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There is only charge: Heisenberg-Coulomb based theory of the quarks, nucleons, and the nuclei

Eshel Faraggi[1,*]

Using the Heisenberg uncertainty principle in a semi-classical formalism, it is shown that mass and nuclear structure can be accounted for by the configuration of electric charge under only the Coulomb potential. In this approach, mass is accounted for by the confinement of electric charge. Tri-polar Coulomb interactions are responsible for the stability of the proton and the neutron, and bipolar Coulomb interactions provide the required stability for the nuclei. Initial calculations from this model are consistent with known nuclear binding energies and configuration. In addition, this approach gives an ab-initio estimates for the radius and mass of the quarks, and the radius of the proton. The estimated value for the radius of the proton is 1 fm, in close agreement with the known value of 0.83 – 0.88 fm.

There is only electric charge (charge). That is the main idea of this work. It is meant in the sense that the distribution of charge is enough to explain the observable universe. To establish this novel claim, it will be argued that gravitational interactions and the interaction of subatomic particle can be explained by relatively simple considerations of the confinement and configuration of positive and negative charge. In this work the angular, magnetic, and spin degrees of freedom will be ignored. This aspect is left for future studies. A semi-classical approximation will be used where quarks are assumed to be "particles" with sharp boundaries. As a side note it is mentioned that any measurement would occur over a finite time interval, hence, the measured charge density will be smooth.

The results of both Special and General Relativity are assumed. [1] They include the relationships between mass and energy, between space/time/momentum/energy, and as a general theory for gravitational interaction between mass. However, as will be discussed below, it is proposed that mass comes about from the potential energy of confined charge. Historically, mass entered physics at a very early stage since it is one of the most easily experienced physical measurements. Having the entrenched position in classical physics it is understandable how the notion that mass results from the quantum confinement of charge [2] is conceptually challenging. Similarly, the first observations of nuclear interactions [3, 4] involved protons and neutrons confined to a nucleus tiny in comparison to the size of the electron orbitals. [4, 5] Hence, it was unclear how this positive charge is confined and the strong nuclear force was conjured for an apparently missing "strong" attraction to hold the protons and nucleus together. [5] However, with the establishment of the quark model of the nucleons [6–8] it is possible to understand nuclear stability as a quantum outcome of Coulomb interactions, without the need for any addition interactions.

Possibly the most fundamental idea of quantum mechanics is the Heisenberg Uncertainly Relations (HUR): [9–11]

$$\Delta x \Delta p \gtrsim \hbar. \tag{1}$$

$$\Delta t \Delta E \gtrsim \hbar. \tag{2}$$

These expressions describe the smallest possible quantum states, with x the position, p the momentum, t time, E the energy of a state, and $\hbar$ the Planck constant. While the HUR have been around for almost 100 years, they still conceal many exciting discoveries. It is guessed that we still do not understand the mathematics and physics prescribed by the HUR. Here, their implications for charge systems will be used. For one thing, the HUR imply that nothing can have zero momentum in the quantum world. The HUR also hints to a finite minimal quantum state. States as such will be refereed to here as Minimal Quantum States (MQS). For these states an equality will be assumed for the inequality in Eqs. 1 and 2. An MQS is a

* Corresponding author E-mail: efaraggi@gmail.com
[1] Research and Information Systems, LLC, Indianapolis, Indiana, USA

"point" particle occupying one quanta of spacetime. It is proposed here that the electron and the quarks are such a MQS. As such, they cannot be broken into smaller pieces (in time or space) since this will violate Eqs. 1 and 2. Additionally, since Δx describes the smallest discernible distance, the densities inside an MQS (e.g., charge density) must be uniform. A non-uniform density would imply a discernible length scale smaller than Δx. As quanta of space, the electron and quarks posses charge confined to their minimal state.

Another straightforward outcome of the HUR is Newton's second law. Since, $\Delta x \Delta p = \Delta t \Delta E$, one easily has that $\Delta p/\Delta t = \Delta E/\Delta x$, which is essentially Newton's second law in absolute value form. Another result of the HUR is for the photon, which obeys the relationship $E = cp$, and hence $\Delta E = c\Delta p$. c is the speed of light in vacuum. The minimal time required to travel a distance Δx is $\Delta t_{min} = \hbar/\Delta E = \hbar/c\Delta p = \Delta x/c$. This indicates that c is the fastest possible velocity as a result of the HUR. A more complete model of the photon will be studied in future work. Since the photon is a massless spin 1 particle, it seems natural to consider it as a traveling oscillating dipole of two MQS. The massless aspect can be due to a dipole configuration that balances the self energy of the dipole parts with the binding interaction between them. Planer MQS may posses this property. In this picture the wavelength of light is given by Δx and its time period by Δt.

