Proton and electron mass derived as the vacuum energy displaced by a Casimir cavity

By: Ray Fleming

Abstract

Two of the great mysteries of physics are the origin of mass and the mysterious mass ratio between the proton and electron of ~1836. In this paper it is shown that the mass-energy of the proton is equivalent to the vacuum energy excluded by a spherical Casimir cavity with an average radius equal to the charge radius of a proton. Likewise the electron mass is shown to be equivalent to the vacuum energy excluded by a spherical shell with an average diameter equal to the Compton wavelength of the electron. The ratio ~1836 is derived as a natural consequence of the vacuum energy exclusion.

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Introduction

There is considerable theoretical and experimental basis behind the idea that the vacuum of space is filled with numerous vacuum fluctuations. The total energy density in space due to these vacuum fluctuations has be calculated to be on the order of 10^{118} GeV/cm^3, using the equation that follows to calculate that energy and the assumption that the highest energy, shortest wavelength vacuum fluctuations are on the order of the Plank Length ~1.6 X 10^{-33} cm. One of the more important examples of a property of vacuum energy, the Casimir Effect, is based on the idea that the presence of matter interferes with the local vacuum fluctuations.[1,2] In a given cavity, vacuum fluctuation wavelengths that are larger than the cavity will not be present inside of it. In the most common example of the Casimir effect, if there are two plates close together, generally on the order of a micron or less to be measurable, the pressure due to the vacuum between the plates pushing the plates apart will be reduced becoming less than the outer pressure pushing the plates together. Consequently the plates are pushed together.

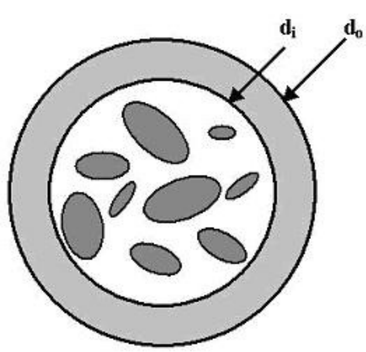

Figure - A sphere can be thought of as a Casimir cavity with vacuum fluctuations inside, simply illustrated as ellipses, and a shell of an inner d_i and outer d_o diameter.

A spherical shell can also be considered as a Casimir cavity, as inside there are always two surfaces bounding each vacuum fluctuation wavelength. Wavelengths of vacuum fluctuations shorter than the inner diameter of the shell exist inside it. Vacuum fluctuations with a wavelength larger than the outer diameter of the shell exist outside it. The vacuum fluctuations with wavelengths between the inner diameter and outer diameter of a spherical shell are excluded from the region of space occupied by the sphere. Based on this physical model it was thought that it would be constructive to compare the vacuum energy excluded by a spherical Casimir cavity the diameter of a proton and compare that to the proton's mass-energy.

Vacuum Energy of a Proton

The spherical shell simulating a proton was taken to have a radius equivalent to the proton charge radius as published in CODATA 2010, 0.8775(51) fm. Likewise the CODATA 2010 value for the mass-energy 938.272046(21) MeV was used. From those values the mass-energy density of the proton was computed to be 3.315 x 10^{38} GeV/cm^3.

The vacuum energy density ρ excluded by a spherical shell can be computed using the equation below.[3] The angular frequencies ω_1 and ω_2 are related to the outer diameter d_o and inner diameter d_i respectively, where $\omega_1 = 2\pi c/d_o$ and $\omega_2 = 2\pi c/d_i$. The speed of light is designated as c and $\hbar$ is the reduced Planck's constant per their standard notation.

$$\rho = \frac{\hbar(\omega_2^4 - \omega_1^4)}{8\pi^2 c^3}$$

To get a first approximation we can initially ignore the ω_1 term for the outer diameter since those longer wavelengths contain a less significant amount of energy, given energy are inversely proportional to wavelength. This allows us to compute the energy density for all wavelengths from the proton diameter, 1.755 fm and larger as a first approximation. This initial result is 4.106 x 10^{38} GeV/cm^3. This first approximation of excluded vacuum energy of a proton sized spherical shell is a quite close to the mass-energy of the proton. If we then set ρ equivalent to the mass-energy density of the proton and solve for ω_1 we find a value for the outer diameter d_o of 2.649 fm, which is somewhat larger than we would expect based on the known charge radius.

