Checkerboard Structure of the Nucleus

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A flat structure of the nucleus better explains such properties of the nucleus as its stability and the existence of the known isotopes. This new model is called the Checkerboard Model (CBM). It has features similar to the Bohr model of the atom and the alpha model of the nucleus proposed fifty years ago.

Any successful theory of the nuclear strong force will have to explain some key properties of the nucleus. The most important of these are:[1]

1) Electrons are not affected by the nuclear force.

2) The nuclear force depends upon whether the spins of the nucleons are parallel or anti-parallel.

3) The nuclear force includes a repulsive component that keeps the average separation of the nucleons at a distance of 1.8 fm. Given this distance and the accepted radius of the proton and neutron (about .45 to .65 fm),[2,3] it must be concluded that only about 1/15 of a *spherical* nucleus contains nuclear matter.[3]

4) The nucleon-nucleon force has a non-central (tensor) component, which is the major contributor to the strength of the strong nuclear force.

5) The neutron distribution extends beyond the proton distribution in large nuclei.[2]

6) The nuclear strong force is known to have a very short range decreasing to 1% of its normal value when the distance between nucleons doubles,[4] making it about the same strength as the electromagnetic force at that distance.

7) For distances of the normal average separation (1.8 fm) the strong nuclear force is 100 times as strong as the electromagnetic force.[4]

8) Size of the nucleus.

9) Binding energy per nucleon.

10) The nuclear force turns repulsive for proton radius of less than 0.5 fm.

The new model that is being proposed is called the Checkerboard Model (CBM) because it starts out by assuming that the nucleons are not oriented in a spherical ball, but instead are oriented on a two-dimensional plane patterned like a checkerboard. The model also assumes, just like in the game of checkers, that the protons can only occupy the dark colored squares of the checkerboard and the neutrons can only occupy the light colored squares. Therefore, there is never a proton next to a proton or a neutron next to a neutron in the nucleus. Since, in this model, bonding essentially only occurs at right angles, this model explains, quite simply, why two protons or two neutrons do not form stable bonds. It also explains why the spin of the nucleus is a multiple of spins of the proton and neutron. Based upon this model, the alpha particle would have the structure shown in Figure 1.

This model evolved from the idea that perhaps the structure of the alpha particle, known to be very stable, was a result of the two like quarks in a nucleon spinning around the odd quark in the nucleon. From this model we see that the +2/3 up quarks of the protons will be approaching the -1/3 down quarks of the neutrons at the perimeter of the nucleons. Also, note that in the proposed alpha particle structure there is one spin up proton and one spin down proton. The same is true for the two neutrons. This gives rise to the rationale for the nucleon pairing stability.

The model requires that the rotational speed of the quarks in the protons and neutrons be matched. This is consistent with the spin of the two nucleons being the same. The matched spins are required since this model postulates that the quarks of opposite charge approaching each other at the nucleon perimeters are the major component of the strong nuclear force (the tensor term). Since the quarks are nearly touching at the perimeter of the nucleons, the force generated by this attraction rises with the inverse square of the distance, thereby accounting for the strength of the tensor component of the strong force. This explains why the nuclear force is so strong, since the approach distance of the quarks is about ten times closer and less random than previously thought. It was also a mystery why a zero charged particle (the neutron) would have a magnetic moment. The CBM can now explain the source of the magnetic moment of the neutron. The magnetic lines of flux also add additional strength to the alpha structure in the third dimension. The orientation of magnetic flux fields also explains why the nucleon spin orientations affect the nuclear binding energy and the strong force.

