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On the Size of the Electron in a Quantum Universe

Lewis Nash

Independent Researcher, Marietta, GA, USA
Email: lewis.r.nash@gmail.com

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Abstract

This study presents a quantitative theoretical approach for computing the radius of the electron based on the dynamic nature of the quantum universe. Measuring the electron's radius directly is a significant challenge due to the extreme weakness of its gravitational field. However, at the Planck scale, the gravitational effects of the electron and the warping of space-time become apparent. By applying a Planck lattice theory of quantum space-time, we can sufficiently quantify the deformation of space-time caused by the electron in relation to the vacuum. Our theory produces a relation that reveals a surprising connection between the radius of the observable universe and the size of the electron, providing new and valuable insight into the dynamics of the vacuum and gravity at the Planck scale.

Keywords

Electron Radius, Quantum Universe, Planck Scale, Space-Time Deformation, Vacuum Dynamics

1. Introduction

According to our current understanding, an electron is considered either a point particle with no internal structure, which means it does not possess a physical radius like a sphere, or as a wave packet where the radius represents a probability distribution of where it is most likely to be found. A point particle is an idealization commonly used in physics. Its defining characteristic is that it lacks spatial extension, which is to say, it does not occupy physical space. To say that an object has mass, but no size implies that it has infinite density. Because infinities of any kind rarely exist in the real world, it is more realistic to suggest that an electron has a non-zero size. Even though we can't directly measure an electron's radius, the concept is used in theoretical calculations to explore phenomena like electron scattering and the behavior of electrons in atoms.

In quantum mechanics, Heisenberg's uncertainty principle complicates the idea of a point particle. This principle suggests that even elementary particles, which are considered structureless, occupy a nonzero volume. It is important to differentiate between elementary particles, like electrons and quarks, which have no known internal structure, and composite particles, such as protons and neutrons, whose internal structures are understood to consist of quarks. Calculations based on classical ideas of a point-like electron with a finite charge density lead to infinite values for the electron's mass when considering its self-interaction with its own electromagnetic field, which means that trying to calculate the electron's minuscule mass based on its supposed tiny radius results in a mathematically divergent result. Currently, this issue is resolved in quantum field theories through a technique called "renormalization," which effectively removes these infinities by adjusting the calculated values based on observed (or known) physical quantities.

The main challenge of this study is to derive the size of an electron, specifically the spatial extent of its mass distribution, from the dynamic properties of the quantum universe[1]. This size differs from the various sizes typically attributed to the electron, such as its classical and electric charge radii, to name just a few. In this study, the electron is assumed to be a uniform, spherical mass with no internal structure, compressed to a fundamental size by the immense pressure of space-time. This assumption also ensures that an electron's electric field appears identical in all directions.

2. Classical Radius of the Electron

The electron, the first elementary particle to be discovered, was identified by J.J. Thomson in 1897. His method of passing a beam of electrons through crossed electric and magnetic fields led to the determination of their charge-to-mass ratio e/m, a finding that was over a thousand times greater than that of the hydrogen atom. This discovery opened up new avenues of exploration in the field of atomic physics, challenging existing theories and inspiring further research. In the same year, J.S. Townsend conducted an experiment that preceded the Millikan oil-drop experiment, demonstrating that the charge of the electron is equivalent to the fundamental unit of charge e in atomic physics. This indicated that the large charge-to-mass ratio of the electron results from its small inertial mass m rather than a large electric charge e. Following this, Abraham and Lorentz proposed models in which the mass of the electron is attributed to the electrostatic self-energy W_e of its charge e, which they assumed to be distributed uniformly throughout a spherical volume of radius R_c. From electrostatics theory, the self-

[1]In this context, the "quantum universe" refers to the dynamics of gravity and the vacuum at the Planck scale for the universe as a whole. This topic is part of an emerging field of research known as quantum space-time dynamics (QSD), which is still in the early stages of development.

energy of such a distribution is[2]

$$W_e = k_e e^2 / R_c \ ,$$

where k_e is the Coulomb constant. Setting $W_e = mc^2$, we obtain[3]

$$R_c = k_e e^2 / mc^2 \approx 2.82 \times 10^{-13} \text{ cm} \ ,$$

which is denoted as the classical radius of the electron [1]. However, the scattering properties of the electron suggest the charge radius of the electron is vastly smaller

$$R_e \ll 10^{-16} \text{ cm} ,$$

which is commonly accepted as an upper limit for the size of the electron.

