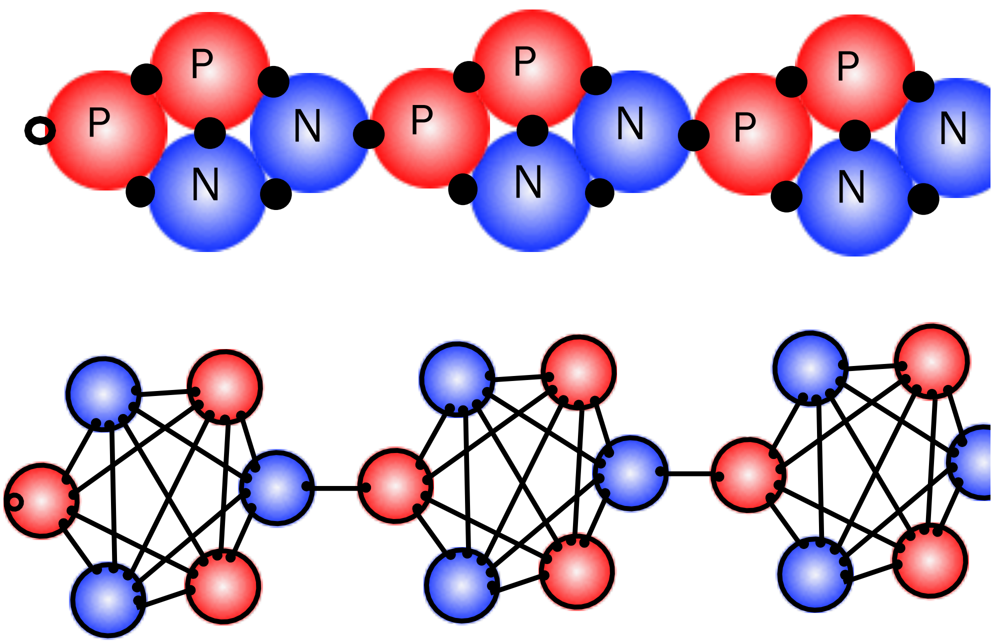


Fig. 7: a) Hypothetical nuclear bonding if there were only two bonds for each proton and neutron. b) Nuclear bonding with three bonds for each proton and neutron. c) Hypothetical nuclear bonding if there were five bonds for each proton and neutron.

If there were more than three bonds for each nucleon, the segments would be larger. For example, clusters of ^{6}Li would form when there are five bonds per nucleon. Also note that the segments form a chain; they would not form a sphere.

5. The Nuclear Electric Quadrupole Moment and the Misconception of Spherical Atomic Nuclei

5.1. Understanding Quadrupole Moments

The quantum electric quadrupole moment of a distribution of charge is a frequently misunderstood topic that deserves review before proceeding.

First, the electric monopole moment and the electric dipole moment will be described. An electric monopole moment is the net charge of an object, assuming the object has a spherical distribution of charge with radial symmetry. Any distribution of charge with spherical symmetry will have only an electric monopole moment. If the distribution has a polarity, with positive charges on one side and negative charges on the other, then the object will also have an electric dipole moment. For example, consider a charge distribution along a line, with a total net charge, but with a positive charge on one side and a negative charge on the other;

this type of distribution would have an electric dipole moment.

If the distribution of charge has a ellipsoidal shape, instead of being perfectly spherical, then the object will have an electric quadrupole moment [38, 39]. The quadrupole moment is related to the eccentricity of the charge distribution, and it can be either prolate (positive, cigar shaped) or oblate (negative, disk shaped). The quadrupole moment of a non-spinning object is referred to as its “intrinsic quadrupole moment”, Q_0, and this is different from the “measured quadrupole moment” Q_m, if the object is spinning. If a prolate object with an intrinsic quadrupole moment Q_0 is spinning, then depending on the axis of spin, the measured quadrupole moment may be smaller than the intrinsic quadrupole moment, and it can even be negative. However, it can never be larger in absolute value. In other words, for a spinning prolate object the measured quadrupole moment can be smaller, in absolute value, than the intrinsic quadrupole moment, and it can be either positive or negative. This is shown in Fig. 8.

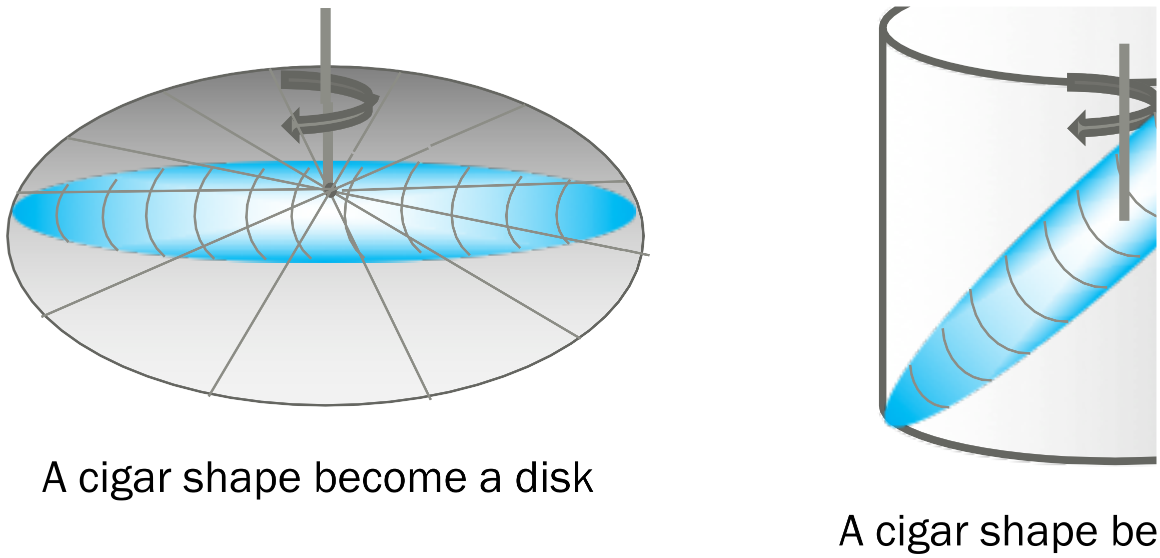


Fig. 8: A spinning prolate object can have a measure quadrupole moment, Q_m, such that $-Q_0 \leq Q_m \leq Q_0$.

If an *oblate* object, with an intrinsic quadrupole moment $-Q_0$, is spinning, then depending on the axis of spin, the measured quadrupole moment can be smaller in absolute value, all the way to zero. It cannot be positive, and it cannot be larger in absolute value. This is shown in Fig. 9.

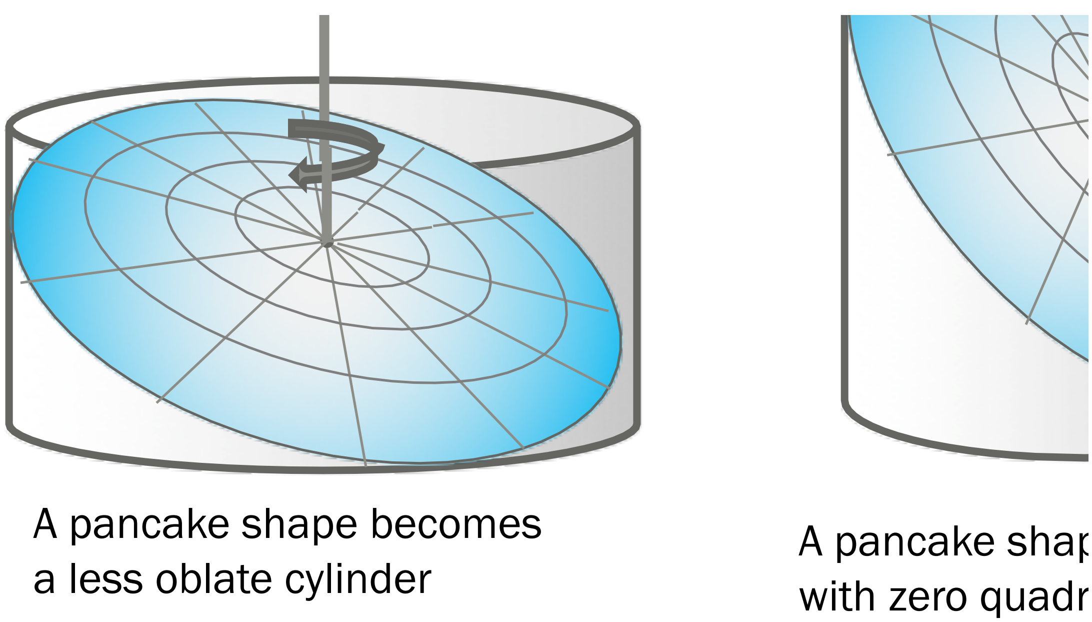


Fig. 9. A spinning oblate object can have a measure quadrupole moment, Q_m, such that $-Q_0 \leq Q_m \leq 0$.

When comparing the measured quadrupole moment with the intrinsic quadrupole moments, another factor to consider is the uniformity of the alignment of the atomic nuclei. For a given sample of atomic nuclei, if the spin axis of the atomic nuclei are not precisely aligned to each other, then a smaller measured value will occur as a result. To summarize, the absolute value of the measured quadrupole moment of a spinning object can never be larger than the absolute value of the intrinsic quadrupole moment.

Taken into the quantum realm, similar principles apply. The measured quadrupole moment, $Q_{measured}$, is related to the intrinsic quadrupole moment, $Q_{intrinsic}$, as shown in Eq. (10).

Qmeasured=Qinstrinsic3K2J+12J+3 (10)

where: K is the projection of the spin axis onto the symmetry axis, and J is the total nuclear angular momentum of the atomic nucleus.

For quantum quadrupole moments, similar regular quadrupole moments, the absolute value of the measured quadrupole moment will always be less than or equal to the intrinsic quadrupole moment. Therefore, if a nuclear model predicts a small inherent quadrupole moment, smaller than the measured quadrupole moment, then this model is inherently flawed. Conversely, if a nuclear model predicts a large inherent quadrupole moment, one that is larger than the measured quadrupole moment, then this inconsistency can easily be explained as being due to the angle of the spin axis or due to the imprecise alignment of the atomic nuclei.

5.2. The Misconception of Spherical Nuclei

With the exception of analyzing quadrupole moments, when researchers interpret the data from an experimentally probed atomic nucleus, the shape of the atomic nucleus is generally assumed to be spherical. Then, for this pre-assumed spherical shape, the best value of its radius R is forced-fit to the data, without any attempt to examine different possible shapes [40, 41]. For example, the interpretation of the electron scattering data only considers the electric monopole moment—in other words, the spherical shape. The interpretation of this data is then normalized over the charge density to force-fit the charge inside a sphere. A Gaussian curve is assumed as the skin of the atomic nucleus, and process is applied without justification or even considering an alternative shape. Thus, regardless of the actual shape, the forced-fit normalized data makes the atomic nucleus appear to be spherical in shape with a Gaussian skin. Even the so-called "model-independent" interpretations of scattering data still assume a spherical shape [42]. This assumption of a spherical atomic nucleus does not compare well to the experimental data regarding the nuclear shape.

Fig. 10a shows the quadrupole moment for atomic nuclei with spin. (All data for Fig. 10a are extracted from reference [43].) Fig. 10b shows the quadrupole moment for zero-spin even-even atomic nuclei. (All data for Fig. 10b are extracted from reference [44].) The blue lines represent the maximum value predicted by the Shell Model. As can be readily seen, atomic nuclei are not spherical in shape. Almost all atomic nuclei have a measured quadrupole moment and deformation parameter that are larger than predicted by the Shell Model. The distortion is not just in a few isolated regions of the nuclear table, but covers the entire range.