Using the relative size of the magnetic moment, the charge on the quarks, and the assumption that both the proton and neutron have the same frequency of rotation, the model gives the relative radius of the proton and neutron using the following equations. Note, the model assumes the quark in the center of each particle does not contribute to the magnetic moment.

$$\mu = I\,A = q_{(\text{rotating quarks})}\, f\,(\pi r^2)$$

$$\mu_{\text{proton}} = 2(2/3)\, f\pi(r_{\text{proton}})^2$$

$$\mu_{\text{neutron}} = 2(-1/3)\, f\pi(r_{\text{neutron}})^2$$

$$\mu_{\text{proton}} / \mu_{\text{neutron}} = -2(r_{\text{proton}} / r_{\text{neutron}})^2$$

$$r_{\text{neutron}}/r_{\text{proton}} = [2\{0.96623707/1.41060761\}]^{1/2}$$

$$r_{\text{neutron}} = 1.1704523\ (r_{\text{proton}})$$

On this basis the neutron is about 17.04523% larger than the

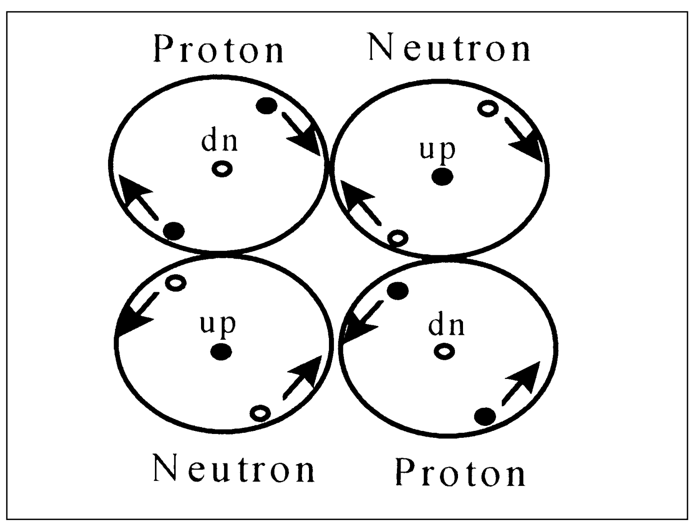

Figure 1. Structure of the helium nucleus. up = Up Quark; dn = Down Quark

proton. It is generally accepted that the neutron is slightly larger than the proton. The ratio of the rms radius of the neutron to proton is (0.8 fm / 0.7 fm), or 1.14 is in agreement with this calculation.

The binding energy difference of the ^3H vs. ^3He (0.76374 MeV/c^2) and the normal assumption that the difference in the binding energy between ^3H and ^3He is due to electrostatic repulsion[5] allow us to calculate the distance (R_c) between the two protons in the ^3He structure, which is assumed to be a linear alignment (proton, neutron, proton) in this model due to the repulsion of the two protons.

$$\text{Binding Energy of } {}^3H = \text{mass } {}^3H - m_{electron} - m_{proton} - 2\, m_{neutron} = 8.48183 \text{ MeV}$$

$$\text{Binding Energy of } {}^3He = \text{mass } {}^3He - 2\, m_{electron} - 2\, m_{proton} - m_{neutron} = 7.71809 \text{ MeV}$$

$$BE({}^3H) - BE({}^3He) = 0.76374 \text{ MeV}$$

$$\text{Coulomb repulsion in } {}^3He = BE({}^3H) - BE({}^3He) = 0.76374 \text{ MeV} = 6e^2/5R_c$$

Solving the above equation for R_c gives a value of 2.262 fm. Using the assumed linear structure for ^3He (PNP), and the radius of the neutron as being 1.1704523 times larger than the proton, results in a size of the proton of 0.5211 x 10^{-13} cm, and a size of the neutron of 0.6099 x 10^{-13} cm. These numbers are in fairly good agreement with published values.[3] In fact, the scattering of the neutron by electrons shows a positive core to the neutron and a negative outer distribution that peaks at about 0.6 fm in agreement with this model.[6] (The accepted rms radius of the neutron is 0.8 fm and the tail of its charge distribution goes out to about 1.2 fm.)