3. Gravitational Energy of the Planck Vacuum[4]

Suppose the kinetic energy of each state $E_n = (n + 1/2) hc/\lambda_n$ of the vacuum is distributed equally among the three independent spatial degrees of freedom of the Planck lattice. In accordance with Boltzmann's equipartition theorem [2], it follows that the total average kinetic energy of each state of the Planck lattice $E_{P,n}$ is related to the corresponding energy state of the vacuum by the following equation:

$$E_{P,n} = 3E_n / 2 \, .$$

Similarly, the zero-point gravitational (ZPG) energy[5] [3] of the Planck lattice and the vacuum [4] are related by the following equation:

$$(E_P)_{o,Gr} = 3E_{o,Gr} / 2 \, .$$

Gravitational waves oscillate along two axes; therefore, the ZPG energy of the vacuum is

$$E_{o,Gr} = hc/2\lambda_{o,Gr} + hc/2\lambda_{o,Gr} = hc/\lambda_{o,Gr} \ ,$$

where $\lambda_{o,Gr} \equiv R_o - R_{S,u}$ is the zero-point wavelength of the vacuum's gravitational field. Given that $\lambda_{o,Gr} > 0$, it follows that $R_o > R_{S,u}$. This result suggests that the curvature of the vacuum is positive, like that of a sphere, which is consistent with the presence of a positive cosmological constant [5].

The Schwarzschild (or gravitational) radius of the observable universe is

$$R_{S,u} = 2GM_b / c^2 \ ,$$

where M_b is the mass of ordinary (baryonic) matter in the observable universe.

[2]For the equations presented in this study G is the gravitational constant, $h = 2\pi\hbar$ is Planck's constant, and c is the speed of light in vacuum.

[3]Note that this assumption suggests that the relativistic mass of the electrostatic self-energy of the electron is equal to its rest mass $W_e / c^2 = m$.

[4]Also called the Planck vacuum state, the Planck vacuum is the zero-point energy state of the Planck lattice. In general, the zero-point energy of the Planck lattice corresponds to the energy of the fundamental mode of oscillation of the Planck vacuum.

[5]The theoretical minimum amount of gravitational energy that would still exist even at absolute zero temperature, according to the principles of quantum mechanics; essentially, it's the energy associated with the "ground state" of the gravitational field, where fluctuations still occur due to quantum effects, even when no other energy is present.

Because the zero-point energy of the vacuum is $E_o = hc/2\lambda_o$, where $\lambda_o = 2\pi R_o$, the zero-point radius[6] of the vacuum [6] is given by

$$R_o = \hbar c/2E_o ,$$

where $E_o = 2E_{P,o}/3$ is the zero-point energy of the vacuum and $E_{P,o}$ is the zero-point energy of the Planck lattice. Similarly, the zero-point radius of the Planck vacuum is given by

$$R_{P,o} = \hbar c/2E_{P,o} .$$

The Planck lattice horizon[7] is in thermal equilibrium with the zero-point energy of the vacuum. Hence, one obtains the following relation for the radius of the Planck lattice horizon and zero-point radius of the vacuum

$$R_P = 2R_o .$$

It immediately follows that the ZPG energy of the Planck lattice can be written, as follows:

$$\left(E_P\right)_{o,Gr} = \frac{hc}{R_{P,o}\left(1 - R_{S,u}/R_o\right)} .$$

The maximum uncertainty in position of quantum space-time is $a_P/2$, which corresponds to a maximum uncertainty in time of $t_P/2$. According to the energy-time quantum uncertainty principle of space-time [7], the minimum energy for Planck lattice zero-point fluctuations is

$$\Delta m \ge m_P ,$$

where $m_P = \sqrt{\hbar c/G}$ is the mass of a test Planck particle [8] [9] (or Planck mass black hole)[8]. Therefore, the smallest possible size of a single particle with non-zero rest mass is equal to the Schwarzschild radius of a Planck particle

$$R_{S,P} = 2Gm_P/c^2 = 2a_P ,$$

where $a_P = \sqrt{\hbar G/c^3}$ is the characteristic or unit length scale of the Planck lattice.

If one considers the Planck lattice to be a closed system with only gravitational forces acting without friction, then its ZPG energy and potential energy are equal in magnitude. Thus,

$$\left(E_P\right)_{o,Gr} = \left|\left(U_P\right)_{o,Gr}\right| = Gm_P m/R_{o,Gr} ,$$

where $\left(U_P\right)_{o,Gr} = -Gm_P m/R_{o,Gr}$ is the potential energy of the Planck lattice and $R_{o,Gr}$ is the ZPG radius[9] of a subatomic particle of mass $m \ll m_P$.

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[6]The minimum size or spatial extent exhibited by a quantum system in its lowest energy (ground) state.

[7]The theoretical boundary or edge of the Planck lattice, which is presumed to coincide with the edge of the observable universe (or cosmic event horizon).