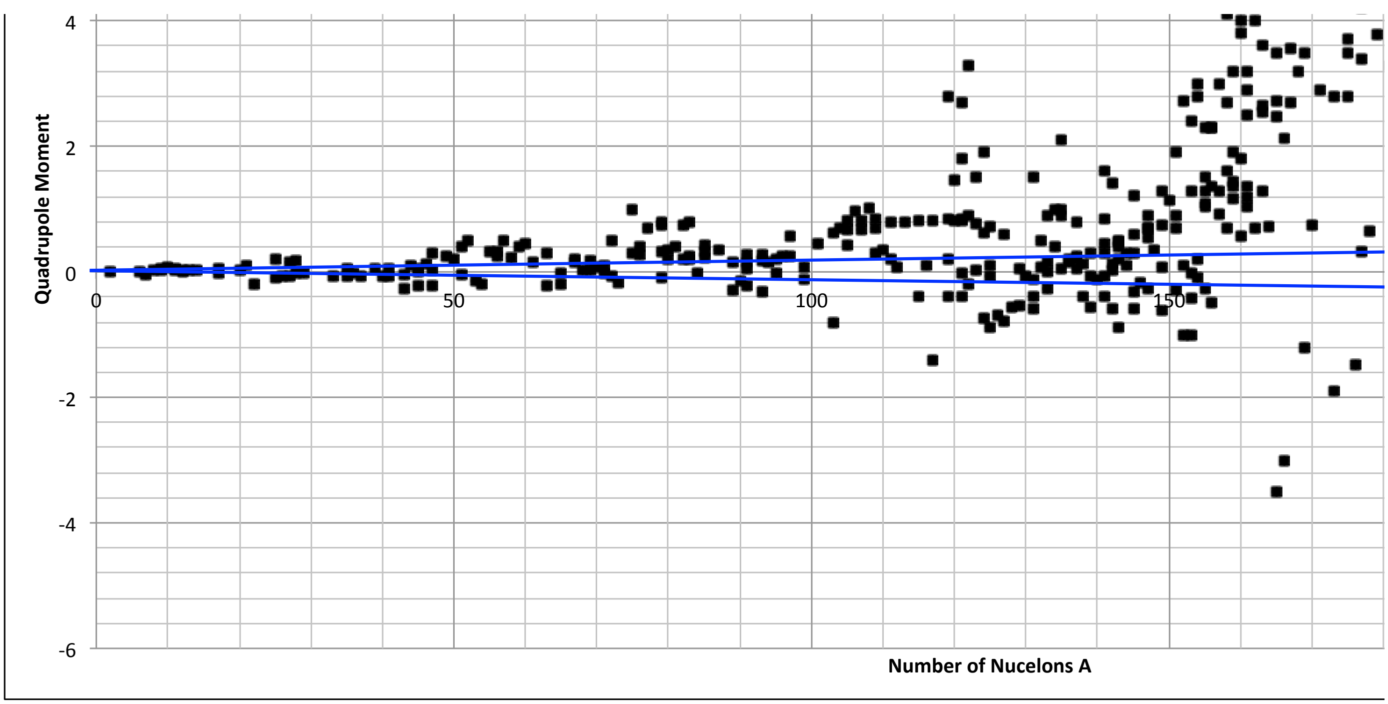


Fig. 10a. Experimental quadrupole moment. The predicted deformation parameter of the Shell Model is shown by the blue lines.

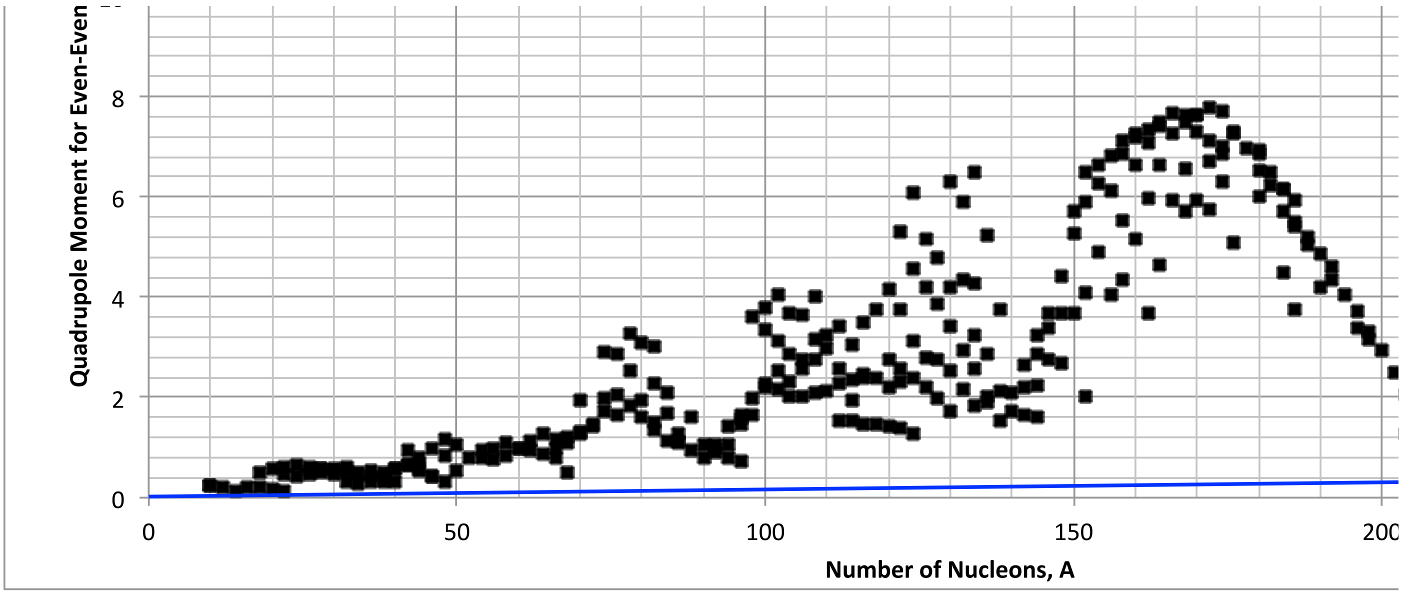


Fig. 10b. Experimental quadrupole moment. The predicted deformation parameter of the Shell Model is shown by the blue line.

The large experimentally-measured quadrupole moments for the vast majority of atomic nuclei is in opposition to the concept of a spherical atomic nucleus. Conversely, the inherent quadrupole moments may be much larger than the measured quadrupole moments, without posing any theoretical problems, as explained previously in section 5.1.

6. Summary of the Electromagnetic Considerations of the Atomic Nucleus

The following is a review of the basic concepts for the Electromagnetic Model.

1. The Electromagnetic Force is valid inside the atomic nucleus.
2. The electric charge and the magnetic moment of the protons and neutrons are contained within the quarks.
3. The quarks inside of the protons and neutrons have a spatial distribution associated with their quantum probability and their resulting subsequent Expectation Value. (An equilateral triangle is assumed for simplicity.)
4. There is a minimum distance between two quarks of two different nucleons, consistent with the Pauli Exclusion principal and the hard core repulsion.
5. A pair of nucleons that are doubly-bonded to each other is called a double-bonded nucleon pair. The hard core repulsion of the nucleons prevents this situation. A doubly-bonded nucleon pair is not allowed.
6. A triple-quark bond is defined as three internucleon quarks attempting to bond together. The hard core repulsion of the nucleons prevents a triple-quark bond, and it is not allowed.
7. There are three possible bonds within each nucleon, one for each valence quark. After three bonds, a nucleon cannot bond to a fourth nucleon.
8. A pair of quarks, one from two different nucleons, is needed for one bond.
9. The protons and neutrons are assumed to be disk shaped, with a finite thickness.
10. The kinetic energy of the quantum angular momentum of the atomic nucleus is properly taken into account.
11. The lowest energy configuration, which only includes the Electromagnetic energies and the kinetic energy of the angular momentum, is assumed for the ground state. No other energies are included in this calculation.

7. The Configurations of the Lowest Energy States for Stable Atomic Nuclei

7.1. The Determination of the Lowest Energy Configurations

Given this understanding of the electromagnetic energy, and assuming the configuration will naturally fall into the lowest energy state, some analytic predictions about the shape of the segments can easily be made. The lowest energy configuration will be with the most number of bonds and with the positive charge spread out as far as possible, while still maintaining the bonds. Any negative charge will be situated at a place that would otherwise have the highest concentration of positive charge.

The lowest energy configurations of the atomic nuclei are determined by using the laws and equations of electromagnetics applied to the quarks. Thermodynamics insists that the stable configuration of the atomic nuclei are in their lowest energy states, and using these lowest energy states, a better understanding of nuclear behavior can be achieved. Any accurate model of the Nuclear Force must consider the lowest energy configuration of that nuclear structure. For a genuine and credible understanding of any structured atomic nucleus, the lowest energy configuration must first be determined. Since the lowest energy configuration is entirely dependent upon the forces and energies within the atomic nucleus, the equations for these energies and forces must be known. Any type of nuclear structure cannot be properly determined unless there is a fundamental mathematical formulation of the forces and energies that are internal to the atomic nucleus, between the nucleons. In this paper the lowest energy configuration of the structured atomic nucleus is determined by using the electromagnetic equations as applied to the quarks, and also to the angular momentum equations as applied to the nucleons.

As previously mentioned, for every atomic nucleus in this paper, the position of each quark is defined in a matrix with xyz spatial coordinates and an electric charge value of either -1/3 or +2/3 of an elementary charge. The value of the magnetic moment, for either the up or down quark, and the three dimensional vector direction of each magnetic moment for each quark are also included in the matrix. Based on the physical constraints of the configuration, a determination is made as to whether the magnetic bond is stacked, angled, or side-by-side.

The various possible lowest energy configurations are tested to determine which configuration is the lowest state. As a result, every atomic nucleus in this paper is in its lowest energy state, in accordance with the rules for electromagnetic energies and spin energies. Also, the configurations are in accordance with the quantum considerations that double-nucleon bonds or triple-quark bonds are not allowed.

7.2. Simplified Representations of ^{2}H, ^{3}H, ^{3}He and ^{4}He.

Shown in Fig. 11 are six different representations of ^{2}H. As before, this is not meant to be a physically accurate representation, but rather a short-hand simplified graphic. Leftmost is ^{2}H, showing the three-dimensional disk shape of the proton and neutron, with the ++ and – charges of the quarks inside, and with the up quarks as red and the down quarks as blue. Below it is the same configuration, but with a different viewpoint. To the right of that, the next representation is more simplified, showing the proton as light a red triangle and the neutron as a light blue triangle, and with the quarks as red and blue dots. In this second representation, the disk-like graphic has been removed in order to make this a more simplified graphic, but the disk-like shape is still implied. The third representation is an even more simplified red-and-blue diagram of the proton and neutron, with an implied quark at each corner. To the very right, is a simplified black and white representation. These simplified diagrams are very useful for representing the larger atomic nuclei.

Please note that these simplified graphic representations are not intended to be a actual physical representations. Nor are they intended to show the relative size of the quarks. Rather, the dot size is chosen to be easily viewable. Also, the colors are not related to the colors in the Quantum Chromodynamic Force Model.

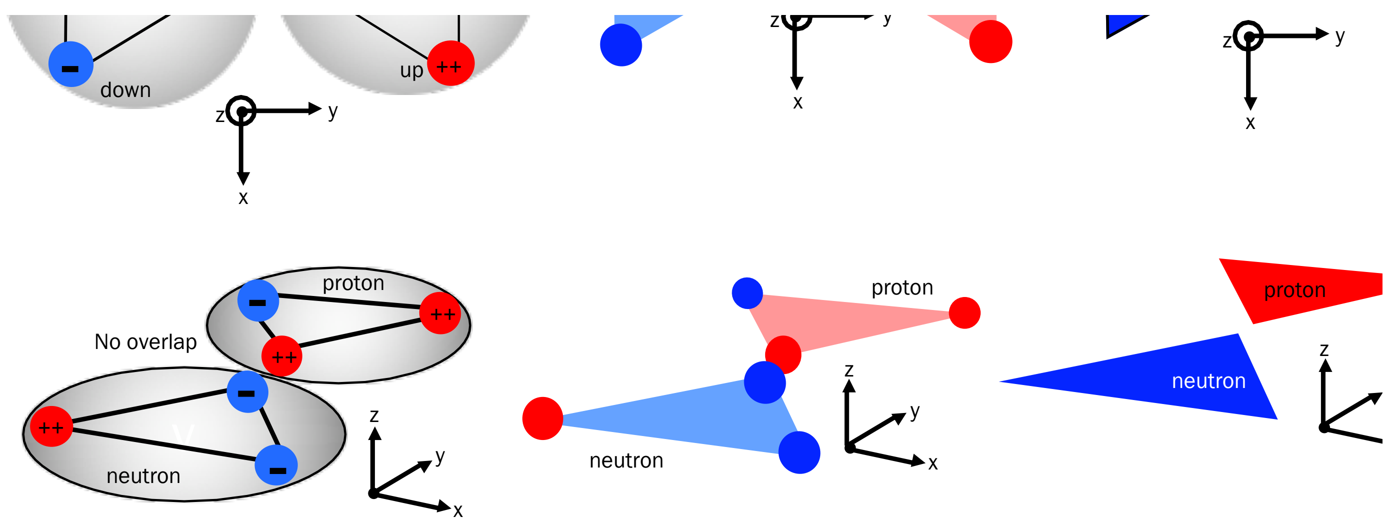


Fig. 11. Eight short-hand simplified representations of ^{2}H, shown from two different viewpoints.