Combining the calculated size of the proton and neutron with the known magnetic moments of the proton and neutron gives the relativistic speed of the up and down quarks.

$$\mu = I\,A = 1/2(q\ v\ r)$$

$$v_{up\ quark} = 2\,\mu_{proton} / \{2\,(q_{up\ quark})(r_{proton})\}$$

$$v_{up\ quark} = \frac{2\,(1.41060761 \times 10^{-26}\ J/T)}{2(2/3)\,(1.602095^{-19} C)(0.5211\ fm)}$$

$$\text{velocity}_{(2\text{ up quarks in the proton})} = 2.53447 \times 10^8 \text{ m/s} = 0.8454 \text{ the speed of light}$$

$$\text{velocity}_{(2\text{ down quarks in the neutron})} = 1.1704523\,(v_{up\ quark}) = 0.9895c$$

Setting up two relativistic simultaneous equations involving the rest mass of the up and down quarks and setting that equal to the known rest mass of the proton and neutron allows the determination of the rest mass of the up and down quark.

$$m_{proton} = m_{down\ quark} + \frac{2\,m_{up\ quark}}{\sqrt{1-\left(\frac{v_{up\ quark}}{c}\right)^2}}$$

$$m_{neutron} = m_{up\ quark} + \frac{2\,m_{down\ quark}}{\sqrt{1-\left(\frac{v_{down\ quark}}{c}\right)^2}}$$

This exercise results in a calculation of the rest mass of the up and down quarks. The surprise of this exercise is that the de Broglie wavelength of the up quark in the proton almost exactly matches the circumference of the postulated size of the proton (less than 1% error).

$$\lambda_v = h / m_v v$$
$$\text{where } h = 6.626068(91) \times 10^{-34} \text{ Joule} - \text{sec}$$

Iterating the size of the proton and neutron along with the speeds of the up and down quark until the de Broglie wavelength of the up quark in the proton is exactly the proton circumference results in the following values:

Radius of the proton	0.519406 fm
Radius of the neutron	0.6079394 fm
Mass of up quark	237.31 MeV/c^2
Mass of down quark	42.392 MeV/c^2
Speed of up quark in proton	0.848123 the speed of light
Speed of down quark in neutron	0.992685 the speed of light

The results of these numbers indicate that the sum of the rest mass of the two up and one down quarks in the proton account for 55% of the mass of the proton; the other 45% comes from the relativistic mass of the two up quarks. The period of revolution of the two quarks in the proton and neutron becomes 1.283533 x 10^{-23} seconds. These values not only give the right values for mass of the proton and neutron, and approximately correct values for the radii of the proton, they by design give the correct value of the magnetic moments for the proton and neutron. Work done by Amaldi has shown that rms radius of the proton is about 0.65 fm based upon pp scattering.[7] Also remember that the nuclear force becomes repulsive for approach distances of less than a radius of 0.5 fm. Could this property of the strong force be justified in this model by the incompressibility of the proton, whose radius is about 0.5 fm in the CBM?

The CBM suggests why the neutron is unstable when it is outside the nucleus and stable inside the nucleus. Inside the nucleus the wavelength of the down quarks in the neutron is 6% smaller than the circumference of the neutron. The model suggests that the neutron gets extra stability from the up quarks in the proton, which have exactly a 1.0000 de Broglie wavelength. Outside the nucleus this reinforcement does not exist. Also a possible shrinking of the neutron by 10% (assuming constant angular momentum) when inside a given nucleus may resolve the 6% offset of the de Broglie wavelength of the down quarks in the neutron and may account for some of the binding energy of the structure.

Any new model of the nucleus must explain the dependence of binding energy per nucleon on the number of nucleons. The best current model that explains nuclear binding energy is the liquid drop model, which uses a bulk term, a surface term, plus a few others to explain the binding energy per nucleon in a continuous curve. The CBM is interesting, since it does not develop a smooth continuous curve, but a curve with more bumps in it, in better agreement for the low mass nuclei. The most naïve approach to this subject would have been to try to estimate the binding energy per bond, count the numbers of bonds (divided by the number of nucleons) and that would be the binding energy per nucleon. This simple approach does not work. But even with this naïve approach it becomes obvious, based upon the structures this model suggests, that ^{56}Fe will be the nucleus of maximum binding energy per nucleon, since it has the highest percentage of 4-bond sites of any nucleus, in this model. There is no other model that predicts that ^{56}Fe will have the maximum BE per nucleon. The BE per nucleon relation is more complicated than a naïve approach would indicate, because of the flux coupling of adjacent and second nearest neighbors. Therefore, the bond