[8]The mass of a Planck particle can be considered the fundamental unit of gravitational charge for a Schwarzschild black hole.

[9]The distance from a particle or distribution of energy where its gravitational potential energy is equal to the ZPG energy of the Planck lattice.

4. Size of the Electron

We could use the same approach to determine the mass radius of the electron used to determine the classical radius. The mass radius determined in this manner is smaller than the Schwarzschild radius of the electron, *i.e.*,

$$Gm^2/R_m = mc^2 \rightarrow R_m = Gm/c^2 = R_S/2,$$

which is not acceptable since electrons are not quantum black holes. Similar to how the classical radius calculation of the electron does not account for the effects of quantum electrodynamics, this calculation of the mass radius overlooks the influences of quantum gravity, which are essential for understanding the true size of the electron.

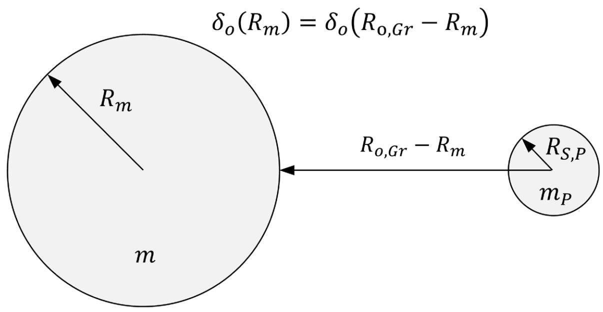

Figure 1. Zero-point displacement δ_o of the Planck lattice [10] near the surface of a spherical subatomic particle of mass $m \ll m_P$ and radius $R_m \gg R_{S,P}$.

As shown in **Figure 1**, let us assume the Planck strain [10] at the surface of a subatomic particle is equal to the Planck strain produced by a test Planck particle located at the ZPG radius of the subatomic particle. Hence,

$$\varepsilon_P(R_m) = \varepsilon_P(R_{o,Gr} - R_m) \rightarrow m/R_m = m_P/(R_{o,Gr} - R_m),$$

which gives us, to a first-order approximation in μ_P, the relation for the mass radius of a uniform spherical subatomic particle

$$R_m = \frac{Gm^2}{(E_P)_{o,Gr}}(1 - \mu_P),$$

where $\mu_P = m/m_P \ll 1$ is the Planck mass ratio. Note that in order for the size of subatomic particles to be constant the ZPG energy of the Planck lattice $(E_P)_{o,Gr}$ must be constant, which implies the gravitational energy of the vacuum $E_{o,Gr} \propto 1/\lambda_{o,Gr}$ is constant, as well.

To ensure our formalism is compatible with composite particles such as the proton[10], we must replace the mass in the equation for the ZPG energy of the Planck lattice with the total mass of a composite particle's constituents (*i.e.*, quarks and gluons)

[10]The proton is a composite subatomic particle [11].

$$m_{tot} = m + \Delta m ,$$

where m is the mass of the particle and $\Delta m = m_{tot} - m$ is the quantum chromodynamic (QCD) binding energy[11] of the particle [12]. Thus, the equation for the ZPG energy of the Planck lattice becomes

$$(E_P)_{o,Gr} = \frac{G(m + \Delta m)}{R_m}(1 - \mu_P) \approx 1.3425 \times 10^{-48}\ \text{J} ,$$

where $R_m = 0.550\ \text{fm}$ for the proton's rms mass radius[12] [13], $m = 1.6726 \times 10^{-27}$ kg and $\Delta m \approx 928.9\ \text{MeV}/c^2$ for the mass and QCD binding energy of the proton, respectively.

In a universe where $R_P = 46.6$ million light-years, which agrees with the current estimate for the comoving distance[13] to the edge of the observable universe [14], the mass of baryonic matter in the comoving observable universe is

$$M_b = \frac{R_o c^2}{2G}\left(1 - \frac{hc}{(E_P)_{o,Gr} R_{P,o}}\right) \approx 1.4869 \times 10^{53}\ \text{kg} ,$$

which is close to the estimated value of 1.5×10^{53} kg derived from the critical density of the universe and its estimated volume [15]. Consequently, the baryonic mass density of the comoving observable universe is

$$\rho_b = M_b / \mathcal{V}_P \approx 4.1253 \times 10^{-28}\ \text{kg/m}^3 ,$$

where $\mathcal{V}_P = 4\pi R_P^3/3$ is the volume of the comoving observable universe. The density ρ_b is approximately 4.85% of the critical density $\rho_c = 8.50 \times 10^{-27}$ kg/m^3, which is in good agreement with the most recent observational estimate $\Omega_b = \rho_b/\rho_c = 4.90\%$ as determined from measurements made by the European Space Agency's Planck Telescope [16]. In a universe defined by these large-scale properties, the mass radius of the electron—an elementary subatomic particle of mass $m = 9.1094 \times 10^{-31}$ kg —is computed to be