There is an interesting quantum aspect about the configuration of ^{2}H, which explains the very low binding energy of ^{2}H. It is known experimentally that the spin of ^{2}H is 1, rather than 0. Thus, the spins of the neutron and proton add rather than cancel. In other words, the spins of the proton and neutron are parallel rather than anti-parallel. This parallel alignment of nucleon spins is also in accordance with the Pauli Exclusion Principal of quantum physics. This parallel spin alignment can only occur if the magnetic bond between the corresponding up and down quarks are a side-by-side bond, rather than a stacked bond. The side-by-side bond, however, is not as strong magnetically as a stacked bond. This is the reason why the bonding energy of ^{2}H is so small; it is because the magnetic bond must be a weaker side-by-side bond in order to accommodate the quantum rules of spin alignment in the Pauli Exclusion Principal.

The stacked and side-by-side magnetic bonds are shown with more detail and from another viewpoint in Fig. 12. Note that there is no overlap of the nucleons. Although the stacked magnetic bond is not present in deuteron, is it present in most other configurations.

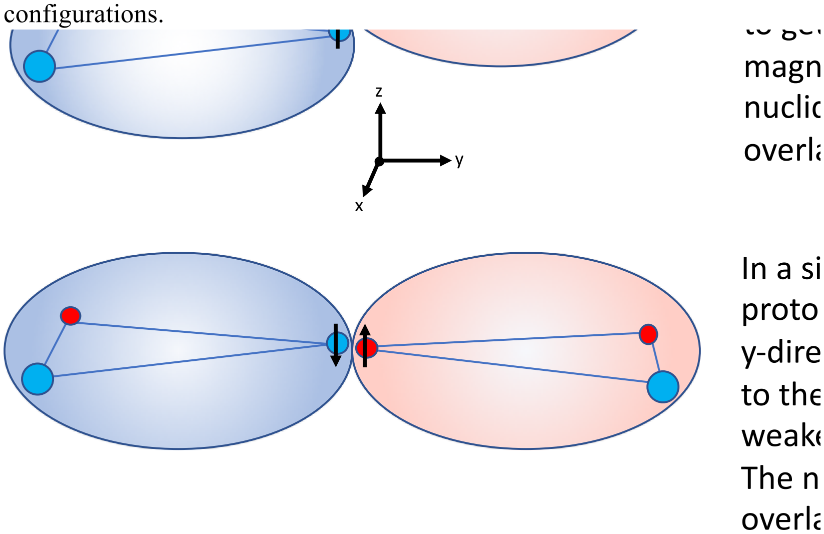


Fig. 12. The stacked and side-by-side magnetic bonds between a proton and a neutron.

Shown in Fig. 13 is the configuration for ^{3}H. Two bonds are stacked bonds, with the up and down quarks are offset in the z dimension to prevent an overlap; the third bond is side-by-side. (In the more simplified red-and-blue diagrams, the reader is to understand that there is always a bond between an up quark and a down quark at the connection point where the triangles meet.) The last diagram to the right shows the disk-shaped proton and neutron, in a different viewpoint, to illustrate the side-by-side magnetic bond and the two stacked bonds. As before, there is no physical overlap of the nucleons. (Even though the two lower-most up and down quarks in the diagrams have a further separation due to the disk shape of the nucleons preventing a closer connection, these two quarks are still considered to be bonded.)

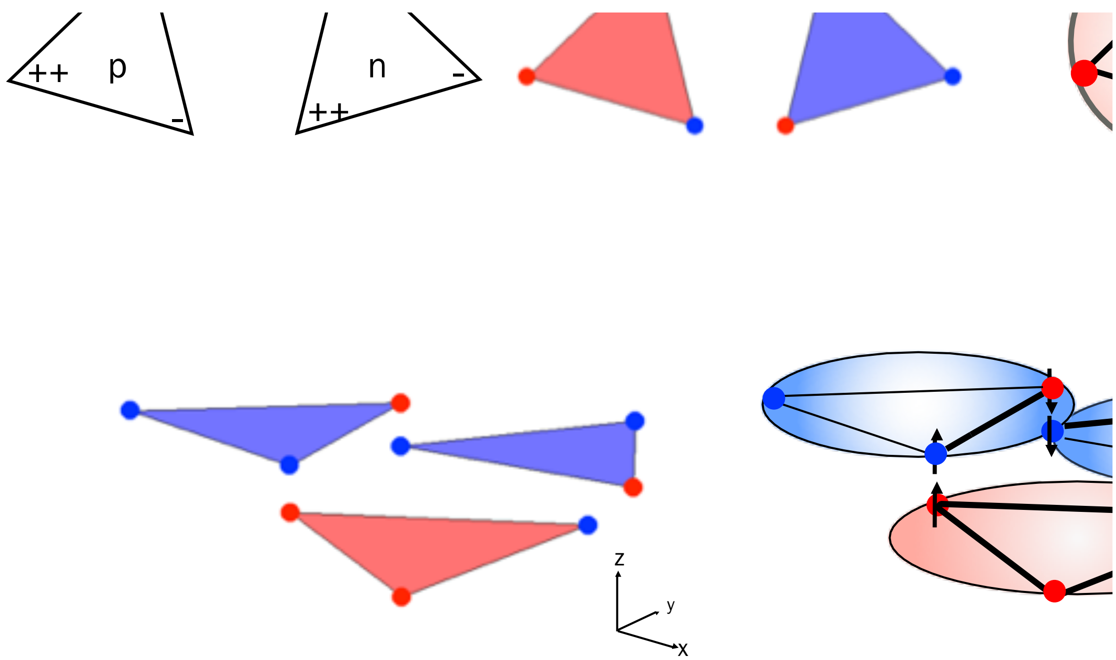


Fig. 13 Short-hand simplified graphics of ^{3}H, showing five different representations.

Shown in Fig. 14 are three variations of the positions for the up and down quarks for ^{3}H. By comparing them in detail, the differences in the exact placement of the up and down quarks can be seen. However, electromagnetically, these are practically the same. For the remaining atomic nuclei in this paper, these numerous alternative configurations will not be shown, but the reader should be aware that they exist.

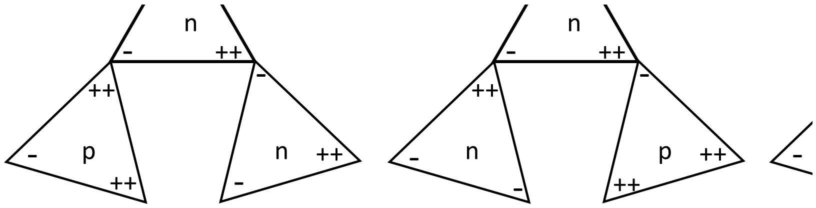


Fig. 14. Alternative configurations of ^{3}H, showing different quark positions within the bonds.

The configuration for ^{3}He is similar to ^{3}H, but with two protons and one neutron. Fig. 15 shows four different representations of ^{3}He. As mentioned previously, it is assumed that double-bounded nucleons and triple-bonded quarks are not allowed. It is assumed that the quarks are in an equilateral triangle within the nucleon, and that the quarks are within the oblate ellipsoidal shape of the nucleon. Plus, there is a finite thickness that prevents the stacking of the nucleons on top of one another. There is no physical overlap of the nucleons.

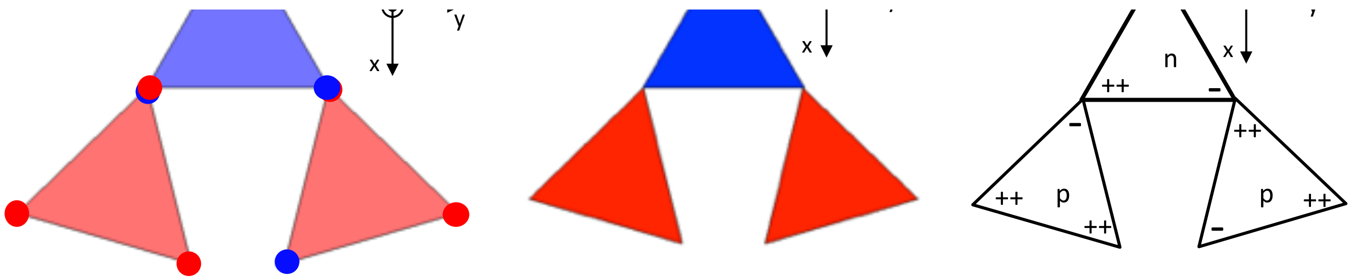


Fig. 15 Short-hand simplified graphics of ^{3}He, shown in three different graphic representations.

The configuration for ^{4}He, shown in Fig. 16, is unique because it is the only atomic nucleus with all of its quarks bonded. This characteristic is what gives ^{4}He such high binding energy and high stability; it is because it has the highest number of bonds per mass number A. This is also why the thermal neutron cross section for ^{4}He is zero; a thermal neutron cannot form a triple-quark bond with a quark that is already bonded in the configuration.

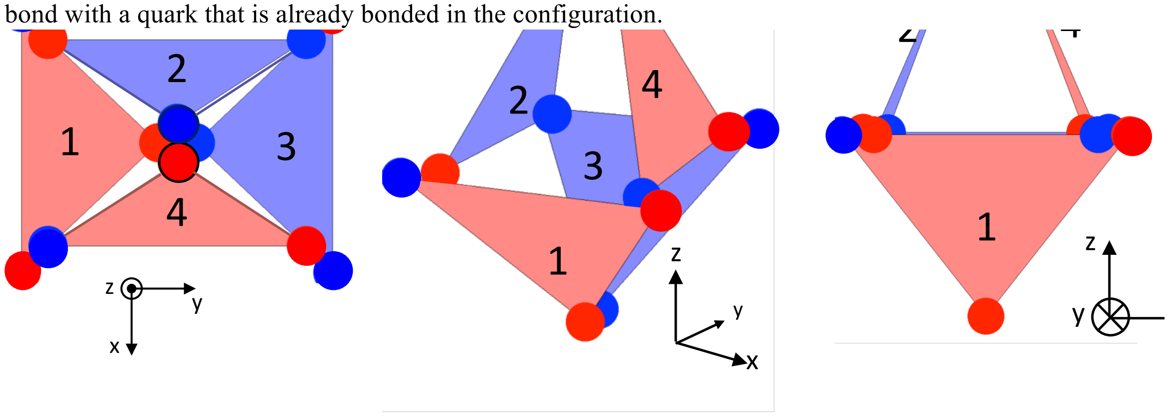


Fig. 16 Short-hand simplified graphics of ^{4}He, shown in four different representations.

Another interesting point about ^{4}He is that it has 6 bonds, as compared to ^{3}He with only three bonds. This explains why there is such a large jump in the binding energy, a difference of 20.58 MeV from ^{3}He to ^{4}He. The large jump is because three more bonds are added in the configuration of ^{4}He compared to ^{3}He. This also explains why the neutron and proton separation energies, S_n and S_p , are so exceptionally high for ^{4}He; it is because to remove either a proton or a neutron, three bonds must be broken. The ^{4}He is not a segment in any nuclear configuration. Rather, it is the alpha segment that predominates in the nuclear molecules.

7.3. Simplified Representations of the Alpha Segment, H4 Segment, and Star Segment

A segment similar to ^{4}He is called the alpha segment. The alpha segment is also made up of two neutrons and two protons, but unlike ^{4}He, it can bond to other segments. The alpha segment is the predominant segment in other atomic nuclei. This segment is illustrated in Fig. 17 in four different representations.

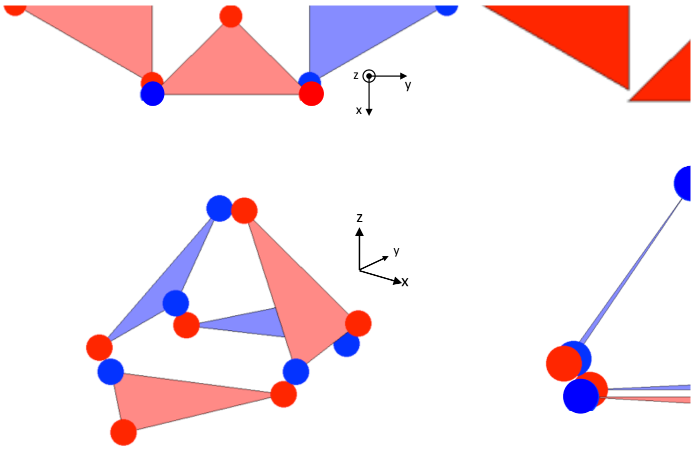


Fig. 17 Shorthand symbolic graphics of an alpha segment, shown in four different representations.