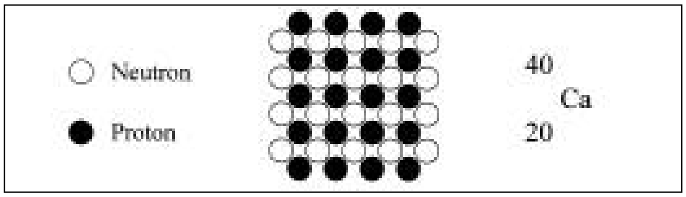

Figure 2. CBM proposed structure of ^{40}Ca.

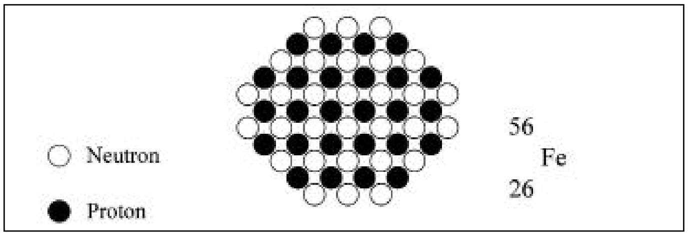

Figure 3. CBM proposed structure of ^{56}Fe.

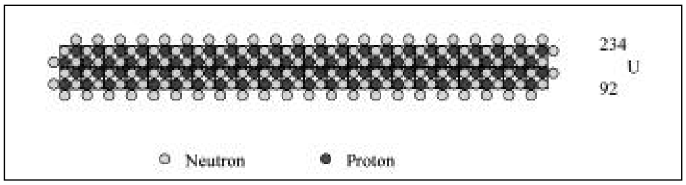

Figure 4. CBM proposed structure of ^{234}U.

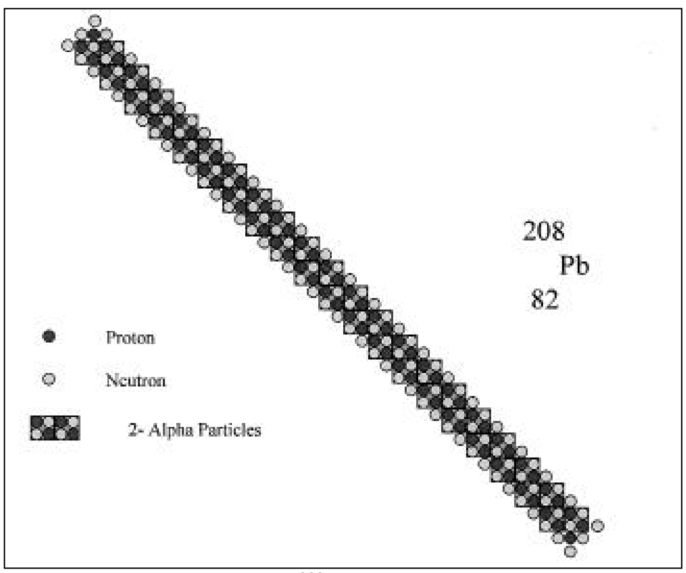

Figure 5. CBM proposed structure of ^{208}Pb.

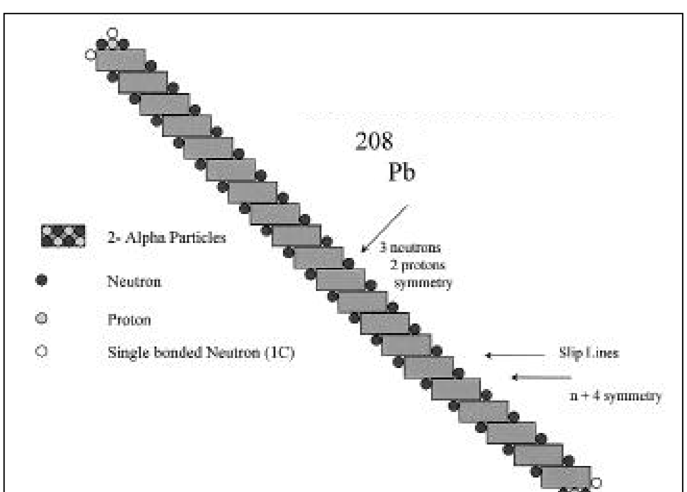

Figure 6. CBM proposed structure of ^{208}Pb.

