On the Mass and Self-energy of the Electron (and other fermions) and the Origins of Quantum Mechanics

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Abstract

There has been a long standing assumption that the electromagnetic mass (self-energy) of a point charge (the electron) is infinite. I am going to challenge that assumption that has been virtually in place since shortly after the electron was discovered over one hundred years ago. I will show that the mass (self-energy) of the electron could be entirely electromagnetic and finite by elucidating what the mass of elementary fermions really is. Connected with that is the origins of Quantum Mechanics.

1. Introduction

Even before the discovery of the electron by J.J. Thomson in 1881, it was realized that the electromagnetic mass of a point charge would have to be infinite. After the discovery, attempts were made after the turn of the century to model the electron as an extended sphere with what is known as the classical electron radius $r_e = e^2/mc^2$. It was soon realized that the classical electron radius was not a real physical attribute of the electron and that the electron indeed seemed to be a point-like charge. This coupled with Poincare stresses, lead to the false assumption that the point-like electron must have a negative non-electromagnetic mass to cancel out some of the very large or infinite mass (self-energy) so that we get the observed mass of the electron. This false assumption remains with us today and is evident in the fact that mass renormalization must be done to get the right results in some QED calculations [1]. Milonni shows the electromagnetic mass of a non-relativistic point charge to be [1],

$$\delta m = \frac{4e^2}{3\pi c^3} \int_0^\infty d\omega. \tag{1}$$

This is of course infinite with ω being angular frequency, $\omega = mc^2/\hbar$. However, with a suitable cutoff of the integral, this can be made to be the observed mass of the electron.

It was thought that this infinite electrostatic self-energy of the electron was linearly divergent until Weisskopf's famous paper in 1939 when he showed using Dirac's new relativistic theory that the divergence is only logarithmic [2]. However, Weisskopf still made a wrong assumption basically carrying over the old classical assumption of a point charge. Weisskopf roughly calculates the electron radius "which is about 10^{-58} times smaller than the classical electron radius". Of course that is much smaller than the Planck length by quite a bit. I will show that while we can still consider the electron to be a point-like particle for interactions, its mass (rest energy) is developed in region of space smaller than approximately the order of the electron Compton wavelength divided by 2pi using a "bag model" similar to that used for quark content in protons. We know that most of the mass in our observable Universe is generated by the interactions of quarks and gluons that are confined to a certain volume so we will make the assumption that the mass of elementary fermions are generated in a like manner.

2. A Heuristic Model for Electron Mass

To construct our heuristic model we will use some very basic elements. We start with the simple form of electron Compton wavelength,

$$\frac{\lambda_C}{2\pi} = \frac{\hbar}{m_e c}.$$

Then rearranging it and multiplying by 1,

$$m_e = \frac{2\pi\hbar}{\lambda_C c} = \frac{2\pi\hbar c}{\lambda_C c^2}.$$

We believe that the form we started with is just shorthand for this correct form as it produces $m_e c^2 = 2\pi\hbar c/\lambda_C$. Now we would like to have an expression that has electron charge in it so we make a replacement using the equation for the fine structure constant in CGS units,

$$m_e = \frac{2\pi\, e^2}{\alpha\, \lambda_C c^2}.$$

Then using the relation of wavelength to angular frequency $\omega = 2\pi c/\lambda$, and we are using electron Compton wavelength and frequency for now we arrive at,

$$m_e = \frac{8\pi^3\, e^2}{\alpha \omega_C^2 \lambda_C^3}. \qquad (2)$$

This is our heuristic expression for the mass of the electron self-energy-wise. We will now interpret it. We can see that it is correct unit-wise for in CGS units, mass = charge^2 time^2/ volume. And, we can see that the mass of the electron in this expression is finite and totally due to electromagnetic interaction! But what are we to make of the electron Compton frequency squared in this expression? And does the volume indicate a size for the electron? However, this expression does perhaps give us a clue as to what c^2 is shorthand for in mc^2.

First let's tackle what the frequency squared component could mean. For a long time after I first developed this heuristic model, I couldn't figure out what the frequency could be then I discovered Hestenes' "Zitterbewegung Interpretation of Quantum Mechanics" and learned that the frequency component is related to Schrodinger's zitterbewegung from the Dirac equation [3]. But why is it squared? In this particular model we have the electron interacting with itself so it should be squared as is the electronic charge squared. However, we will show later that the interpretation of the point-like electron interacting with itself is probably wrong. So Hestenes' interpretation also supports the reduced Compton wavelength components for the volume. The electron jitters about in a volume corresponding to the size of that volume perhaps. The really amazing part of this interpretation is that the electron seems to be moving at the speed of light, c while it is jittering around in this volume. For me, that can only mean that the "bare" entity involved with the electron must be massless and that the mass associated with an electron comes from an interaction.