Another segment similar to the alpha segment is called an H4 segment, made up of three neutrons and one proton. This is illustrated in Fig. 18 in four different representations.

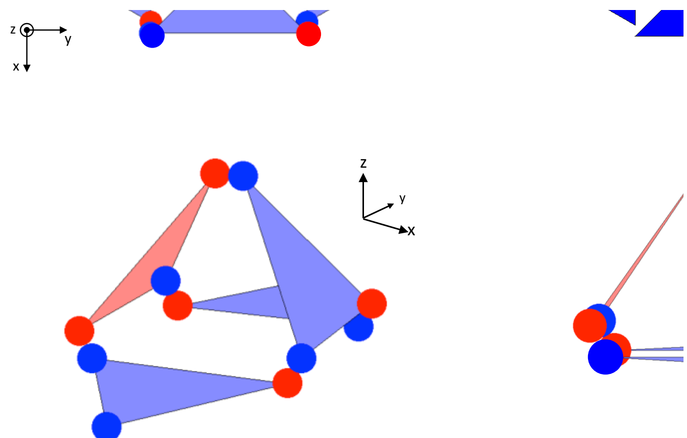


Fig. 18 Short-hand simplified graphics of Hydrogen, ^{4}H, shown in four different representations

Another segment similar to an alpha segment is called the star segment. The star segment is similar to an alpha, but with one less bond. This is shown in four different representations in Fig. 19.

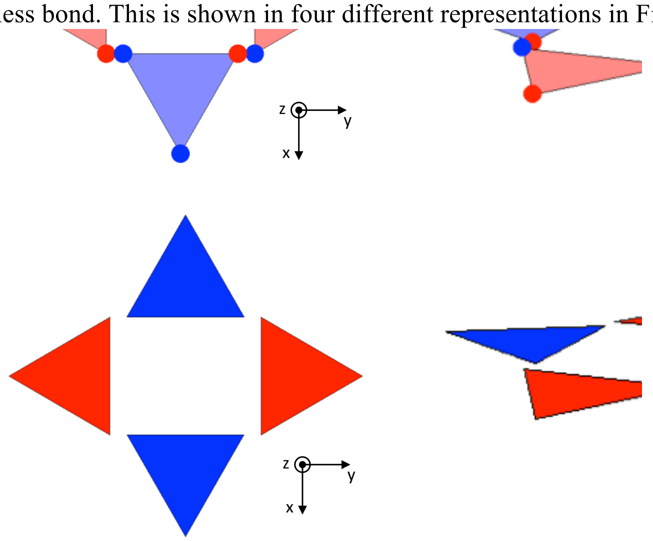


Fig. 19. Short-hand simplified graphics of a star segment, shown in four different representations.

The star segment is similar to an alpha segment in that it has two protons and two neutrons. When this segment is part of a larger configuration, the two up quarks will bond to the other segments, and the two down quarks will remain unbonded. The star segment is required in order to remove the electric dipole moment from the configuration. If the star segment were no in the configuration, an electric dipole moment would exist with a line of charge having a positive unbonded quark on one end and a negative unbonded quark on the other end. By including the star segment, there are two down quarks in the middle that mitigate the high electric field there. Furthermore, the two unbonded up quarks both are on the ends, where their high positive electric charge density is more readily dissipated on the end. The star segment is thus able to reduce or remove the dipole moment associated with the y-dimension. Also, the star segment can remove or reduce the dipole moments associated with the x and z dimensions as well, by rotating the two unbonded down quarks as needed. (The two neutrons of the star segment, with their unbonded down quarks, may rotate in three dimension, but they are drawn always as being flat for simplicity.)

A reminder should be made here that the drawings are not meant to be physically realistic in that the nucleons are not really red or blue, or flat triangles. Rather, the drawings for these nucleons are shorthand symbolic graphical representations to show the quarks, the bonds, and the segments, and to also show how these segments form into chains-like nuclear molecules.

With regard to the cluster formation that the nucleons generally follow when they form into segments, here are some simple considerations to bear in mind.

- When a bond is formed the net charge of the bond is +1/3 of an elementary charge. This net positive charge is present at every bond. Similarly, there is a net magnetic moment which is the vector sum of the two magnetic moments of the two quarks involved in the bond.
- The protons and neutrons cluster into segments, as described in the Electromagnetic Model. This clustering is due to the Electromagnetic Force situating the atomic nucleus into its lowest energy configuration.
- Due to the consideration that each proton or neutron can only bond a maximum of three times, the protons and neutrons will tend to cluster into alpha segments, with each segment consisting of two protons and two neutrons. The alpha segment is the predominant type of segment within atomic nuclei.
- Any additional protons and neutrons that are not part of an alpha segment will form other types of segment.
- A tritium segment consists of one proton and two neutrons.
- An He3 segment consists of two protons and one neutron.
- A star segment is an alpha segment with one less bond. When part of a configuration, it has two unbonded down quarks and it bonds to the rest of the segments with two up quarks.
- An H4 segment is made of one proton and three neutrons, and it is similar in shape to the alpha segment.
- A single neutron that is not part of any other segment is called a single-neutron segment.
- A single proton that is not part of any other segment is called is called a single-proton segment.
- In the lowest energy state, each segment can bond to either one or two other segments to form a chain-like structure. There is no branching.

7.4. Simplified Representations of ^{5}He, ^{6}Li, ^{7}Li, ^{8}Be, ^{9}Be, ^{10}B, and ^{11}B.

The smaller stable atomic nuclei are ^{6}Li, ^{7}Li, ^{9}Be, ^{10}B, and ^{11}B. (Although there are no stable isobars for A=5 or A=8, the figures for ^{5}He and ^{8}Be are also shown for consistency.) From ^{12}C upwards, the stable atomic nuclei follow a relatively simple pattern. The atomic nuclei smaller than ^{12}C cannot follow this pattern simply because they do not have enough protons and neutrons to do so. A discussion of the pattern for the stable atomic nuclei with A≥12 will be made after these the smaller atomic nuclei are first discussed.

The next atomic nucleus to discuss is ^{5}He. The lowest energy configuration for Helium ^{5}He is an alpha-neutron configuration. This is shown in Fig. 20 in four different representations.

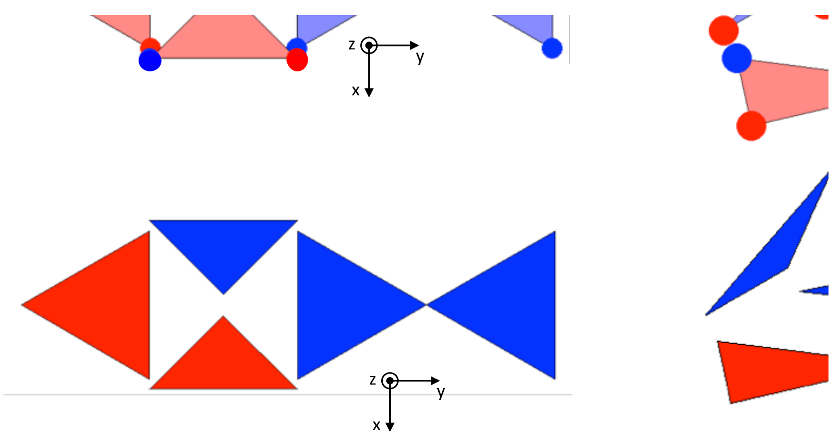


Fig. 20 Short-hand simplified graphics of Helium ^{5}He, shown in four different representations.

The next stable atomic nucleus to discuss is ^{6}Li. The configuration for ^{6}Li is a combination of ^{3}H and ^{3}He, bonded together, as seen in Fig. 21. These are referred to as tritium segments and He3 segments, respectively. (Note that in the top view, both quarks of the stacked bonds are not readily seen, since they are stacked on top of each other, offset in the z-dimension. Even though the top viewpoint obscures the lower quark, the reader should know that both quarks are there, as can be easily seen in the angled viewpoint. There is no physical overlap of the nucleons.) The bond linking the two segments together is a stacked magnetic bond.

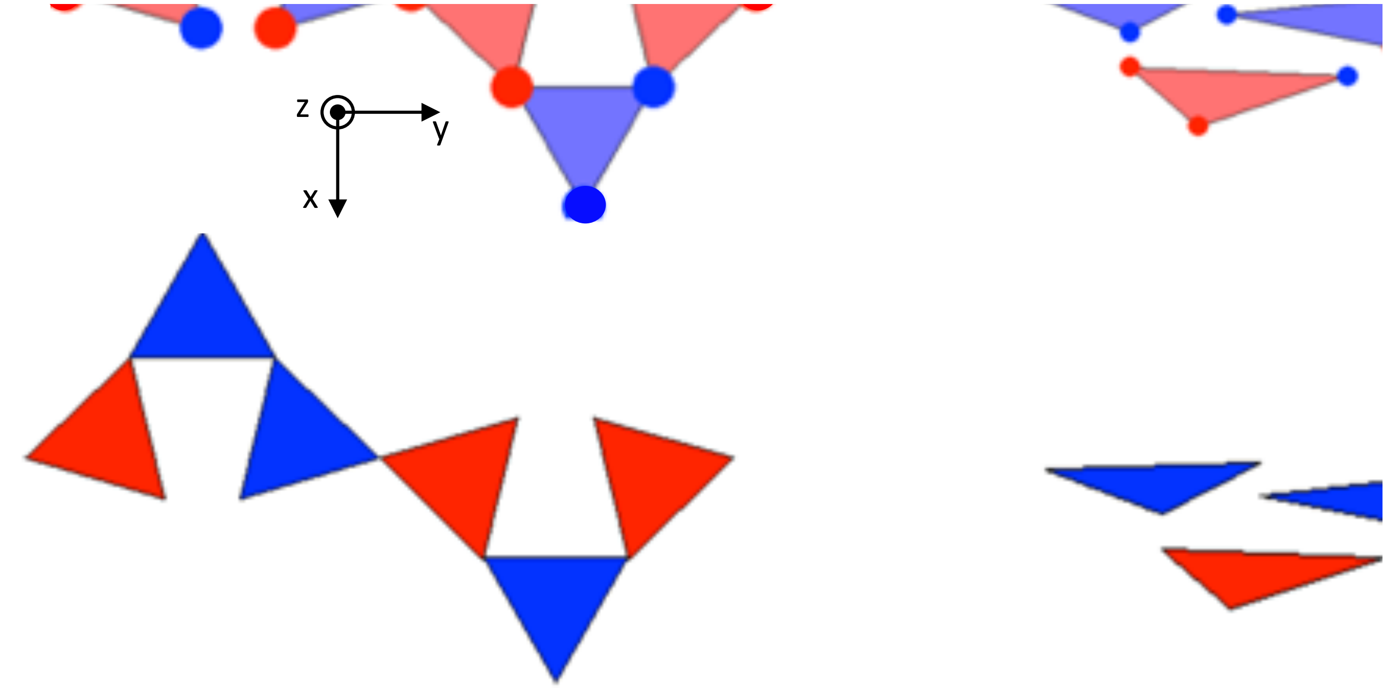


Fig. 21. Short-hand simplified graphics of ^{6}Li, shown in four different representations.

The next stable atomic nucleus is ^{7}Li. The configuration for ^{7}Li is a combination of a tritium segment, a neutron segment, and an He3 segment, bonded together in a tritium-neutron-He3 configuration, as seen in Fig. 22.