How is charge confined in a MQS such as the electron? This question will not be explored here and it is speculated that a new form of mathematics will be needed to consider it. Conceptually, we would need a discrete math that is not simply an approximation of continuous space. Rather, it will be built from the constraints quantum mechanics imposes. For example, standard discretization of continuous space implies an infinity sharp separation between states, in immediate violation of the HUR. For the rest of the work here it will be assumed that charge confinement is a natural consequences of the quantization of space-time. A single particle is a discrete (unique) MQS.

The electron and quarks are examples of a MQS. As discussed below, their mass can be described as a quantum effect, resulting from the potential energy of the confined charge. In MKS units, for a sphere with charge Q and radius r, the self energy, the work required to assemble the charged sphere from parts far away, is $\frac{3}{5}\frac{KQ^2}{r}$, with K the Coulomb constant. It is proposed here that this value is equal to the rest energy of the particle: mc^2, with m the inertial mass. If we denote by $-e = -1.6 \cdot 10^{-19}$ C the charge of the electron, r_e its radius, and $m_e = 9.11 \cdot 10^{-31}$ kg its mass, then we have,

$$r_e = \frac{3K(-e)^2}{5m_e c^2} = 1.69 \text{ fm}. \quad (3)$$

This result is sometimes known as the *classical radius of the electron.* [2] More frequently without the 3/5 factor. The resulting size of the electron is of the order of the size of a nucleon and in that sense can be interpreted as reasonable. It is the first hint at the possibility that mass is a self Coulomb energy. The size of the electron obtained from Eq. 3 is also consistent with the size of the atom, being much smaller than atomic radii.

Before estimating the mass and size of the quarks under the framework of a purely electromagnetic theory, it is critical to understand how the internal configuration of the proton and neutron is feasible under such an approach. To start, it is noted that the proton and neutron are not considered a MQS since they are composed of quarks. The quarks are considered a MQS, however there is no direct evidence for the mass of the quarks. There is good evidence for the masses and radii of the proton and neutron. Hence, understanding the configuration of the quarks within the nucleons is the first step.

To understand the stability of the proton under only electromagnetic interactions, first note that according to the quark model, the proton is composed of a two up quarks (u) with charge $+2e/3$ and one down quark (d) with charge $-e/3$. [4] The total charge of the proton is the sum of the three quarks or $+e$. However, according to the standard model the sum of the masses of the three quarks does not add up to the mass of the proton, where the missing mass is stored in the strong interaction between the quarks. [12] Here, it will be argued that the mass of the proton and neutron are the sum of the masses of their constituents quarks minus the Coulomb energy of bonds between the quarks. This is the case for any other composite system, such as the nucleus, atom, etc.

The most symmetric stationary configuration for the proton is udu as in Fig. 1. In this configuration the d quark is equidistant between the two u quarks. This configuration is classically unstable if the distances between the d quark and the two u quarks become unequal, as the d quark would then be increasingly attracted to the closer u quark. The stability of this configuration is a quantum effect. Schematically, as the distance between the d and u quarks decreases, the uncertainty in their position is reduced, which according to Eq. 1 increases the uncertainty of the momentum, enabling events where the d quark escapes from the Coulomb field of one u quark to the Coulomb field of the other u quark. In such a way the d quark oscillates between the two u quarks. Approxi-

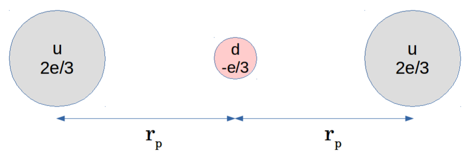

Figure 1 Cartoon of the structure of the proton.

mately, we can consider it positioned symmetrically between them.