Now we will relate this to the mass of a proton or neutron. It is well known that most of the mass of a nucleon is from the interaction of the constituent quarks and gluons that are confined in the nucleon. However, the gluons are massless and the individual quark masses are small compared to the total mass of the nucleons so that is why most of the mass is from their interactions. We want to use this same concept and apply it to the mass of an electron only inside-out. In other words, the electron is confined to the certain volume mentioned above and its mass is from interactions on the surface of that volume. But what confines the electron to that particular volume? And also a big difference is that the particles the electron is interacting with are outside of the "bag" instead of inside like with protons.

We postulate that it is the vacuum polarization of the quantum vacuum that confines the electron to that particular volume (at rest). And it is the interaction with the constituents ("virtual" fermionic pairs) of the quantum vacuum that actually gives the electron its mass (and other properties). So the electron is not really interacting with itself. Normally, vacuum polarization is taken to be a higher order effect but we want to make it a first order effect. How do we do that? If the quantum vacuum is a polarizable medium then we have to take electronic charge to be, e, the effective charge (as seen at a distance) and thus the unscreened charge will be greater. Milonni shows the following expression which is an approximation that has been verified by experiment up to about 100 GeV [1],

$$e_{bare} = \sqrt{\frac{e_{obs}^2}{1 - \frac{2\alpha}{3\pi}\, log\frac{\Lambda}{m}}}.$$

If Λ is taken to the Plank scale (very short distance), the bare charge is about only 1.5 percent larger than observed electronic charge so we have to say that observed charge is very close to bare charge over a very wide range. For this reason, vacuum polarization is usually taken to be a small effect but this is due to higher order effects and not first order confinement. However, things are not quite so simple as this as we will see due to geometrical considerations. Anyways, we have to assume that the charge of the quantum vacuum constraining the electron will be the same as electronic charge but with some small higher order corrections. Or it might be better to assume that at any instance of time, the interaction is with one other component of the virtual fermionic pairs and the frequency is the repetition rate. We might wonder at this point what screens the charge of the virtual fermionic pairs. But they are the structure of the quantum vacuum and their net charge is zero so we don't think we have to worry about that. However, there are some screening effects when in the presence of a single electron and this is what is responsible for the higher order vacuum polarization effects.

If we take a look at the energy density (pressure) of the Coulomb field due to an electron with a radius of our reduced Compton wavelength we obtain,

$$u_{coul} = \frac{1}{8\pi}\left(\frac{e}{r^2}\right)^2 = \frac{16\pi^4 e^2}{8\pi\lambda_C^4} = \frac{2\pi^3 e^2}{\lambda_C^4}.$$

Then if we look at the energy density for our heuristic model with spherical symmetry, we obtain,

$$u_{model} = \frac{6\pi^2}{\lambda_C^3} m_e c^2 = \frac{6\pi^2}{\lambda_C^3}\frac{8\pi^3\, e^2}{\alpha\omega_C^2\lambda_C^3}c^2 = \frac{12\pi^3 e^2}{\alpha\lambda_c^4}.$$

We can see that we have a difference of a factor of $6/\alpha$. However, our calculation for the Coulomb energy density is not quite right since it is well known that for the Coulomb energy to equal the rest mass energy of an electron, the radius would be $e^2/m_e c^2$ which is also the reduced Compton wavelength times the fine structure constant. So $2\pi e^2/\lambda_C$ doesn't give us the correct energy to start with for the energy density. However, if we adopt a special geometry for the electron based on a 3-sphere topology, it has been shown that the Coulomb pressure can equal the electron pressure at a radius of,

$$r_m = \frac{\hbar}{\sqrt{2} m_{qm} c} \cong 2.7449 \times 10^{-11}\text{cm},$$

where m_{qm} is a slight correction to the electron mass due to quantum mechanical considerations [4]. Considering this, we need to adjust our volume for the energy density by a factor of $3/4\alpha$ which would give only about 100 times the Coulomb energy density. This makes us think that alpha is a geometric factor involved with the 3-sphere topology. And this would also make it necessary to adjust our volume for the electron mass with a corresponding adjustment in frequency. We see the Coulomb field as a "tilt" of the fermionic pairs of the quantum vacuum so they don't exist where the "bag" is developing charge, mass, spin and electron magnetic moment. This is different than what the authors above were presenting as they are doing a standing wave model and had their Coulomb field energy density inside the electron. But the important thing here is that it does seem possible that the electron could be confined by the surrounding virtual fermionic pairs that it brings forth from the quantum vacuum.