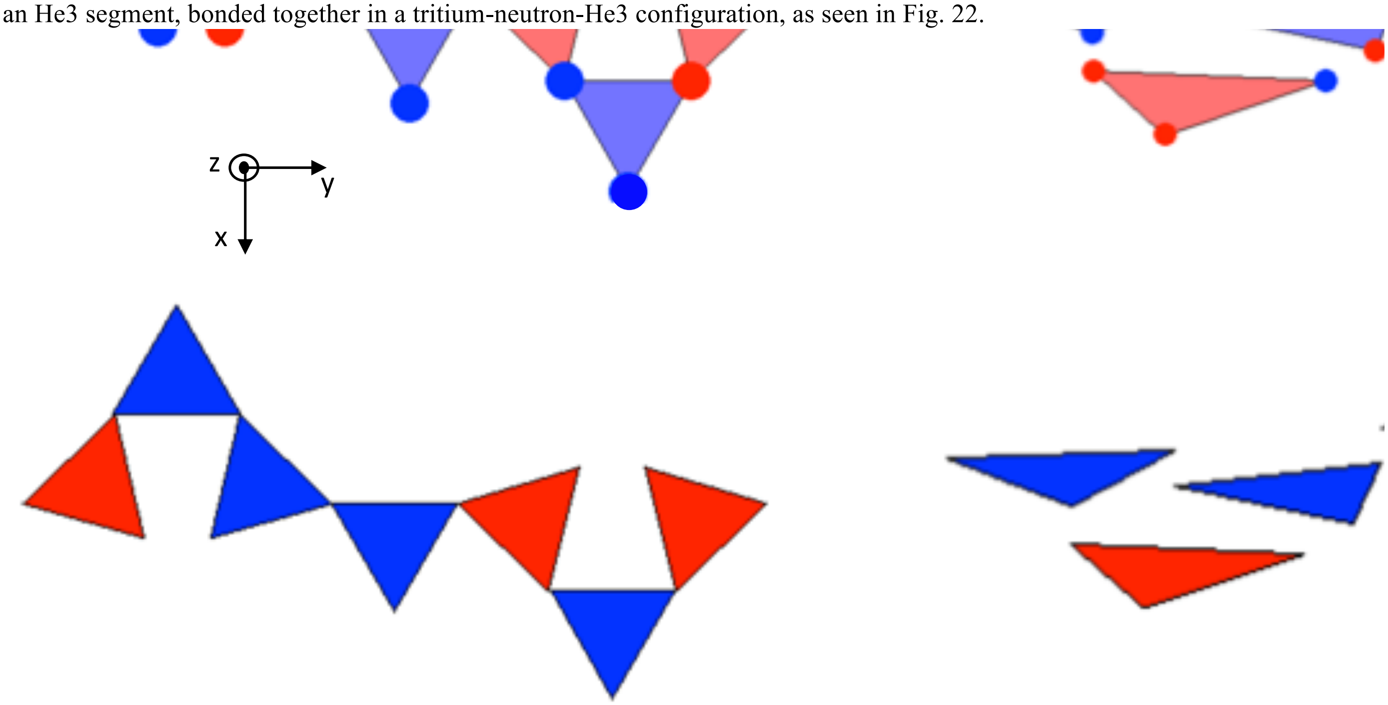


Fig. 22. Short-hand simplified graphics of ^{7}Li, shown in four different representations.

The next atomic nucleus to consider is Beryllium ^{8}Be. There are no isobars with A=8 that are stable, but ^{8}Be is shown for consistency. The lowest energy configuration for Beryllium ^{8}Be is a star-alpha configuration, shown in Fig. 23 in two representations.

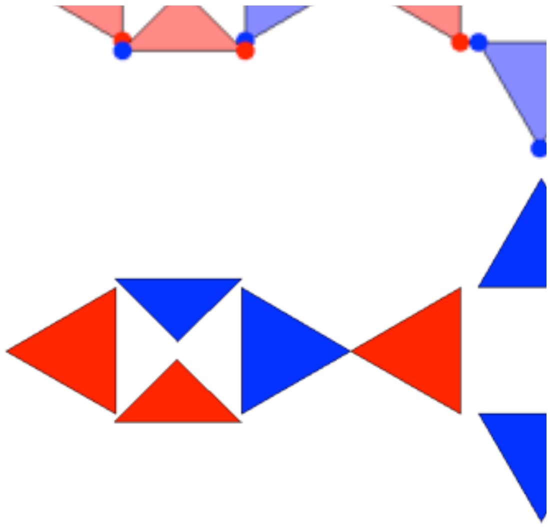


Fig. 23. Short-hand simplified graphics of Beryllium ^{8}Be, shown in two different representations.

The next stable atomic nucleus is Beryllium ^{9}Be. The lowest energy configuration for ^{9}Be is a triton segment, a triton segment, and an He3 segment, as shown in Fig. 24. This is one of the very few stable atomic nuclei that does not contain an alpha segment.

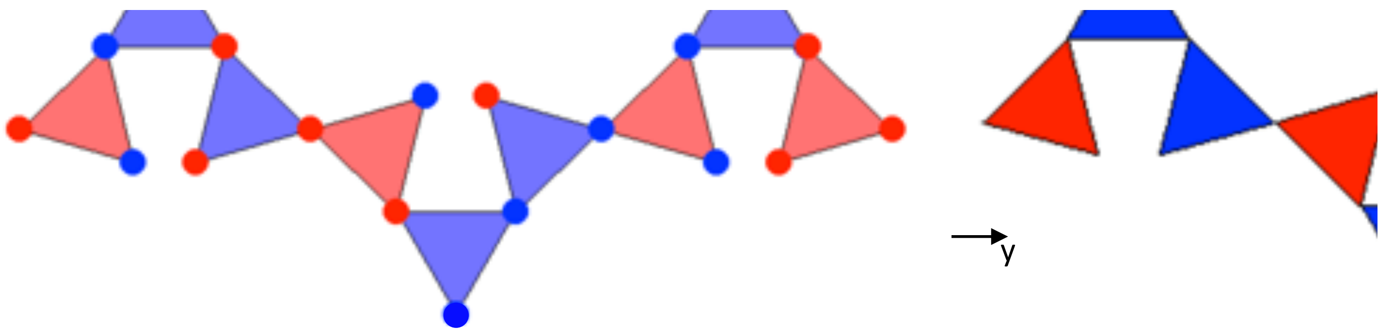
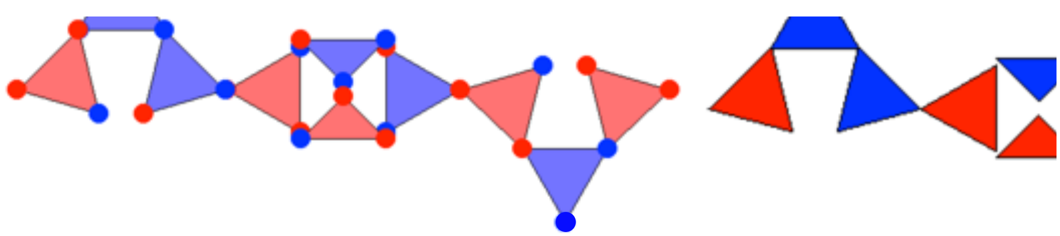


Fig. 24. Short-hand simplified graphics of ^{9}Be, shown in two different representations

The next stable atomic nucleus is Boron, ^{10}B. The lowest energy configuration for ^{10}B is a triton-alpha-He3, shown in Fig. 25. Recall that the electrical charge is located in the quarks, rather than being homogenously distributed throughout the protons. Each bond has a net charge of +1/3 an elementary charge, each unbonded up quark has a charge of +2/3 an elementary charge, and each unbonded down quark has a charge of -1/3 an elementary charge. In Fig. 25, there is also a verbal representation, using the segment names, triton-alpha-He3.



He3-alpha-triton

Fig. 25 Short-hand simplified graphic representations of ^{10}B.

The next stable atomic nucleus is Boron ^{11}B. The lowest energy configuration for ^{11}B is a tritium-star-alpha configuration, shown in Fig. 26, with two graphic representations and one verbal representation.

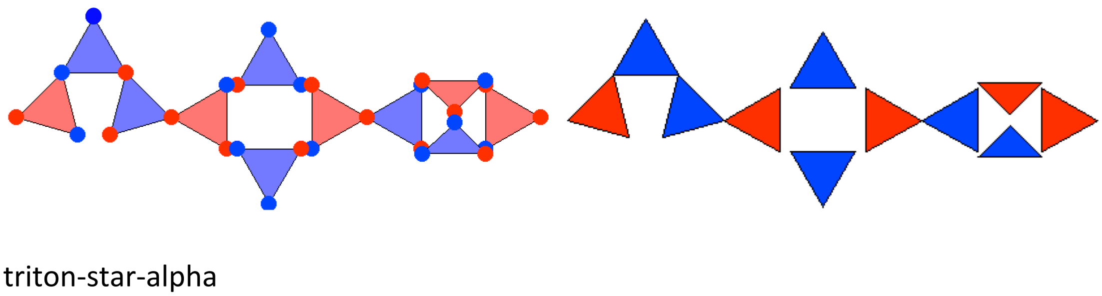


Fig. 26. Short-hand simplified representations of ^{11}B.

7.5. Basic Pattern for the Configurations of the Stable Atomic Nuclei with A≥12

The Electromagnetic Model of the Nuclear Force has successfully modeled both stable and unstable atomic nuclei, all the way up to Californium ^{250}Cf, using the electromagnetic equations. As previously mentioned, the stable atomic nuclei follow a relatively simple pattern, from ^{12}C upwards. This basic pattern is now presented, describing the stable atomic nuclei from ^{12}C and larger.

The configuration of ^{12}C is shown in Fig. 27, in an alpha-star-alpha configuration.

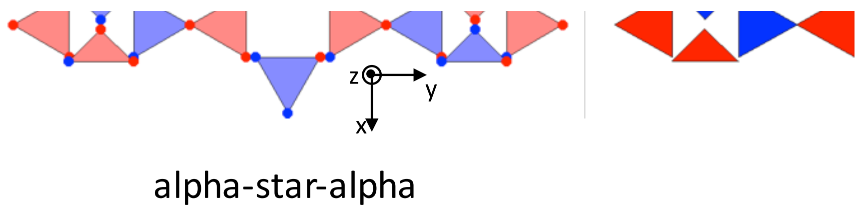


Fig. 27. Short-hand simplified representations of ^{12}C.

This is the lowest energy state of ^{12}C, with spin 0. On each end of ^{12}C is an unbonded up quark, and in the middle, there are two unbonded down quarks. Other physical configurations are possible; however, if ^{12}C is configured in differently, it would either have fewer bonds, more Coulomb energy, or more kinetic spin energy. Therefore as a result, different configurations would be in a higher energy state.

For the larger atomic nuclei, the diagrams become too complex and awkward to show all the red and blue dots representing the quarks in the configuration. Thus, only the red-and-blue representation and the verbal representation will be shown for the atomic nuclei larger than ^{12}C. (When looking at the illustrations, the reader is to understand that any unbonded quark on a neutron is a down quark and any unbonded quark on a proton is an up quark.)

Adding a neutron to ^{12}C creates ^{13}C, shown in Fig. 28 in both the red-and-blue and verbal representations. The additional neutron in ^{13}C adds an additional unbonded down quark in the configuration. This additional unbonded quark lowers the average number of bonds per A, as compared to ^{12}C. This, in turn, gives ^{13}C a lower binding energy per A, as compared to ^{12}C.

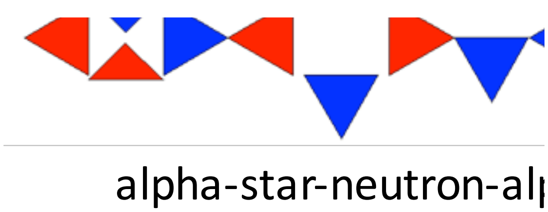
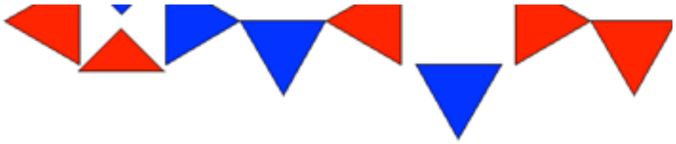


Fig. 28. Two short-hand simplified representations of ^{13}C.

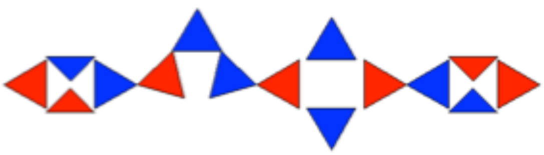
The configuration for nitrogen ^{14}N has the addition of another proton compared to ^{13}C. For ^{14}N, shown in Fig. 29, the additional proton adds an additional unbonded up quark into the configuration, such that there are 6 unbonded quarks. This gives ^{14}N an even lower binding energy per A, as compared with ^{12}C or ^{13}C. As with all atomic nuclei, there are numerous different ways to physically configure ^{13}C and ^{14}N, and these different configurations are the higher energy states. (The single proton segment and the single neutron segment cannot be situated next to each other in a stable atomic nucleus, because they would attempt to form a double-nucleon bond, which is not allowed.)



Alpha-neutron-star-proton-alpha

Fig. 29. Two short-hand simplified representations of ^{14}N.