If we instead assume that the proton charge radius is the average of the inner and outer diameters of the spherical shell and set the vacuum energy density equal to the known mass-energy density of the proton, we can calculate the inner and outer diameters. In this case d_i = 1.586 fm and d_o = 1.924 fm. These values are more consistent with the charge radius than the first approximation above.

The difference in the inner and outer diameters is 0.338 fm, which equates to a shell thickness of 0.169 fm. This value is interesting in that it is similar to the wavelength of a virtual proton-antiproton pair at the pair production energy, 0.330 fm = $\lambda_{p\text{-}a} = hc/4m_p$, where m_p is the mass-energy of the proton. The shell thickness is essentially what we would expect if the shell were composed of something the size of vacuum fluctuations.

Note that the exclusion of wavelengths on the order of the shell thickness was not considered at this juncture based on the idea that any physical particle structure is unlikely to be infinitely smooth. If the proton shell were to be some type of open frame, possibly fullerene-like structure, then smaller, higher energy vacuum fluctuations would still exist in and around it, so they would not being excluded and therefore would not contribute to the mass-energy.

Particle structure issues aside, based on these simple computations it is readily apparent that the proton rest mass-energy is equivalent to the energy of the excluded vacuum fluctuation wavelengths if we assume that the proton is, or is surrounded by, a spherical shell of some kind. It is important to note that the solution for a given radius and shell thickness is unique, since the density of a sphere varies with the radius cubed and the vacuum energy density varies with the diameter to the fourth power. Also note that at this stage of development, this mass origin theory does not preclude the concept that the proton contains additional dimensionless particles carrying other properties of the proton.

Vacuum Energy of an Electron

The electron is a bit more trouble as there are several radii associated with it, or possibly none at all for a bare electron. In the minds of most physicists of today the point-like particle model is favored, but to quote MacGregor from *The Enigmatic Electron*, "a rather compelling case can be made for an opposing viewpoint: namely *that the electron is in fact a large particle which contains an embedded point-like charge*."[4] Unfortunately an experimental value for the electron radius in the realm of Compton scattering has never been firmly established. What is known is that the scattering radius of the electron with respect to photons and other electrons is many orders of magnitude larger than the scattering radius due to protons and other high-energy particles.

Using the same equation as before, if we allow the mass-energy density of the electron to vary by trying various diameters while computing the vacuum energy density for the same diameters, we quickly find that the mass-energy density and excluded vacuum energy density numbers coincide at or near an electron diameter equivalent to the Compton wavelength. This is not too terribly surprising as the Compton wavelength is associated with both the scattering of photons by an electron and also with mass by the relationship $\lambda_c = h/m_e c$, where m_e is the rest mass of the electron. It is commonly accepted that the Compton wavelength equates to the rest mass-energy of an electron.

We can then compute the mass-energy density of the electron using the Compton wavelength as the electron diameter, CODATA 2010 value 2.4263102389(16) pm, and the CODATA 2010 value for the electron's mass-energy 0.510998928(11) MeV. The energy density of the electron is then calculated to be 6.833 x 10^{25} GeV/cm^3.

If we initially set d_i equal to the Compton wavelength, the energy density of the excluded wavelengths from that point and larger is 1.124 x 10^{26} GeV/cm^3, which we can see is very close to the electron mass-energy density. Then by setting the vacuum energy density equal to the mass-energy density of the electron we can solve for d_o = 3.066 pm, which is only slightly larger than the Compton wavelength. This first approximation is in good agreement with the electron rest mass, and gives a reasonable diameter relative to the Compton wavelength.