$$R_{m,e} \approx 0.413 \times 10^{-20}\ \text{cm} ,$$

which agrees with the approximate theoretical upper bound[14] $R \approx \lambda_C |g_{exp} - 2| < 10^{-20}$ cm given by Brodsky and Drell for the simplest composite theoretical model of the electron [17], where $\lambda_C = 0.39 \times 10^{-10}$ cm is the reduced Compton wavelength of the electron and $|g_{exp} - 2| = 1.1 \times 10^{-10}$ is the magnitude of the gyromagnetic ratio difference between experiment g_{exp} and the theoretical prediction from the Dirac equation for spin-1/2 particles [18] $g_{Dirac} = 2$. Moreover, the ZPG radius of the electron $(R_{o,Gr})_e$ is approximately 0.50 m, while

[11]The energy required to separate the quarks within a proton, held together by the strong nuclear force described by QCD.

[12]Root-mean-square (rms) mass radius is a fundamental property related to the average spatial distribution of mass within a composite subatomic particle, like a proton, derived from its energy-momentum tensor and gravitational form factors.

[13]Comoving distance factors out the expansion of the universe, giving a distance that does not change in time except due to local factors, such as the motion of a galaxy within a cluster.

[14]Observation of a single electron in a Penning trap suggests the upper limit of the particle's radius to be approximately 10^{-22} meters [19].

that for a Planck particle is vastly greater

$$\left(R_{o,Gr}\right)_e \ll \left(R_{o,Gr}\right)_P = Gm_P^2 \big/ \left(E_P\right)_{o,Gr} \approx 1.18\times10^{22}\ \text{m},$$

which is over a million light years. This outcome not only suggests that our method for deducing the size of the electron is on the right track but that our estimate for the electron radius is plausible. The formalism derived in Section 3 yields

$$E_{P,o} = 3\hbar c/R_P \approx 2.1499\times10^{-52}\ \text{J}$$

for the zero-point energy of the Planck lattice. Most notably, this result is only 1.38% larger than the value predicted by the cosmological photogravity effect [20]. Furthermore, it follows, in general, from the perspective of quantum gravity and the Planck vacuum, that the mass radius $R_{m,\alpha}$ and $R_{m,\beta}$ of two "stable" subatomic particles of mass m_α and m_β, respectively, are related by the following expression:

$$R_{m,\alpha} = \left(m_\alpha / m_\beta\right)^2 R_{m,\beta},$$

which is surprisingly straight-forward. In the case of a composite subatomic particle like the proton or neutron, the mass and radius denote the particle's total constituent mass and rms mass radius, respectively.

Among the six types, or "flavors" of quarks, only the two lightest—the up and down quarks—are truly stable. The other four, known as heavy quarks, are extremely unstable and decay into lighter stable quarks almost instantly. Our theory estimates the sizes of the up and down quarks to be $R_{m,u} \approx 6.36\times10^{-20}\ \text{cm}$ and $R_{m,d} \approx 3.61\times10^{-19}\ \text{cm}$, respectively, which is consistent with the upper bound 4.3 × 10^{-19} cm for the effective quark radius established from high-precision HERA electron-proton scattering data [21].

5. Some Closing Remarks

The observed spin angular momentum and magnetic dipole moment of the electron can be shown to arise from its wave nature [22], which is linked to the dynamics of space-time at the Planck scale [23]. The size of the electron is tied to its particle nature, indicating that the electron's size cannot be derived from its spin angular momentum or magnetic dipole moment. Notably, the electron radius determined in Section 4 is a million times smaller than the classical electron radius. This aligns with the point-like scattering behavior observed in scattering experiments, from which the upper limit for the electron's charge radius is determined.

The complex ideas explored in this study reveal a deep and fascinating connection between the incredibly small and the unimaginably large. For example, our formulation of the ZPG energy of the Planck vacuum was based on the size of the proton. This connection echoes William Blake's famous quote, "To see a world in a grain of sand," where the "world" represents the universe and the "grain of sand" symbolizes the electron. While this approach may appear speculative, it is physically consistent and aligns with key large-scale properties of the universe as established by accepted cosmological models and astronomical observations. If proven valid, this study could deepen our understanding of the quantum universe and its role in shaping properties of the cosmos at large, as well as the various sizes of its fundamental building blocks of matter.

Conflicts of Interest

The author declares that they have no known competing financial interests or personal relationships that could have influenced the work reported in this study.

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