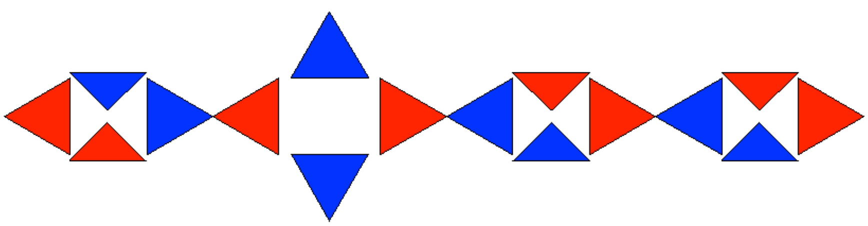
The configuration for ^{15}N has an additional neutron compared to ^{14}N, but it is able to form more bonds as a result of the added neutron. The ground state configuration for this atomic nucleus is shown in Fig. 30 in both the red-and-blue and verbal representations. For ^{15}N, there are only 5 unbonded quarks. Thus, when compared to ^{14}N with 6 unbonded quarks, the binding energy per A for ^{15}N is slightly increased, as is experimentally observed.



alpha-triton-star-alpha

Fig. 30. Short-hand simplified representations of ^{15}N.

The configuration for ^{16}O has an additional proton, compared to ^{15}N. The lowest energy configuration for this atomic nucleus is shown in Fig. 31, and is comprised of three alpha segments and one star segment, in an alpha-star-alpha-alpha configuration.



alpha-star-alpha-alpha

Fig. 31. Short-hand simplified representations of ^{16}O.

Once an understanding of the pattern from ^{12}C to ^{16}O has been gained, the configurations for the lowest energy states of the atomic nuclei are easily reproduced, with only a few simple energy-related rules. This pattern continues from ^{12}C to ^{250}Cf with the following energy-related rules. The first four rules apply to all atomic nuclei.

1. Due to the repulsion of the net electric charge, the particles separate themselves as far away as possible, while still maintaining as many bonds as possible.
2. There is one alpha segment for every two protons and two neutrons.
3. A star segment is in the middle, with two unbonded down quarks. The unbonded down quarks offset the high Coulomb energy in the middle of the atomic nucleus, and they help to separate the net positive charges. Good examples of these first three rules of the pattern are ^{20}Ne and ^{40}Ca, shown in Fig. 32.
4. If Z is odd and N=Z, there is a single neutron segment and a single proton segment. A good example of rule 4 is illustrated in ^{14}N (shown previously in Fig. 29).

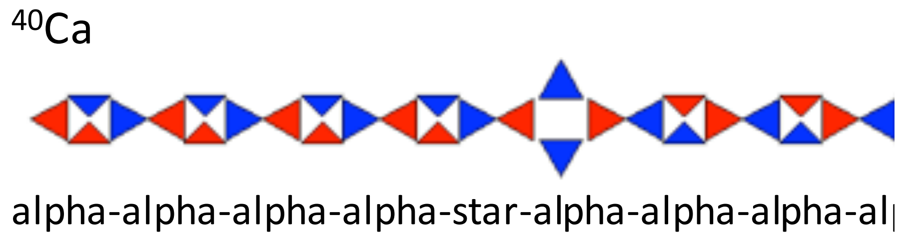


Fig. 32. Short-hand simplified representations of ^{20}Ne and ^{40}Ca.

The next three rules relate to atomic nuclei with more neutrons than protons. These rules are:

5. For even Z and N=Z+1, N=Z+2, or N=Z+3, the extra neutrons will be single neutron segments spaced between the alpha segments. The single neutron segments tend to be situated in what would otherwise be the highest concentration of positive charge, and they are situated between the alpha segments. Examples of the rule 5 are ^{13}C (shown previously in Fig. 28) for one extra neutron and ^{42}Ca for two extra neutrons, shown in Fig. 33.
6. For odd Z and N=Z+1, there is one tritium segment, as in ^{31}P. A good example of rule 6 is Phosphorous ^{31}P, shown in Fig. 33.
7. If there are enough extra neutrons to do so, N=Z+4 or greater, there will be two H4 segments, one on each end. These segments have an unbonded down quark on each end, as seen in ^{56}Fe. Any additional extra neutrons will be single neutron segments spaced between the alpha segments, as in ^{100}Ru and ^{208}Pb. Fig. 34 shows the configurations of ^{56}Fe, ^{100}Ru and ^{208}Pb.

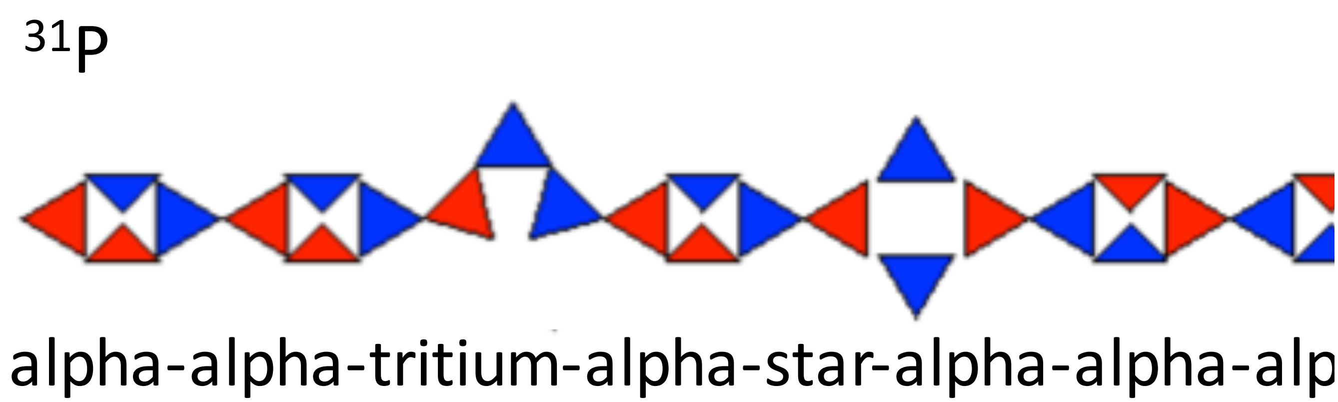


Fig. 33. Short-hand simplified representations of ^{42}Ca and ^{31}P.

^{100}Ru

H4-alpha-alpha-neutron-alpha-alpha-neutron-alpha-alpha-neutron-
alpha-alpha-star-alpha-alpha-neutron-alpha-alpha-neutron-alpha-a
alpha-neutron-alpha-alpha-H4

^{208}Pb

H4-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha
alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha
alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha
alpha-neutron-alpha-neutron-star-alpha-neutron-alpha-neutron-a
alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha
alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha
alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha

Fig. 34. Short-hand simplified representations of ^{56}Fe, ^{100}Ru, and ^{204}Pb.

From Fig. 34, it is easy to understand why iron ^{26}Fe has such a high binding energy per A. It is the largest stable atomic nucleus with only 4 unbonded quarks. Also, as can be noticed in Fig. 34, for the representations of the larger nuclei, such as ^{208}Pb, it is difficult to see the graphical representation due to its large size. It is easier to view the verbal representation of it.

7.6. Summary of the Basic Pattern for the Configurations of Stable Atomic Nuclei

The Electromagnetic Model has successfully computer simulated both stable and unstable atomic nuclei, all the way up to californium ^{250}Cf, using the electromagnetic equations and the equations for quantum angular momentum. From carbon ^{12}C upwards, the stable atomic nuclei follow a relatively simple pattern. This basic pattern is not mere speculation, but rather the pattern is due to the lowest energy configuration of the protons and neutrons, when taking into consideration the laws of electromagnetics, as applied to the quarks. The pattern is as follows:

- There is one alpha segment for every two protons and two neutrons.
- There is one star segment with two unbonded down quarks, near the middle of the configuration. These two unbonded down quarks have a negative charge, which offsets the high Coulomb energy in the middle of the atomic nucleus, and also allows the net positive charge to spread out slightly.
- When there are more neutrons than protons, the extra neutrons are either combined in a tritium segment or in single-neutron segments. These segments are interspersed within the net positive charge of the alpha segments, in such a way as to lower the overall positive electric field of the atomic nucleus.
- If there are enough extra neutrons, there will be two H4 segments, one on each end of the configuration. The inclusion of these H4 segments changes the end-most unbonded quarks from positive to negative charges, thereby eliminating the high positive charge density associated with the unbonded up quarks.
- This pattern continue up until there are more single neutron segments than alpha segments. That occurs at ^{209}Bi.

These configurations of the lowest electromagnetic energy are based on detailed computer simulations, with the numerous possible configurations being tested and compared. These configurations are not just mere speculation.

To summarize, the pattern is as follows. The various segments are linked together in a chain-like structure. There is one alpha segment for every two protons and two neutrons. There is one star segment near middle of the configuration. If N>Z and Z is odd, there is one triton segment in the configuration. Any extra neutrons with their unbonded down quarks are interspersed between the alphas. These unbonded down quarks have a negative charge which offsets and separates the net positive charge of the atomic nucleus. The unbonded down quarks tend to be situated in a region that would otherwise be a high concentration of positive charge. If there are enough extra neutrons in the atomic nucleus, they form H4 segments on both ends of the atomic nucleus. This increases removes any unbonded up quarks, with their high positive charge density, from the configuration. For the largest stable atomic nuclei, more unbonded down quarks, with their negative charges, are needed to offset the increasing net positive charge. These single neutron segments, with their unbonded down quarks, are situated between the alpha segments. This pattern continues up to ^{209}Bi, which is the largest stable atomic nucleus.

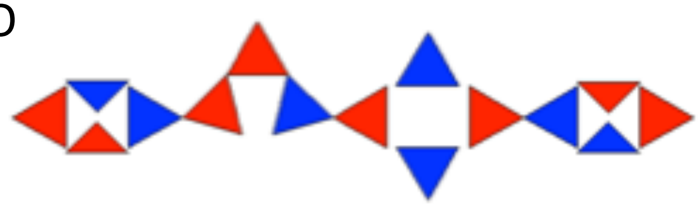
While these short-hand simplified graphic representations are drawn out as straight chains of segments, it should be mentioned that if the actual shape of the protons and neutrons interferes with the magnetic bond in such a way as to prevent a perfectly straight stacked bond between the segments, then these chains may be bent, curled, or spiraled. If so, this effect would not only decrease the intrinsic quadrupole moment, but it would also decrease the bonding energy very slightly, due to the Coulomb energy. This effect would be more pronounced for the larger atomic nuclei, which have a large excess of neutrons.

8. Basic Pattern for Radioactive Atomic Nuclei

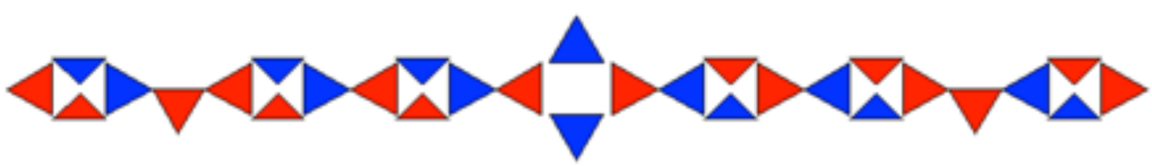
For the radioactive atomic nuclei, there are two more considerations for their lowest energy configurations. Again, these patterns are based on the patterns that emerge as a direct result of the electromagnetics energies.

- Any atomic nucleus with more single neutron segments than alpha segments will have the single neutron segments doubled-up, with no alpha segments in between them. These doubled-up single neutron segments tend to be near the middle of the chain, due to the electric force. For example, Uranium ^{238}U, which is shown in Fig. 35.
- When there are more protons than neutrons, the protons will either be single proton segments as in ^{13}N, or there will be in an He3 segment made of two protons and one neutron, as in ^{15}O and ^{30}S. Examples of these two additional rules for the radioactive atomic nuclei are shown in Fig. 35.

^{15}O



^{30}S



alpha-proton-alpha-alpha-star-alpha-alpha-proton-alpha

alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-n
alpha-neutron-neutron-alpha-neutron-neutron-alpha-neutron-star-neutron-alpha-neutron-neutron-alpha-neutro
neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutror
neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutron-alpha-neutror

H4-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-
α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-
α-n-n-α-n-n-α-n-s-n-α-n-n-α-n-n-α-
n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-
n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-α-n-H4

Fig. 35. Short-hand simplified representations of ^{13}N, ^{15}O, ^{30}S, and ^{238}U.

For ^{238}U, the neutron segments are spaced between the alpha segments, with the star segment in the middle. Also note that the adjacent double-neutron segments are also near the middle. It is interesting to note that there are no stable atomic nuclei with doubled-neutron segments.

8.1. Summary of the Basic Pattern for Radioactive Atomic Nuclei

Above ^{209}Bi, there are more extra neutron segments than alphas segments. For any atomic nuclei larger than ^{209}Bi, the extra neutron segments but must be doubled up in pairs, with no alpha segments in between, for example as seen in ^{238}U.