As before we can set the average diameter of the electron shell equal to the Compton wavelength and solve for the inner and outer diameter. The resulting shell diameters are d_i = 2.123 pm and d_o = 2.472 pm. The difference between those two diameters is 0.349 pm, giving a shell thickness 0.175 pm. We can immediately take note that the shell thickness is in similar proportion to the particle diameter as it was with the proton. And, once again the shell thickness is essentially what we would expect if the shell were composed of something the size of electron-like vacuum fluctuations.

Any electron shell structure at the Compton wavelength must be transparent to smaller higher energy particles such as protons, as that is required by experiment. In this case we can say with certainty that the electron shell structure is not infinitely smooth and must be in some manner open, confirming the previous discussion regarding the proton if we assume a similar type of structure for both. Whatever the electron shell is composed of must also not interact with protons while at the same time interacting readily with electrons and photons. Given this mass origin model for an electron the size of the electron must be determined by electron scattering not proton scattering, while at the same time the size of the proton is determine by proton scattering.

The difference between the inner and outer diameters when the electron diameter is set equal to the Compton wavelength is, however, a little over half the virtual electron-positron wavelength of 0.6066 pm = $\lambda_{e\text{-}p} = hc/4m_e$ at the pair production energy. This is inconsistent with the equivalent ratio that was found for the proton, by a factor of approximately two. If instead we set the shell thickness equal to $\frac{1}{2}\lambda_{e\text{-}p}$ to match the proton and solve for the average radius where the vacuum energy density equals the mass-energy density we find that r = 1.592 pm, d_i = 2.880 and d_o = 3.487. This leads to the intriguing possibility that the proton and electron could have identical shell structures composed of some open frame structure with the thickness equivalent to wavelength of vacuum fluctuations of a similar energy vacuum. This is not to say that these particle shells are composed of vacuum fluctuations, as that would be too speculative a statement at this point.

Discussion

A closer examination of Casimir-van der Waals forces needs to be made at the particle scale so that they are consistent with a particle shell model. In particular the van der Waals force between two protons when the minimum distance a between them is in the range $d_i < a < d_o$ needs to be analyzed in greater detail taking into account a shell structure, exclusion of vacuum fluctuation wavelengths over that range, and the transparency of the particles to shorter wavelengths. If the van der Waals force were to vary in proportion to $1/a^4$, for example, it would be equivalent to the nuclear force strength over that range. The Casimir force would diminish as the distance a becomes less than the wavelength that makes up the shell structure, allowing Coulomb repulsion to exceed Casimir attraction at smaller separation distances. At larger distances the vacuum fluctuations transmitting van der Waals forces will be smaller than the openings in the shell structure, causing those forces to fall off rapidly at larger distances as well.

Having a fundamentally electromagnetic description of mass brings up some additional questions, perhaps the biggest of which is that if mass is a purely electromagnetic phenomena then gravity must be as well. This will certainly give those in search of a grand unified theory some hope. Having a simple electromagnetic description of mass should lead to a better understanding of gravity.

Conclusion

It has been shown that the mass of the proton is equal to the vacuum energy it displaces if it were a spherical shell structure with an average radius equal to its charge radius. The electron mass can also be derived based on the vacuum energy it excludes if it were a spherical shell with an average diameter equal to its Compton wavelength. Alternatively the electron could have a radius of ~1.6 pm if it has a virtual particle structure that is equivalent to the proton. Experimental verification of the electron charge radius will be necessary to determine the actual radius of the electron. The proton to electron mass ratio of ~1836 is also accounted for in the process as a simple relation due to the vacuum energy density equation and the particle diameters. The simplicity of the technique is compelling even though a major re-evaluation of what we think we know about particles will be necessary to make broader particle theory consistent with this result.

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[4] MacGregor M. H., The Enigmatic Electron, Kluwer, Dordrecht, Netherlands (1992) p. 5