energy must be studied empirically based upon some few selected nuclei. The nuclei chosen for this empirical fit are: ^{2}H, ^{4}He, ^{40}Ca, ^{56}Fe, and ^{234}U. ^{2}H is chosen because it characterizes the single bond site. ^{4}He is chosen because it characterizes the double bond site. Since ^{40}Ca is only comprised of 2-bond and 4-bond sites, it is used to determine the strength of a 4-bond site, since we already know the value of a 2-bond site. ^{56}Fe being a mixture of 2-, 3-, and 4-bond sites allows us to calculate the value of a 3-bond site. ^{234}U is used to calculate a value of a 1-bond site with two adjacent second-nearest-neighbor sites. These are common in the very high mass structures and are called, in this model, a 1c site. A single bond with no second-nearest-neighbor flux coupling is a 1a site, and if the 1-bond site has one second-nearest-neighbor to add flux coupling, it is a 1b site. Here are the values needed to calculate the binding energies per nucleon:

1-bond site	1.11 MeV/c^2
2-bond site	7.07 MeV/c^2
3-bond site	8.13 MeV/c^2
4-bond site	9.53 MeV/c^2
1c-bond site	1.73 MeV/c^2
1b-bond site	1.42 MeV/c^2

Two-bond and 4-bond sites always have the same number of second-nearest-neighbors. It is possible that a 3-bond site will have one or two nearest-neighbor sites, but these structures are not common in ground state nuclei and they would add only slightly to the 8.13 MeV/c^2 this bond site already contains. These values give very good agreement with the accepted binding energy per nucleon values. See Figures 2, 3, and 4 for the structures of ^{40}Ca, ^{56}Fe, and ^{234}U used to make these calculations.

One interesting feature of this model is that ^{208}Pb turns out to be a structure that has a very symmetric shape (four-fold symmetry). See Figure 5. It is disturbing because it is long and thin, not what one would have expected, especially by traditional nuclear physicists. Another of its symmetries is a 3:2 symmetry. It is an alternating pattern of three neutrons followed by two protons. With the three extra neutrons, due to neutrons on both ends of the structure, this structure is perfectly symmetric and gives a logical and structural support to the 3:2 ratio of neutrons to protons of this nucleus. Another symmetry of this structure is a periodic two alphas plus two neutrons (four protons, six neutrons, or two alphas per step). See Figure 6. For the radioactive heavy nuclei, we know there are four decay families, based upon (n, n+1, n+2, n+3) protons. Therefore, there is a natural structure of the heavy radioactive nuclei that repeats every four protons (and every six neutrons). The symmetry of both ^{234}U and ^{208}Pb give structural logic to the reason why there are four radioactive series. Also notice that the neutrons naturally extend beyond the protons.

At first glance the ^{234}U structure looks even more bizarre than that of ^{208}Pb. See Figure 4. It looks very unstable because of all the single bond sites, but as clarified above these are 1c sites with more stability than just the 1a sites. The additional stability comes from the flux coupling of the second-nearest-neighbor sites. A close look at these two structures will reveal that the ^{234}U structure is the square root of two times shorter than ^{208}Pb. This came about naturally and was not forced. This means that there is more proton repulsion in the ^{234}U than in the ^{208}Pb structure, and not just because it has more protons. In this respect ^{234}U is like a compressed spring. Because of its symmetry it is stable for long periods of time, but any break in this symmetry (like an alpha emission) is like a hair trigger that eventually causes the whole structure to deform and stretch out, taking on the final structures of the Pb nucleus (more stretched out). This is an interesting feature of this model.

