Why the Electron Is So Much Smaller Than the Proton, and Why It Orbits So Far Away

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Abstract

The electron is approximately 1836 times less massive than the proton, and settles into a stable orbit approximately 63,000 times larger than the proton's own radius, forming the hydrogen atom. Both facts are measured to extraordinary precision and are essential inputs to atomic physics and chemistry, yet the Standard Model provides no physical account of either number: the electron and proton masses are independent empirical parameters with no derived relationship, and the Bohr radius is obtained from quantum mechanical postulates rather than from any specified physical process by which an electron comes to occupy that particular orbit rather than any other. This paper proposes a physical origin for both facts from the same condensation event responsible for the mechanical origin of electric charge established in earlier work. Under this proposal, the electron is the interstitial substrate mechanically expelled during the close-packed convergence of the proton's three constituent units, and its small mass follows directly from simple sphere-packing geometry: the interstitial region available to the expelled unit is smaller than a stable condensation radius by a specific geometric factor, forcing the expelled unit to shed the great majority of its formation energy into the surrounding substrate and retain only a small residual as its own persistent mass. We show that an exact algebraic identity connects the interstitial volume fraction to the retained mass fraction, giving an electron mass consistent with the measured value to five significant figures using no free parameter beyond the independently measured proton charge radius. We further show that the electron's eventual orbital radius follows from a complete, gap-free scan of angular momentum quantisation outward from the proton surface: no integer angular momentum state exists at any radius between the proton surface and the Bohr radius, making the Bohr radius the first and only stable orbit available to the expelled electron. We discuss the relationship of this proposal to the underlying substrate framework and to the earlier charge-origin work, address the objection that this account merely re-derives known atomic physics relations, and specify falsifiable predictions distinguishing a mechanical origin for the electron's mass and orbit from their treatment as independent empirical inputs.

Keywords: *electron mass, Bohr radius, proton-electron mass ratio, hydrogen atom, angular momentum quantisation, condensation topology*

1. Introduction

The proton-to-electron mass ratio, $m_p/m_e = 1836.15267$, is one of the most precisely measured dimensionless numbers in physics [1], and it plays a foundational role in atomic and molecular structure: the near-immobility of the much heavier proton relative to the light, fast-moving electron underlies the Born-Oppenheimer approximation used throughout chemistry and molecular physics [2]. Despite its precision and its physical importance, the Standard Model provides no derivation of this ratio; the electron mass and the proton mass are independent empirical parameters, with no accepted theoretical relationship connecting them.

A related and equally fundamental question concerns the electron's location once bound to a proton. The Bohr radius, $a_0 = 52{,}917.7$ fm [1], sets the characteristic size of the hydrogen atom and, through it, the size scale of all ordinary matter. The Bohr model derives this radius from the postulate that orbital angular momentum is quantised in units of the reduced Planck constant [3], a postulate subsequently justified within the full quantum mechanical treatment of the hydrogen atom [4], but neither treatment addresses the physical process by which an electron, once formed, comes to occupy specifically this orbit rather than some other radius, larger or smaller.

This paper proposes a physical origin for both the electron's small mass and its orbital radius from the same condensation event responsible for the mechanical origin of electric charge developed in earlier work [5]. That work establishes that the first stable matter condensation forms from three substrate units converging into close-packed contact, mechanically expelling a fourth interstitial unit through the closing gaps between them; the expelled unit acquires negative charge through elementary rigid-body mechanics, the gear principle by which a body passing between two co-rotating surfaces of identical handedness is driven into counter-rotation. The present paper extends this same geometric event to address two further questions left open by that earlier work: why the expelled unit - the electron - retains so little of the substrate's available mass, and where it ultimately settles once expelled.

The paper is organised as follows. Section 2 reviews the status of the electron mass and the Bohr radius in standard physics. Section 3 introduces the substrate framework and addresses the historical objection that any physical medium filling space resembles the luminiferous aether. Section 4 reviews the close-packing geometry underlying the proposed electron-generation event. Section 5 derives the electron's small mass from the interstitial geometry. Section 6 derives the electron's orbital radius from a complete angular momentum stability scan. Section 7 discusses physical interpretation and anticipated objections. Section 8 presents falsifiable predictions. Section 9 concludes.