For the stationary configuration, one can immediately surmise from symmetry that the force on the d quark is zero. The net Coulomb force on the right u quark is directed left, towards the other two quarks, and has a magnitude of $K\cdot(e/3)\cdot(2e/3)/r_p^2 - K\cdot(2e/3)^2/(2r_p)^2 = Ke^2/9r_p^2$ for any r_p. That is, there is a net attraction between the right u quark and the other two quarks. A similar result is obtained for the left u quark. The d quark mediates the repulsion between the two u quarks, resulting in net attraction between them. This indicates this configuration is stable regardless of the value of r_p.

There are two important points to be made here. 1) If one of the quarks is perturbed a distance Δy perpendicular to the line joining it to the others (line of symmetry), then assuming $\Delta y << r_p$, there is a restorative force proportional to Δy with the proportionality constant on the order of $\frac{Ke^2}{r_p^3}$. Hence, the quarks may undergo additional harmonic oscillations perpendicular to the line of symmetry. 2) If one assumes that the d quark is undergoing motion in the plane perpendicular to the line of symmetry (symmetry plane), then the attractive force on the two u quarks is reduced. If we assume the d quark will sample a disk of radius b in the symmetry plane and its charge is taken to be spread uniformly on this disk, then the electric field due to the charged disk at a distance a along its axis of symmetry is $\frac{2Ke}{3b^2}(1 - a/\sqrt{a^2+b^2})$. The field due to the other u quark is $\frac{Ke}{6a^2}$ and opposite in direction. Equating the magnitudes of the two fields and defining $\xi = (b/a)^2$ one obtains the equation $4(1 - 1/\sqrt{\xi+1}) = \xi$, which yields a solution $\xi = 1.438$, or $b = 1.199\cdot a$. That is, if the charge of the d quark is spread over a length scale defined by b, then the effective net force on all three quarks is zero.

So far it was shown that if we consider only Coulomb forces, the proton is so stable that it would collapse on itself. This does not happen because of the HUR. It is proposed that as either of the two u quarks approaches the d quark, Δx between the u and d quarks is reduced causing an increase in their momentum according to Eq. 1 and a restoration of their separation. In addition, we have two other effects. In one, the increase in momentum will also increase the kinetic energy of the d quark, which will result in a reduction of the d quark charge density in the symmetry plane and a reduced attraction between the u and d quarks. In the second, the reduction in potential energy due to the increased binding between the u and d quarks will also correspond to an increase in the kinetic energy of the d quark, and this in turn will also reduce its charge density in the symmetry plane and reduce the attraction between the u and d quarks. These effects combine to achieve a balanced state for the two u quarks around the d quark.

An order of magnitude estimate for the size of the proton can be obtained as follows. First, assume that the increase in momentum due to the HUR is shared evenly by the u and d quarks. Next we have to consider the spatial divide of this momentum. Since motion toward the d quark is distinct from motion away from it, we have six distinct directions in space (two for each axis). Therefore, under this approximation, the momentum is divided among 12 degrees of freedom. In other words, we estimate that 1/12 of the momentum increase due to Eq. 1 will go towards separating the u and d quarks. Now, at the radius of the proton, r_p, the Coulomb attractive potential energy is balanced by the increase in the kinetic energy of the u quark corresponding to the increase in momentum due to the HUR. Using $p = \sqrt{2m_u E}$ for the u quark, with m_u its mass, and using $E = \frac{K\cdot e/3\cdot 2e/3}{r_p} = \frac{2Ke^2}{9r_p}$ for the Coulomb potential energy between the d and u quark, one obtains from Eq. 1 (expressed as $r_p p = \hbar$): $r_p = \frac{\hbar^2}{24Ke^2 m_d}$. If one approximates $m_u = m_p/3$, as will be discussed below, one finds $r_p \approx 1$ fm. A remarkably close value to the observed radius of the proton [13–15] given the approximations made. This shows the ability to model a stable proton under only electromagnetic interactions, without mention of any "strong" nuclear force. The calculation for the neutron yields a similar stability analysis under the configuration dud. However, the collapsing force on the two d quarks composing the neutron is almost twice as strong as that of the proton. This result may be related to the beta decay of free neutrons and will be touched on briefly below. A more complete discussion of beta decay requires a treatment of spin and will be done in future work.