A model of the nucleus must be able to explain nuclear excited states. Why should ^{6}He and ^{6}Be have only three known states?[8] (Early references show that ^{6}He and ^{6}Be have only two known states and they should have the same number, since they were mirror nuclei.[9]) ^{6}Li, on the other hand, has six known excited states. Since all three nuclei have six nucleons, and the forces between nucleons are supposedly independent of the type of nucleon, a first approximation would expect these nuclei to have the same number of excited states. Complicated quantum mechanical models have attempted to explain the number of states for each of these nuclei. The CBM predicts that there should only be three excited states of ^{6}He and ^{6}Be and one is obviously more stable than the other. See Figure 7. This model also naturally explains why ^{6}He and ^{6}Be are mirror nuclei. Notice by exchanging protons for neutrons, and visa versa, we transform one nucleus into the other. They both have the same structures. ^{6}Li being a nucleus with three protons and three neutrons has more possible configurations to arrange into nine shapes on a checkerboard, including a very unstable, and perhaps unfound, linear array of (p, n, p, n, p, n). Four of these nine structures are two sets of mirror nuclei. The number of excited states of other light nuclei also seem to agree with the CBM. CBM has not yet been developed enough to predict the value of the energy levels of these excited states.

Recent findings using the Gammaball (gamma ray energy detector) developed at Berkeley and Argonne have found that the y-rast excited states of many heavy nuclei have regular spacings. Equally spaced energy states seem to defy a simple explanation in QM terms. The nuclear physics community is at a loss to explain why these levels are equally spaced. As seen in the CBM, the large nuclei are spread out, similar to Pb, although some intermediate heavy nuclei have three helium structures per step. There appears to be a correlation between the number of steps in the CBM of the heavy nuclei and the number of these evenly spaced energy levels.

The nuclear force is sometimes considered to be a two pion exchange force, and the CBM suggests a justification of the two particle pion exchange force. Interestingly, the rest mass of 2p mesons is almost exactly the sum of the rest mass of the up and down quarks in this model (0.2% error).

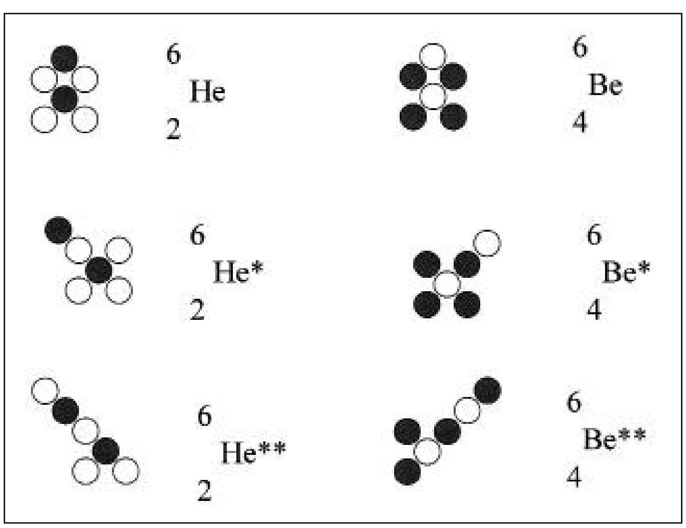

Figure 7. CBM proposed stucture of excited states of ^{6}He and ^{6}Be.

During the 1970s and 1980s, in attempts to understand the existence of neutron stars, a number of quantum mechanical theories were developed that explained the structure of the nucleus as: semi-lattice, layered lattices (both 2- and three-dimensional), and the cluster models. Nucleon lattice structures have also been used to explain the break-up of large nuclei in multifragmentation studies. The theory and the data seem to agree, quite surprisingly. A review of this subject can be found in the work of N.D. Cook and D. Valerio, specifically their references 11-19.[10] A detailed description of the layered lattice model can be found in R. Tamagaki.[11] These models not only explain the layered model in quantum mechanical terms but also explain the rationale for the neutron stars. A number of aspects of the CBM agree with these earlier models:

1) CBM assumes that the tensor force between nucleons is the primary component of the nuclear force and, therefore,

2) The pairing of the protons and neutrons is a result of opposite orientated spin pairs of protons and neutrons, and

3) The alpha particle is the basic building block, having one spin up and one spin down, proton and neutron. The CBM deviates from some of these past works, since it is a two-dimensional model, not a three-dimensional model of the nucleus. CBM assumes that three-dimensional cubic structures are necessary to explain neutron stars.