This does bring up a quandary if this boundary for observed charge is on the order of the reduced electron Compton wavelength because scattering experiments show that the electron is much smaller than that and is, in fact, consistent with a point-like particle. Now comes the fun part! We mentioned above that the entity involved with an electron is jittering about at the speed of light within that volume and have shown that it could be constrained by vacuum polarization. Due to relativistic effects, the point-like entity will end up being brane-like; in other words, it really is existing in many "places" at once from a certain perspective. But there is still a circulation within the brane that represents the real wave characteristics of the electron. Now, you have to consider that space-time only exists due to the electron being in the quantum vacuum and is actually being defined by the electron's existence within that particular volume. Milonni says, "It should be emphasized that the 'spread' of the electron associated with relativistic effects does not alter the fact the electron in QED is regarded as a pure point particle. The 'spread' is associated with quantum fluctuations in the position of the point electron: the electron jiggles around as a consequence of vacuum fluctuations."[1] Now, our branes are not at all like those from superstring theory as there is no tension. But there is a circulation within the brane.

So what happens when a photon interacts with an electron? First of all, we have to assume that a low energy photon will be interacting with the pairs that are screening the electron's charge and not directly with the electron. Only a higher energy photon that could penetrate the screening pairs could interact directly with an electron. But we have to visualize that the screening pairs are also brane-like. So in both cases, the interaction picks out a point on the brane so it appears that the "wavefunction" collapses to a point. But if we remember that this is a real wave interpretation then the collapse is really just an illusion. So this is a possible explanation of the origins of quantum mechanics. It is due to the "fuzziness" caused by relativistic effects on the microscopic scale. It was quite an accomplishment that quantum mechanics allowed us to proceed with predictions of microscopic physics without knowing the exact nature of what is happening within the interaction "blob". However, quantum mechanics still to this day cannot explain the true nature of a "point" charge. Due to relativistic effects it is not really a "point" until an interaction happens. But we also have to take into consideration that our concept of spacetime at this microscopic level should not be the same as our everyday (3+1)D experience of spacetime. Perhaps we will never know what is physically happening at this level but that doesn't prevent us from making guesses. Anyways as we know, the probabilistic procedure of quantum mechanics has worked well for us while we lacked the knowledge of the actual physics at an interaction point.

Attempts were made in the past to model an electron as an extended charge surface and/or density but most of those attempts had some kind of problem [1]. The electron with relativistic effects added really is point-like and spread out at the same time. It depends on the nature of the interaction. It is true that no internal substructure of the electron will be found; any structure will be external to the point-like entity involved due to relativistic and quantum vacuum effects. This is how the electron's mass, charge, spin, and magnet moment all arise. This also applies to all fermions. However, in the case of quarks the situation is complicated by color charge adding to the mass. In other words, the mass of the quarks is from electromagnetic plus Quantum Chromodynamic interactions with the quantum vacuum. What about neutrinos? Well, they are the least confined of all elementary fermions since they only couple to the heavy gauge bosons.

3. Naive Model of the Quantum Vacuum

A few years ago I devised a simple geometrical model of the quantum vacuum when working with Dr. Inopin that had some interesting properties [5]. It was based on an Apollonian Gasket type structure for 2D (see figure 1). However, without the circular boundary that is typical of the gasket. It would be unbounded of course for the quantum vacuum. Each radius of each circle becomes a mass basically via the Compton wavelength formula,

$$m = \frac{2\,\pi\,\hbar c}{\lambda_m}.$$

And we normalize it to the electron mass being the radius of the largest circle. So the mass of the other circles can be figured out geometrically. But each circle represents the fermionic pairs of the structure of the quantum vacuum. Yes! It is a mass generating scheme. However, it is easy to see that it generates a lot of masses that are not explained. But there