An estimate for the masses of the quarks and their sizes can be obtained from measurements of the mass and size of the proton and neutron. The radius of the proton, neutron, u quark, and d quark will be designated as r_p, r_n, r_u, and r_d, respectively. Corresponding indexes will be used for their masses: m_p, m_n, m_u, and m_d. Equating the Coulomb potential energy needed to assemble a proton (including the energy needed to form the quarks) to its relativistic inertial energy, one has:

$$m_p c^2 = Ke^2\left(\frac{8}{15r_u} + \frac{1}{15r_d} - \frac{2}{9r_p}\right), \quad (4)$$

and for the neutron:

$$m_n c^2 = Ke^2\left(\frac{4}{15r_u} + \frac{2}{15r_d} - \frac{7}{18r_n}\right). \quad (5)$$

In Eqs. 4 and 5 the first term is the self electromagnetic energy of the u quark/s and the second is the self electromagnetic energy of the d quark/s. The third term represents the Coulomb energy between the quarks. Defining $\epsilon_p = m_p c^2 + \frac{2Ke^2}{9r_p}$ and $\epsilon_n = m_n c^2 + \frac{7Ke^2}{18r_n}$, and using $r_p = 0.88$ fm[1] and $r_n = 0.8$ fm, [16] one obtains: $\epsilon_p = 939.7$ MeV and $\epsilon_n = 941.7$ MeV. Additionally, using Eqs. 4 and 5 one has $\epsilon_p - 2\epsilon_n = -\frac{Ke^2}{5r_d}$, and $\epsilon_n - 2\epsilon_p = -\frac{4Ke^2}{5r_u}$. This gives: $r_d = 3.05 \cdot 10^{-19}$ m, and $r_u = 1.23 \cdot 10^{-18}$ m. It is worth noting that $r_u / r_d = 4.03 \approx 4$. We can also obtain an estimate for the masses of the quarks assuming, as done for the electron, that the mass results from the electromagnetic self energy of the contained charge: $m_d c^2 = (3/5) \cdot K \cdot (e/3)^2 / r_d$ for the d quark, and $m_u c^2 = (3/5) \cdot K \cdot (2e/3)^2 / r_u$ for the u quark. This gives $m_u c^2 = 313$ MeV, and $m_d c^2 = 315$ MeV, and $m_u / m_d = 0.99$. In general, $m_u / m_d = 4r_d / r_u$. One should also note that these values for the mass of the quarks are a significant deviation from previous estimates [12]. This is to be expected since previous estimates assumed the mediators of the strong field carried a portion of the mass. Here, the sum of the masses of the quarks composing a nucleon is greater than the mass of the nucleon, the difference being the Coulomb binding energy. This is similar to any other composite system known, including the nucleus and atom.

Before going into a discussion of assembly of the light nuclei, a few notes about the stability of the neutron. As was mentioned, the collapsing force (the force on the outer quarks) for the neutron is almost twice as large as that for the proton, yet the mass of the quarks is essentially the same. This seems to indicate that the neutron is less stable than the proton, as is well known. In addition, as it was shown that $r_u \approx 4r_d$, from Eq. 1 it can be expected that the d quark will have 4 times the momentum of the u quark. This spread of momentum induces a dumbbell, rather than a spherical shape to the neutron, and limits the ability of the u quark to spread its charge and reduce the collapsing force on the two d quarks. Finally, it seems plausible that a system with one moving part (the d quark in the proton) would be more stable than a system with two moving parts (the two d quarks in the neutron). As the two d quarks collapse on the u quark, enough energy is released to create a virtual proton-anti-proton pair, and as briefly discussed below, the neutron decays. A quantitative treatment of the instability of the neutron will not be carried here because it requires a treatment of the spin degree of freedom which is left for future work.

So far it was shown that electromagnetic interactions can explain the stability of the nucleons and that mass can be consistently interpreted as the self electromagnetic energy of a MQS. Gravitational attraction between two particles can be interpreted as the response of one particle to the curved spacetime created by the self electromagnetic energy of the other according to the laws of general relativity.