There will be some skeptics of this model who will say this two-dimensional structure is unrealistic and not useful. In 1925 E. Ising published a paper using a simple one-dimensional model to explain ferromagnetism.[12] That paper led to the extension of this one-dimensional model into a two-dimensional model by L. Onsager[13] in 1944, which has found great applicability and has opened up the theoretical field of low-temperature phase transitions. This work has been expanded upon by many other authors.[14] Onsager's solution introduced the concept of correlation length, which has become very important to our understanding of the critical point in a phase transition. This was the one and only paper ever published by Ising. Ising, in many respects, remains unknown to most in the field of physics, yet to this day the concept of a systems critical point in a one-dimensional model is referred to as the Ising model. Therefore, new concepts even in one-dimension can eventually lead to a better understanding of the real physics of nature. Take, for another example, the concept of the quark itself.

The real beauty of CBM comes in its ability to explain the existence and stability of some of the very unstable nuclei. As just one example of the power of this model, the structure in Figure 8 would explain the existence of ^{8}He, ^{11}Li, ^{14}Be, ^{17}B, ^{20}C, ^{23}N, ^{26}O, ^{29}F, ^{32}Ne, and ^{35}Na. The first four of these isotopes along with ^{6}He and ^{12}Be are referred to as the halo isotopes, because the neutrons in these structures are known to be far out from the core of the nucleus, which results in the term halo neutrons. It is also known that the outer "two" neutrons are loosely bound to the core. When one considers the symmetry that CBM predicts, the above description fits, even though there are two loosely bonded neutrons on each

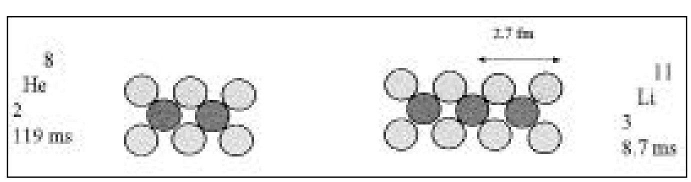

Figure 8. CBM proposed structure of the first two halo nuclei.

end of the structures in Figure 8.[15]

In the case of ^{6}He and ^{12}Be this model would suggest that these structures have their two halo neutrons on "one" end of the structure. How else could both ^{6}He and ^{8}He be halo, each resulting in only "two" halo neutrons? One thing this model does not resolve is why experimentalists have not found ^{9}Li to be a single-ended halo structure, yet.

These two-dimensional structures also give approximately correct values for the radii of larger nuclei. The diameters of the flat plates that this model predicts are in good agreement with the diameters of a spherical nucleus, since the proton and neutron in this model are significantly smaller than the extrapolated values based upon spherical models (1.23 fm). These plates are similar to projections of a sphere onto a plane. For nuclei above Fe, the structures get elongated, and therefore a single number can no longer define the size of the nucleus. An approximate size (cross section) of these larger nuclei can be determined by calculating the two-dimensional area of protons and neutrons and converting the result into an effective diameter of the nucleus. This results in sizes that are, again, reasonably close to accepted values.

This model is the only one of the existing models that can suggest why linear alpha chains can exist. Evidence for linear alpha chains has been found all the way up to six alphas long, ^{24}Mg.[16] The shell model, which relies on spherical structures, is at a loss to explain linear alpha chains. The liquid drop model does not do much better. The cluster model is the only model that can come close to an explanation. CBM has no problem with linear alpha structures, yet prediction of their stability, even in this model, is still not resolved.

CBM explains why the electron does not bond via the strong nuclear force to the nucleus. Since the electron is itself an elementary particle (point charge,) it cannot engage in interactions with the rotating quarks. Therefore, only rotating particles with three quarks can interact strongly with protons and neutrons.