For atomic nuclei in which Z>N, there is only one stable atomic nucleus and that is ^{3}He. For all other atomic nuclei in which Z>N, they are radioactive. For the radioactive atomic nuclei with Z>N, there are either single proton segments or He3 segments in the configuration. Both of these segment types have unbonded up quarks associated with them, and as a result, they also have a high positive electric field in the immediate vicinity of the unbonded up quarks. Thus, the unbonded up quarks, with their high positive charge, tend to be at or near the end of the configuration in order to disburse this excess positive field as much as possible.

9. Results

9.1. Binding Energy Results

There remains only one parameter to be selected for the best fit to the binding energy data, the minimum distance between the two quarks of the two different nucleons—the "minimum internucleon quark-to-quark distance". This model has only one parameter to determine. The value for the minimum internucleon quark-to-quark distance is selected to be 2.11082 $*10^{-16}$ meters. The semi-empirical binding mass formula, which is also known as the Weizsäcker formula, uses five variables and a conditional logic statement to achieve its mathematical curve-fitting. The Electromagnetic Model of the Nuclear Force is able to get comparable results with only one variable. This is a significant achievement, and strongly implies the correctness of this model.

Hundreds of atomic nuclei have been modeled using this method to calculate the binding energy based on electromagnetics. This has been done for every atomic nucleus shown in Fig. 35. Each atomic nucleus is placed in the lowest energy configuration. Using this configuration, the electromagnetic energy and spin energy are then calculated, from which the binding energy is determined.

Using this value for the minimum distance between quarks, the resulting bonding energy curve is shown in Fig. 35. For comparison, two sets of values are shown: the calculated binding energy, shown below in red squares, and the experimental binding energy, show in light blue circles. (All experimental data has been extracted from reference [44].) Fig. 35a shows all the points from A=2 to A=208. Fig. 35b shows the detail of the points for the smaller atomic nuclei, from A=2 to A=60, for ease of viewing the details of this curve.

For the larger atomic nuclei, the kinetic energy due to nuclear spin is not a significant contributor to the binding energy. However, the smaller atomic nuclei, their binding energy is more strongly dependent on spin, as well as on the axis angle of the spin. For consistency, the axis angle has been set to 45° with respect to the y-axis, for all atomic nuclei. However, in actuality, the true axis angle of the spin could vary from this artificially fixed 45° setting. For the smaller atomic nuclei, this actual variation can appreciably affect the calculated binding energy, and this variation could easily explain the larger differences seen in the calculated binding energy for the smaller atomic nuclei.

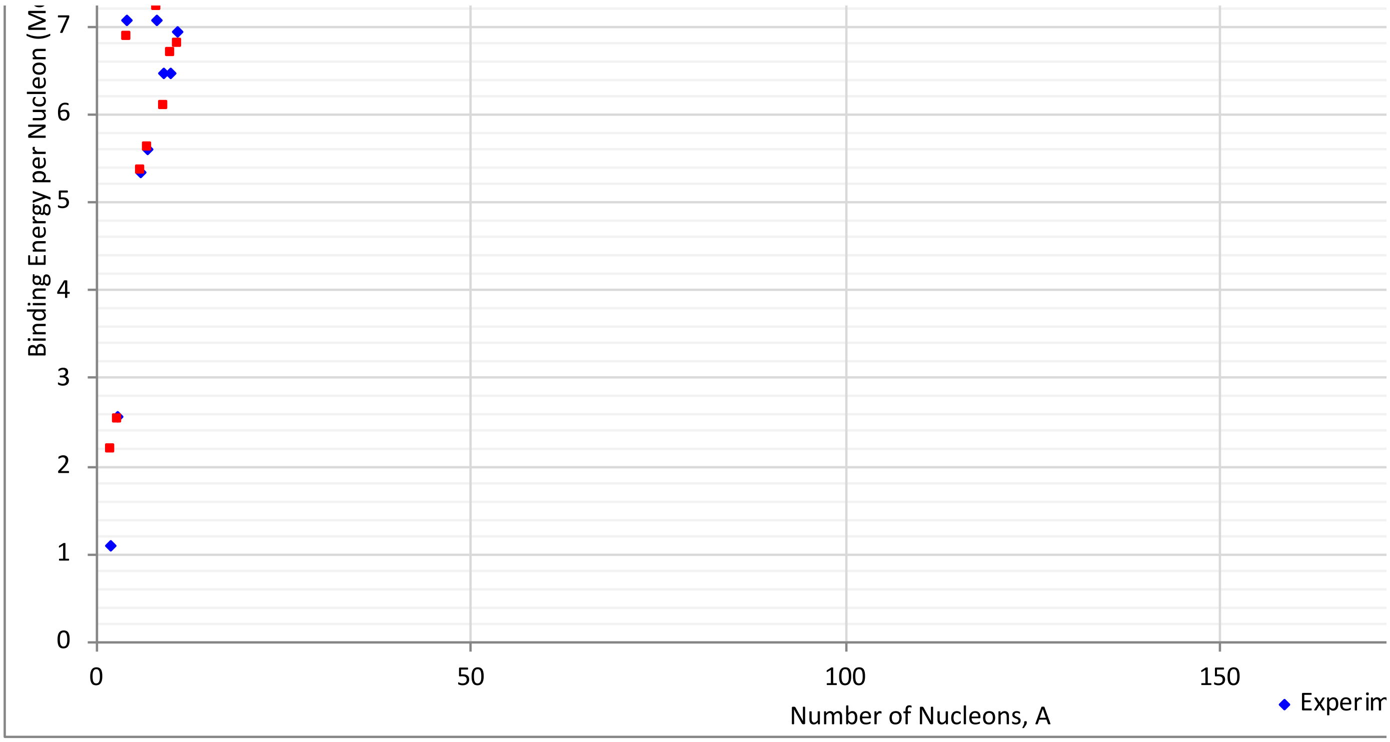


Fig. 35a Binding energy per A versus A, for the stable atomic nuclei, for both calculated and experimental data, from A=2 to A=208.

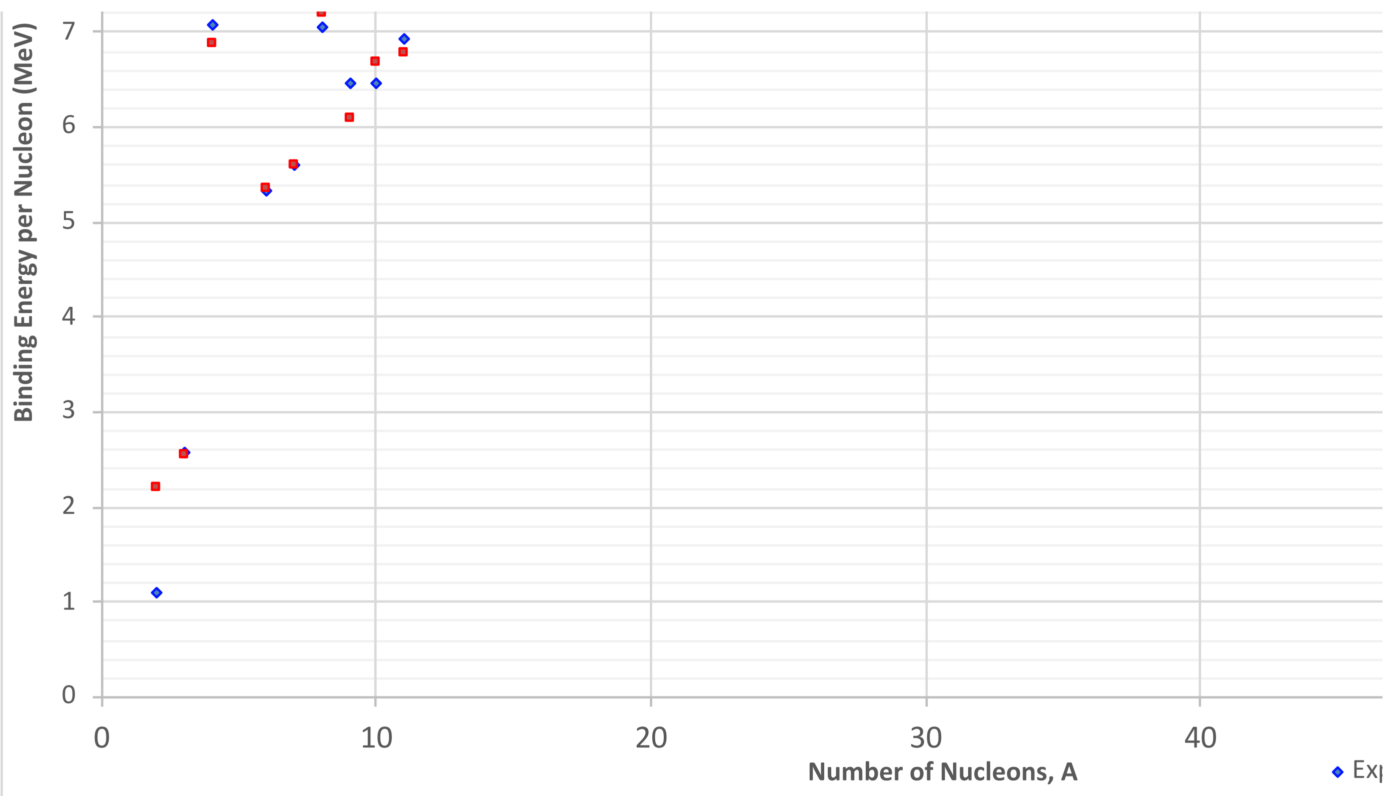


Fig. 35b Binding energy per A versus A, for both calculated and experimental data, showing detail for the smaller atomic nuclei.

This data show excellent reproduction of the experimental binding energy; most of the atomic nuclei fall within a one or two percent error. For the atomic nuclei with large A, the predicted downward slope is not as much as the experimentally observed downward slope. The largest error is 8.3%.

No other model has been able to predict such a tight correlation of binding mass. (Empirical numerical curve fitting is not a model.) Nor can any other model reproduce the general shape of this curve with only *one* variable. This is an unprecedented success in this result.

9.2. Results for Other Nuclear Behaviors

The Electromagnetic Model is also able to explain numerous results of other nuclear behaviors, behaviors that other models of the Nuclear Force have difficulty explaining. For example, excited energy states are very easily explained as being different configurations for the structure. Previous models do not incorporate structure into the models, rather they prefer to model the nucleus as independent particles in an energy well, or as a liquid drop, or as an energy shell. As a result, these models do not consider the concept of nuclear structure. Thus, the concept of different configurations of the atomic nucleus is not considered or explored. Because the Electromagnetic Model incorporates the concept of structure, excited states are easily understood as being a configuration that is not the lowest energy configuration for the Electromagnetic Force. The high energy states may or may not have a different spin, but they will always have a different configuration from the ground state configuration.

Particle decay is defined as when an atomic nucleus changes its mass number A, such as when a proton, neutron, or alpha particle is ejected from it. The previous models have difficulty explaining why particle decay occurs and why the Nuclear Force should suddenly turn itself off. Mathematically valid and coherent answers are not forthcoming the previous older models, except to say that experimentally, particle decay is energetically allowed. However, such experimentally based answers do not prove the validity of any model. Hence, there remains many unanswered questions and incongruities with these previous older models.

The Electromagnetic Model can easily explain particle decay as being either an attempt of the nucleons to double bond or triple-quark bond. Both of these attempts are not allowed due to the Pauli exclusion principal and the hard core repulsion. When the Electromagnetic Force attempts to double bond or triple-quark bond, the bonds break, and particle decay results. (This will be discussed in further detail in subsequent papers.) The concept of nuclear structure is necessary for the understanding of particle decay.

Regarding the experimentally measured electric quadrupole moments, they are much larger than what older previous models, such as the Shell Model, can explain. These large quadrupole moments are simply due to the inherent chain-like structures of the atomic nuclei in their lowest energy state. There are several legitimate explanations as to why the measured quadrupole moment may be smaller than the inherent quadrupole moment. The converse, however, is not easily explained at all. Thus, the previous older models of the nuclear force cannot explain the large quadrupole moments. The Electromagnetic Model can readily explain the large measured quadrupole moments as being due to the inherent chain-like structure of the lowest energy state.

Thus, the techniques of incorporating a structure into the nucleus and determining the lowest energy configuration are extremely important for the understanding nuclear behaviors. Structure and configuration are attributes that are able to explain much about nuclear behavior that the other previous older models can not explain.