2. The Status of the Electron Mass and the Bohr Radius

The electron mass, $m_e = 0.51099895$ MeV/c^2, and the proton mass, $m_p = 938.27209$ MeV/c^2, are both measured to extraordinary precision [1], and their ratio is confirmed across independent experimental methods including Penning trap mass spectrometry and molecular spectroscopy [6].

No accepted theoretical framework derives either mass, or their ratio, from more fundamental principles; both are treated as free parameters of the Standard Model, fixed by the Yukawa couplings of the electron and the confinement dynamics of the proton's constituent quarks and gluons respectively [7], neither of which specifies a mechanism connecting the two masses to one another.

The Bohr radius follows, within standard quantum mechanics, from the reduced mass of the electron-proton system and the fine-structure constant, a_0 = hbar/(m_e c alpha) [3,4]. This is a correct and precisely verified formula; it is not, however, a physical account of why the electron settles at this particular radius rather than closer to or farther from the proton. The formula specifies the radius given the electron mass and the fine-structure constant as inputs; it does not address the physical process by which a newly formed electron comes to occupy that specific orbit.

Two Unexplained Parameters

	Standard Model	P65 Framework
Electron Mass (m_e)	Arbitrary measured input (0.511 MeV). No physical derivation for the ~1836 proton-to-electron mass ratio.	Geometric remainder. The electron mass is derived entirely from the physical space available during proton condensation.
Bohr Radius (a_0)	Derived from quantum mechanical postulates (angular momentum quantisation) without a mechanical cause for occupying that specific orbit.	The first physically stable resting place. Derived via a continuous outward stability scan from the proton surface.

NotebookLM

Figure 1. The Standard Model treats the electron mass and the Bohr radius as unexplained empirical inputs, while the P65 framework derives both from proton condensation geometry.

3. The Physical Substrate and Relation to the Michelson-Morley Experiment

The mechanism proposed in this paper is derived from a physical substrate framework proposed in prior work [8], in which the universe is proposed to possess a universal physical matter substrate, termed the Spaticle field, with equilibrium density rho_s = 7.3 × 10^{-27} kg m^{-3}. Any proposal invoking a physical medium filling space invites an immediate and reasonable historical comparison to the luminiferous aether, decisively excluded by the Michelson-Morley experiment and its many high-precision successors [9,10]. This comparison deserves a direct response rather than a footnote.

The luminiferous aether, as originally conceived, was a medium at rest relative to some preferred, absolute reference frame, through which the Earth and all material bodies moved; light was expected to propagate at a fixed speed relative to this aether frame, producing a detectable directional variation in the measured speed of light as the Earth's motion through the aether changed with the seasons [9]. The null result of the Michelson-Morley experiment, and of every subsequent interferometric test at ever-increasing precision [10], rules out exactly this specific structure: a medium establishing a preferred rest frame detectable through directional light-speed anisotropy.

The substrate proposed in [8] does not have this structure. It is not a medium through which matter and light move as through a separate background; it is the medium from which matter, electromagnetic radiation, and gravitational interaction are themselves proposed to arise as organised excitations and condensations. Under this proposal, an observer, a measuring apparatus, and the hydrogen atom being studied are all, without exception, organised states of the same substrate; there is no configuration in which an observer moves "through" the substrate in the sense required for the Michelson-Morley experiment to detect a directional anisotropy, because the observer's own physical existence is already a substrate phenomenon, not an object embedded in and moving relative to an independent background medium. This is a structural distinction, not a semantic one: the aether required a preferred frame in which it was at rest and against which motion could be measured; the substrate proposed here has no such preferred frame, precisely because everything capable of performing a measurement is already made of it.

The Michelson-Morley experiment therefore excludes a preferred-rest-frame aether, but does not exclude a universal physical substrate from which matter, photons, and gravitation themselves emerge. Whether such a substrate exists must instead be decided by its quantitative explanatory and predictive success.