Time and space prevent a discussion of all the structures that have been studied. However, one final structure of merit should be mentioned. If we look at the mirror nuclei of the halo structures, we begin to see a reason why a nucleus could become an emitter of two protons. If two protons were at the end of one of these structures, then their mutual repulsion would distort the position of the two end protons, leading to the breaking of the strong coupling of the tensor force, leading to two proton emission.

One final argument in support of this new model. This model predicts the rest mass of the up quark as 237.31 MeV/c^2 and the down quark as 42.392 MeV/c^2. These values definitely conflict with the current standard model, but do they have any redeeming qualities? If one enjoys symmetry, then the fact that the 2/3 charged quarks in the other two generations are more massive than the -1/3 quarks, and may lead to a rational expectation that the up should be heavier than the down, and by a ratio similar to the ratio between the charmed and strange quark. A more significant observation is found regarding the mass difference between the Phi(1020) and the W(782) mesons. Both these mesons are excited states of the p mesons, which are made of up and down quarks. These two mesons have all the same quantum numbers "0-(1-,1-)." They are the lowest excited states of the p meson, and therefore their masses are very precisely known. The currently accepted mass of the Phi (1020) meson is 1019.413 ± 0.008 MeV/c^2, and the mass of the W(782) is 781.94 ± 0.120 MeV/c^2. The mass difference of these two mesons is 237.47 ± 0.13 MeV/c^2. Notice that the lower limit of this difference (237.34 MeV/c^2) is very close to the predicted mass of the up quark in this model (237.31 MeV/c^2). Besides this example, there are other examples where the mass difference between excited states of the p mesons with the same quantum numbers appear to be related to either the values of 237.3 MeV/c^2 or 42.39 MeV/c^2 or multiples of these masses. Another example of this mass difference: eight times 42.39 MeV/c^2 is 339.14 MeV/c^2, which is the mass difference between two excited states of the eta mesons, Eta(1295) - Eta(958), which have a current (1998) accepted difference of 339.2 ± 2.9 MeV/c^2.

In summary, the model explains many of the properties of the nucleus. The basic premise of this model is that the stability of the nucleus is explained in terms of the electromagnetic force of rotating synchronized fractional charges. A semi-classical approach was taken to arrive at a ratio of the size of the proton and neutron using the structure of this model and the known magnetic moments of these two particles. The binding energy difference between the ^{3}He and ^{3}H was used to predict the radii of the proton and neutron using a linear structure of both of these nuclei. The relativistic speeds of the up and down quarks in this model were set to agree with the magnetic moments of the proton and neutron. The mass of the up and down quarks were determined using the standard Einstein relativistic mass equation to account for the known mass of the proton and neutron. These values were refined so that the de Broglie wavelength of the up quarks in the proton exactly matched the circumference of the proton. The predicted size of the proton agrees adequately with published values based upon proton-proton scattering results. The negative peak in charge distribution within the neutron, based upon electron scattering, agrees with this model. Sample structures of stable and unstable isotopes are presented to add additional support to this model; only a few were discussed here, but many more have been analyzed. The CBM leads to a prediction of the rest mass of the up and down quarks significantly different from the standard model.

All new models need to make a prediction to test their validity. Experimental evidence of a negatively charged down quark at the center of the proton with mass equal to 42.392 MeV/c^2 would add credibility to this model. Since recent data from the Deutsches Electronen-SYnchrotron's (DESY) HERA accelerator have found an apparent hard core in the center of the proton, this prediction may soon be verified. Both the ZEUS particle detector and the H1 particle detector at the DESY's HERA accelerator have found significantly more hard hits from the center of the proton than the standard model can explain.[17] This accelerator uses positrons as the probing particle. Since the positron is positively charged, one might expect more collisions with a negatively charged down quark in the center of the proton. If the mass of this hard core can be determined and turns out to be near 42.4 MeV/c^2, this would add significant support to this model.

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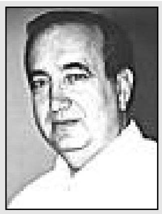

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