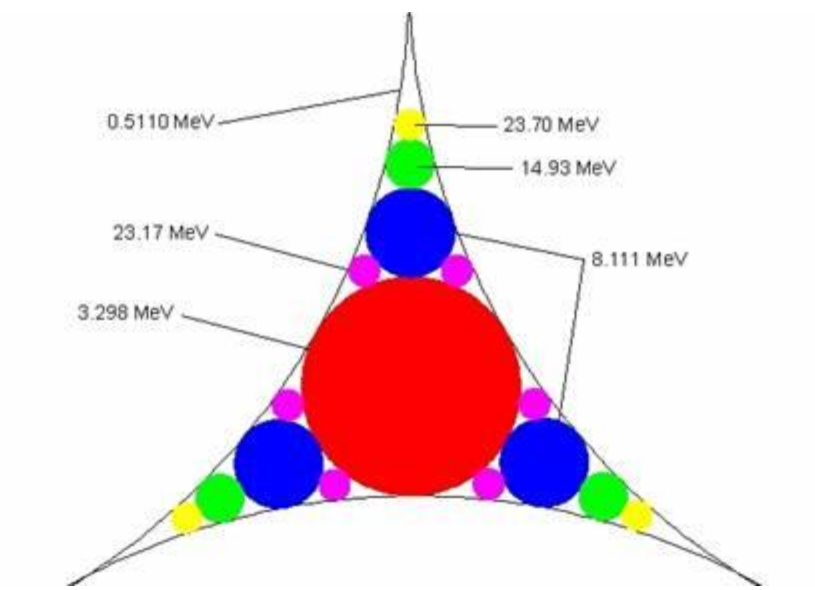

Figure 1. Center of three large circles with circles inside

is an interesting trapped three-way symmetry in the center that is suggestive of quark confinement. Possibly the 3.298 MeV and 8.111 MeV circles represents up and down quarks. Anyways, this is very simplistic but possibly is a clue to how fermion masses and different symmetries can be elucidated from a geometrical configuration of the quantum "vacuum" as a relativistic medium composed of “less than virtual” fermionic pairs. And… with the advent of Joy Christian’s discovery that all quantum correlations can be explained by a parallelized 7-sphere topology [6], the geometrical configuration probably requires extra spatial dimensions. Is there a geometrical math wizard in the house? ☺

4. Discussion and Conclusion

We have shown that the mass of elementary fermions could be due to interactions with elements of the quantum vacuum. In the Higgs mechanism, the mass of fermions is taken to be a Yukawa type coupling with the Higgs. It seems strange that a simple spin zero scalar boson could have all the different couplings required to produce the elementary fermion masses. It seems much more plausible that a more complicated interaction geometry is required to produce all the necessary masses that we observe in nature. Then of course we have to wonder what produces the Higgs boson mass itself recently to be presumed to be about 125 GeV. Of course the Higgs mechanism is required to give us the proper gauge boson masses and it does so in a wonderful fashion but we doubt that it has the complexity to give us the fermion masses. We may actually know in our lifetime whether it does or not.

Another strange feature of our model is that an elementary fermion is a half-hole in the quantum vacuum. In other words, we assume that all the energy states are positive and filled in the “sea”. This makes us wonder if the neutral half-holes (low pressure density) represented by atoms have a slight attraction to each other and this is where gravity emerges from. It is also mind boggling that matter is actually less than the quantum vacuum from this perspective. Has Nature played an incredible trick on us? We think so.

References

[1] P.W. Milonni, *The Quantum Vacuum: An Introduction to Quantum Electrodynamics*, Academic Press, New York, 1994.

[2] V.F. Weisskopf, *On the Self-Energy and the Electromagnetic Field of the Electron*, Phys. Rev. **56**, 72 (1939).

[3] D. Hestenes, *The Zitterbewegung Interpretation of Quantum Mechanics*, Found. Phys. **20**, 1213-1232, (1990).

[4] E. Schonfeld, et. al., *A New Theoretical Derivation of the Fine Structure Constant*, PROGRESS IN PHYSICS, 1, 3-5 (2012).

[5] C.F. Diether and A.E. Inopin, *Quantum Vacuum Charge*, Proceedings of Physical Congress-2004 - Fundamental Problems of Natural Sciences and Engineering, Volume 29, p.98 (St. Petersburg, Russia, 2004). This paper can also be found at http://www.vacuum-physics.com

[6] J. Christian, *Disproof of Bell's Theorem: Illuminating the Illusion of Entanglement*, BrownWalker Press, Boca Raton, 2012. http://www.brownwalker.com/book.php?method=ISBN&book=1599425645