9.3. Our Intended Endeavor for this Paper

As discussed in the introduction, the intended endeavor of this paper was to explore how much of the nuclear behavior can be explained by the Electromagnetic Force. The Electromagnetic Model can predict numerous aspects of nuclear behavior, and it can duplicate the binding energy curve better than the previous older models of the Nuclear Force. This model is can also explain many other aspects of nuclear behavior, better than any other singular model can do.

In the intended endeavor of this paper, the Electromagnetic Model is very successful. The answer to this investigation is that almost all of the nuclear behavior can be explained by electromagnetism. As intended, this investigation is done without having to include the mathematical equations or complicated simulations of other models—such as the Shell Model, Independent Particle Models, or the Residual Color Force Model—in order to understand nuclear behavior. This statement, that almost all nuclear behavior can be explained by electromagnetism, is a significant finding.

10. Conclusions

The laws of electromagnetics are valid inside an atomic nucleus, and these laws should not be disregarded. It is the electromagnetic properties of the quarks within the nucleus that create the Nuclear Force, the force holding the atomic nucleus together. Due to the electromagnetic properties of the quarks, the electromagnetic energies configure the protons and neutrons into the lowest energy state. This electromagnetic energy and the specific lowest energy configurations of the atomic nuclei are what control the nuclear behaviors. A better understanding of nuclear behaviors can be gained through this model by applying this knowledge and insight. Nuclear behaviors are a direct consequence of the Electromagnetic Forces acting within that nuclear structure. Thus, by recognizing the Electromagnetic Forces within the nuclear structure, a better understanding of nuclear behavior can be obtained. This model has directly unified the Nuclear Force to the Electromagnetic Force.

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Appendix: More Information about the Residual Color Force Model

1a. History

The Residual Color Force is also known as the "Residual Strong Force", the "Residual Strong Interaction", and the "Residual Chromodynamic Force". These are just different names for the same concept. The Residual Color Force Model is one of the many theoretical models of the Nuclear Force.

The Nuclear Force was thought, in 1935, to be mediated by virtual mesons. This theoretical development included a description of the Yukawa potential [1a] as an early representation of the nuclear potential. By the 1970s, particle physicists determined that nucleons were composed of quarks, and that the bond between nucleons was actually a bond between the internucleon quarks for neighboring nucleons. The Residual Color Force Model of the Nuclear Force hypothesizes that this internucleon quark-to-quark bond is related to the quark's color. Also, the Residual Color Force is presumed to be a residual effect of the Quantum Chromodynamic Force. However, this hypothesis is not confirmed experimentally, and it remains as a strictly theoretical concept. Because color forces cannot be directly measured, there is no direct evidence to corroborate the concept that the internucleon quark-to-quark bond is caused by quark color. Thus, it is strictly a hypothetical supposition that the Nuclear Force is based on quark's color rather than on the quark's electromagnetic properties.

2a. Introduction

Quantum Chromodynamics (QCD) is the theory of the color interactions inside the hadrons [2a]. It deals with quarks, gluons and their interactions. QCD is also part of the Standard Model of Particle Physics. QCD is a non-Abelian gauge field theory with color SU(3) as the underlying gauge group.

The Residual Color Force Model, which is based on QCD, is one of the many numerous models of the Nuclear Force, and it theorizes that the force between nucleons is a residual of the QCD color interaction, similar to the van der Waals force between electrically neutral molecules. The Residual Color Force Model is an extremely complex problem that can only be solved with brute computing power on a discretized, Euclidean space-time lattice, known as lattice QCD. In other words the quarks are positioned in a lattice of three dimensions of space and one dimension of time.

Similar to the Yukawa Model, the hypothesis of the Residual Color Force Model claims that the Nuclear Force is mediated by the exchange of mesons, in particular virtual pi-mesons, or pions. There is no closed mathematical form for the Residual Color Force. There are relatively few published scientific papers that attempt to perform simulations of the Residual Color Force, and these simulations use extremely complex lattice QCD calculations. The simulations of the Residual Color Force have been relatively unsuccessful in duplicating nuclear behavior, with extremely large errors in the resulting simulated quantities. Also, these computer models use quark masses which are much larger than what the quark mass is estimated to be, by as much as a factor of 50 or more. Thus, the computer simulations for the Residual Color Force are not only sparse, but also lacking credibility.

The hypothesis of the Residual Color Force Model is that most of the Quantum Chromodynamic Forces, which are due to the gluons and the quarks inside of the nucleon, cancel each other outside of the nucleon. In other words, when viewed from the outside, the nucleons are color neutral. The interaction between the various colors of the gluons and quarks inside the protons and neutrons is called the "Quantum Chromodynamic Force". The interaction between the various colors outside the protons and neutrons is called the "Residual Color Force". Not only does the name of the force change, but the range of the force also changes. Outside the proton or neutron, the force becomes a short range force, of only 1 to 2 femtometers. Also, the mediating particle of the force changes from a massless gluon to a virtual pi-meson.

3a. Virtual Particles

Note that these mediating pi-mesons are virtual particles; they are not actual physical particles. Virtual particles are believed to be a result of quantum energy fluctuations, existing for energies and time durations that are below the detection of the quantum uncertainty principles. Thus they can be conceptualized as going in and out of existence as the quantum fluctuations occur. These virtual particles are not an actual physical or measurable entity. As seen in lattice field theory, it is possible to perform quantum field theory calculations that are completely absent of the concept of virtual particles. As a result, it is often said that virtual particles are simply a conceptual or mathematical tool [3a].

4a. Computer Simulations and Equations from the Researchers, Aoki et al

In the computer simulations done by Aoki et al [4a], the Residual Color Force has a potential V that is the sum four components, including a central potential VC(r) and a tensor potential VT(r). Also included in the sum are VLS and O(v2), where VLS is the potential due to spin orbit, and O is the energy due to its velocity v. This sum is written mathematically, as shown in Eq. 1a:

$$V=VCr+VTrS12+VLSr\mathbf{L}\cdot\mathbf{S}+Ov2$$ *Eq. 1a*

where r is the center-to-center distance, and L and S are vector angular momentum quantum numbers.

The expression for the central potential VC is shown below, in Eq. 2a:

$$VCr=E-1\Delta rQS12\psi21rH0\wp\psi21r-\wp S12\psi21rH0Q\psi21r$$ *Eq. 2a*

And the tensor potential VT is shown in Eq. 3a:

$$VTr=1\Delta rQ\psi21rH0\wp\psi21r-\wp\psi21rH0Q\psi21r$$ *Eq. 3a*

In both of these equations, Δ(r) is also a function of r, and is defined by Eq. 4a:

$$\Delta r\equiv\wp\psi21rQS12\psi21r-Q\psi21r\wp S12\psi21r$$ *Eq. 4a*

Once these potentials have been determined, they are used in the Schrödinger equation in order to consider the quantum wave-like properties of the system. This is done in an attempt to duplicate the Reid diagrams of the Nuclear Force—diagrams that plot energy and force as a function of distance, for a single nucleon interacting with another nucleon. However, unrealistically large quark masses must be used in order to facilitate convergence of these computer simulations.

5a. Computer Simulations and Equations from the Researchers, Beane et al.

The scattering behavior between two nucleons has been calculated using the theoretical model of the Residual Color Force Model by Beane et al [5a]. By theoretically examining two nucleons contained within a box of length L, with their center of mass at rest, the energies of the low lying energy levels can be computed in terms of p cot δ. The values of p2 that solve Eq. 5a give the locations of all of the energy eigenstates in the box, including bound states, for which p2 < 0.

$$p\cot\delta p=1\pi LSLp2\pi2$$ *Eq. 5a*

where the value of S is a function of η, as shown in Eq. 6a.

$$S\eta\equiv j\Lambda j1|j|2-\eta-4\pi\Lambda j$$ *Eq. 6a*

The authors state that this derivation is valid within the radius of convergence for the Effective Field Theory without pions. In the limit L >> a (where a is the scattering length), an approximation for the attractive binding energy of the two nucleon system can be obtained. The approximate energy of the lowest lying state is shown in Eq. 7a:

$$E-1=\gamma2M1+12\gamma L11-2\gamma pcot\delta'e-\gamma L+\ldots$$ *Eq. 7a*

where:

$p\cot\delta'=ddp2p\cot\delta$ is evaluated at p2=-γ2 and the quantity γ is the solution of the Eq. 8a:

$$\gamma+p\cot\delta|p2=-\gamma2=0$$ Eq. 8a

This quantity γ is the bound state binding energy, in the infinite-volume limit. The scattering behavior caused by the Residual Color Force between two nucleons is then simulated, to extract the desired quantitative information.

In a subsequent follow-up paper [6a], the researchers determined the binding energy for both exotic hyper-nuclei (which contain strange quarks) and non-exotic nuclei. The results of this computer calculation for the non-exotic nuclei are shown in Table 1a:

Nuclide	Calculated Binding Energy as calculated in this referenced report, in MeV	Actual Binding Energy	%error
H-2	19.5	2.22	878%
H-3	53.9	8.48	636%
He-3	53.9	7.72	698%
He-4	107	28.3	378%

Table 1a: Calculated binding energies from the Residual Color Force, compared to the actual binding energies for 4 nuclei. Note this is binding energy, not binding energy per A.

As can be seen in this table, the calculated binding energies have extremely large errors when compared to the actual binding energies. It should also be noted that in these simulations, the quarks masses are set to values much larger than the currently accepted value. The results are then extrapolated to the smaller quark masses, a process that could introduce very large errors.

6a. Computer Simulations from the Researchers, Hatsuda et al.

In another lattice QCD calculation, the nucleon-nucleon (NN) potential was studied by Hatsuda et al [7a]. For this study, it must again be noted that unrealistically large quark masses were used. This paper only studied exotic nucleons, which are thought to exist theoretically only in neutron stars, and are not normally found in nature. Thus, the results of this paper are more of interest to cosmology than to the topic of this paper.

There are other papers related to binding energy of nuclei and lattice QCD, however they are not considering quarks nor the Residual Color Force in the simulations. Rather they examine only the Effective Field Models.

7a. An Inherent Problem with the Residual Color Force Model

In Table 1a, the calculated binding energy of the 3H and the 3He are the same. (Also in the referenced paper, the exotic nuclei with A=4 have the same binding energy as 4He.) This result is because the Residual Color Force Model considers only the color of the quarks and not the flavor of the quarks. The nucleons all have three colors—red, green, and blue—inside of them. Nucleons are distinctive from each other due the flavor of the quarks—up, down, top, bottom, charm or strange.

For example, consider isobar with the same A but with different Z and N values. A computer simulation of the Residual Color Force might look at the nuclear binding energy of an isobar, with a given mass number A, and it would erroneously conclude that the binding energy for all the isobars are the same. This is because the Residual Color Force Model does not consider the flavor of the quarks, ignoring the up and down attributes of the quarks. With only the quark color as a consideration, all isobars are essentially identical. (This is especially true if the Coulomb energy is also ignored.) This is an inherent problem for the Residual Color Force Model, and this effect is seen in the binding energy simulations of this force. For example, the binding energies of 3H and 3He are identical [5a]. More tellingly, for the A=4 nuclei in the referenced paper, the binding energies for all the exotic nuclei with A=4 and the non-exotic nuclide of 4He are also exactly the same.

If the bonds between the nucleons are bonds based only on the color of the quark, as the Residual Color Force Model speculates, then all isobars for a given A would have the similar binding energy and similar behavior, differing only slightly due to Coulomb energy. Empirically it is known that such behavior is not representative of reality.

8a. Summary of Research about the Residual Color Force

The simulations of the Residual Color Force Model are complex, difficult, and have yielded only a relatively small amount of data. Furthermore, there has been little recent progress in this field. Thus the Residual Color Force Model is not a viable or practical solution for the understanding nuclear structure, nuclear behavior, or nuclear physics.

References for Appendix:

1a.) Yukawa, H. (1935). "On the interaction of elementary particles". *Proc. Phys. Math. Soc. Jpn.* 17: 48.

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3a.) https://en.wikipedia.org/wiki/Virtual_particle

4a.) Sinya Aoki et al., (2010). "Theoretical Foundation of the Nuclear Force in QCD and its Applications to Central and Tensor Forces in Quenched Lattice QCD Simulations" *Progress of Theoretical Physics,* Vol 123. No. 1.

5a.) S.R. Beane, et al. "Two Nucleons on a Lattice" arXiv:hep-lat/0312004v1. *Phys. Lett.* B585:106-114 (2006.)

6a.) S.R. Beane, et al. "Light nuclei and hyper nuclei from quantum chromodynamics in the limit of SU(3) flavor symmetry" *Physics Review* 87, 034506 (2013.)

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