Now consider nuclear reactions. Since geometrically, fission is a significantly more complicated problem than fusion, only fusion will be considered here. The qualitative treatment and the rest of the discussion will use the following tri-symbol notation: The proton will be represented as d_u^u, and the neutron as u_d^d, where, as before, the letters u and d represent the up and down quarks, respectively. A bar above a letter or over the entire tri-symbol indicates the antiparticle. For example, the anti-proton is represented as $\bar{p} = \overline{d_u^u} = \bar{d}_{\bar{u}}^{\bar{u}}$. We can understand neutron decay with the aid of a virtual proton-anti-proton pair. This pair is virtual as its products are intermediaries that are used during the reaction. The overall energy of the process is conserved. Neutron decay can than be represented as: $u_d^d \rightarrow u_d^d + d_u^u + \overline{d_u^u} \rightarrow d_u^u + u_d^d + \bar{d}_{\bar{u}}^{\bar{u}} \rightarrow d_u^u + d\bar{u}$. It is speculated here that since the combination $d\bar{u}$ is unstable, it forms an MQS electron and an anti-neutrino. The anti-neutrino is necessary for the conservation of angular momentum and it corresponds to a shockwave created in the transformation $d + \bar{u} \rightarrow e^- + \overline{\nu_e}$. This process will be studied in future work.

The deuteron is the simplest composite nucleus, composed of a proton and a neutron. Its creation is an exothermic process, releasing 2.22MeV upon the combination of

[1] Recent results indicate the size of the proton may be closer to 0.83 fm, [14, 15] however this will only slightly change the numerical values reported here and otherwise does not affect the work presented.

the proton and neutron. $p + n \rightarrow {}^2\mathrm{H} + 2.22$ MeV. [17] Since for the proton the charge of the d quark is spread over the symmetry plane, it will attract the oppositely charged u quark of the neutron. The ability of the neutron to reduce the charge density in the symmetry plane further stabilizes it. The attraction of the two outer d quarks of the neutron to the two outer u quarks of the proton stabilizes the deuteron and puts the proton and neutron in a face-to-face pose. Under this picture the deuteron can be represented as ${}^u_u d u^d_d$. For simplicity it will be assumed that the single contact between the central d and u quarks is responsible for the 2.22 MeV of binding energy. The complete interaction between all six quarks leads to corrections. If the distance between the central quarks is denoted by d, the following equation follows: $K\frac{e/3 \cdot 2e/3}{d} = 2.22$ MeV. This gives: $d = 0.15$ fm. The order of magnitude of this value, obtained solely on the basis of Coulomb interactions, is consistent with the size of the deuteron.

The next simplest stable nucleus is Helium 3. It is composed of two protons and a neutron, and follows the reaction ${}^2\mathrm{H} + {}^1\mathrm{H} \rightarrow {}^3\mathrm{He} + 5.49$ MeV. [17] Due to repulsion between the two protons a simple stable configuration in this case is a planner configuration ${}^u_u d\, u^d_d\, {}^u_u d$. The addition of another neutron will stabilize a three-dimensional compact configuration with a pn plane stacked on top of a np plane, forming a ^{4}He. For ^{3}He, we have essentially added three new contacts to the formation of ^{2}H. Again, for simplicity it will be assumed that these three new contacts account for the 5.49 MeV of binding energy. Denoting by d' the distance between the ^{1}H and the ^{2}H after forming the ^{3}He, we have: $3 \cdot K\frac{2e/3 \cdot e/3}{d'} = 5.49$ MeV. This yields $d' = 0.18$ fm. Again, a value consistent with the known size of ^{3}He. One should note that since the planer configuration of ^{3}He is symmetric, both the internal configuration of ^{2}H and ^{1}H will change upon forming it, and one will have a symmetrical configuration ${}^u_u d \overset{d}{\underset{d}{u}} d^u_u$. One can estimate the various distances between the quarks using the mass of ^{3}He. However, for the purpose of showing that charge is sufficient to establish the stability of nuclear structure these calculations suffice.

In summary, a semi-classical picture of the universe was presented where electromagnetic charge accounts for both mass and nuclear binding without reference to a "strong nuclear force". This picture is grounded in the Heisenberg relations of quantum mechanics and on classical electromagnetism. Before concluding this paper, it is important to note that the treatment here was for a stationary system. This was an approximation made for clarity and to establish the ability of the Coulomb potential to make matter. Since there is no preferred direction in space, it is expected that all the systems studied have a rotational component that was ignored here and will be treated in future studies.

Dedication

Dedicated to the memory of my father, Moshe Faraggi. Who in a warm desert car in Be'er-Sheva, insisted we are missing something fundamental about the Heisenberg uncertainty relations. Circa 2008.

Key words. Charge, Mass, Quark, Nucleon, General unified theory, Minimal quantum state, Heisenberg uncertainty, Proton charge radius, Neutron charge radius

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