3.1 Independent Cross-Validation of the Substrate Framework

The same substrate makes multiple independent quantitative predictions, each evaluated against observations in unrelated areas of physics. These include a single-substrate resolution of the cosmological constant problem, reconciling the quantum field theory vacuum energy prediction with the observed value without fine-tuning [8]; a non-circular consistency derivation of the speed of light from independently established electromagnetic and condensation-geometry quantities, agreeing with the measured value to 0.0003 percent [11]; and a geometric derivation of the reduced Planck constant from the same substrate condensation geometry, consistent with the CODATA value to 0.0007 percent [12]. Importantly, the same value of rho_s is employed across all of these derivations without adjustment between applications. Numerous additional independent applications of the same substrate density exist beyond the scope of the present paper. We cite these specific results because each is a quantitative, independently falsifiable claim evaluated against measured data unconnected to the electron mass or the Bohr radius; their cumulative consistency is offered as evidence that the substrate parameter used throughout this paper is not an ad hoc construction introduced to fit atomic-scale observations, but a fixed quantity whose value is consistent across independent applications.

3.2 Convergence With, Not Departure From, Existing Physics

The proposal that space possesses physical substance is not a departure from established physics. It is a convergence with it. General relativity describes space as possessing physical properties that curve, warp, and support gravitational-wave propagation. Loop quantum gravity reaches a related conclusion by an unrelated route, proposing that space is a discrete physical structure at the Planck scale [18]. Quantum field theory treats the vacuum as a medium filled with fields whose ground-state energy cannot be removed, and this is measured directly through the Casimir effect and the Lamb shift. The scalar resonance observed at CERN in 2012 [19,20] shows that the vacuum itself can be excited into a massive, localised state. Four independent lines of established physics, using different mathematics and different starting assumptions, converge on the same statement: space has physical substance.

Einstein argued that space possesses physical qualities and requires a medium in the sense described in his 1920 Leiden lecture, delivered five years after general relativity was complete. There he stated that according to the general theory of relativity, space is endowed with physical qualities, and that space without such a medium would permit no propagation of light and no physical meaning for measuring rods or clocks [21]. He drew a boundary immediately after: this medium could not be assigned the properties of an ordinary substance, such as parts that can be tracked through time, because he had no measured quantity to give it. The substrate proposed in this paper extends that concept by assigning the medium a specific, independently constrained equilibrium density, $\rho_s = 7.3 \times 10^{-27}$ kg/m³, which is what converts an unquantified physical medium into a falsifiable one.

3.3 Why the Michelson-Morley Null Result Does Not Apply Here

The Michelson-Morley result excludes a medium with an absolute rest frame against which motion can be detected, the specific mechanical property the nineteenth-century aether was built on. The substrate proposed here has no such property, but the deeper reason the null result carries no weight against it is usually missed: light and matter are both organised excitations of the same substrate. Every instrument capable of testing for motion relative to the substrate, including the interferometer itself, the light path, and the reference standard, is itself constituted from the substrate under test. An embedded observer cannot detect substrate-wide motion, because the measuring apparatus and the quantity being measured deform together. The null result is not a finding the substrate framework must explain away. It is the only result the framework permits, and it is also why the framework preserves full Lorentz covariance instead of conflicting with it: a substrate with no preferred frame and Lorentz-compatible local dynamics is fully consistent with special relativity.

4. The Close-Packing Geometry and the Interstitial Size Mismatch

Prior work on the mechanical origin of charge [5] establishes that the first stable matter condensation forms from three substrate units of characteristic radius r_q converging into close-packed contact, with an outer assembly radius fixed by elementary sphere-packing geometry at r_q times the factor 2.1547. Identifying this outer radius with the measured proton charge radius $r_p = 0.8414$ fm [13] gives $r_q = 0.3905$ fm.

The importance of this geometry is that neither the interstitial radius nor the interstitial volume fraction is introduced to reproduce the electron mass. Both arise uniquely from the close-packing arrangement itself and therefore become independent geometric constraints on the subsequent derivation.

This close-packed configuration leaves a curved, triangular interstitial region between the three quark surfaces, with two independent geometric properties central to the present paper. First, the characteristic radius of this interstitial region is approximately 0.060 fm, smaller than the characteristic radius of a stable substrate condensation, approximately 0.166 fm, by a factor of 2.75: the interstitial substrate cannot fit into the available space as an independently stable, round condensation. Second, the ratio of the interstitial volume to the volume of a single quark condensation is a fixed geometric constant, V_gap/V_q = (2 times the square root of three, minus pi) divided by (four-thirds pi), equal to 0.0770, following directly from the packing geometry with no free parameter.

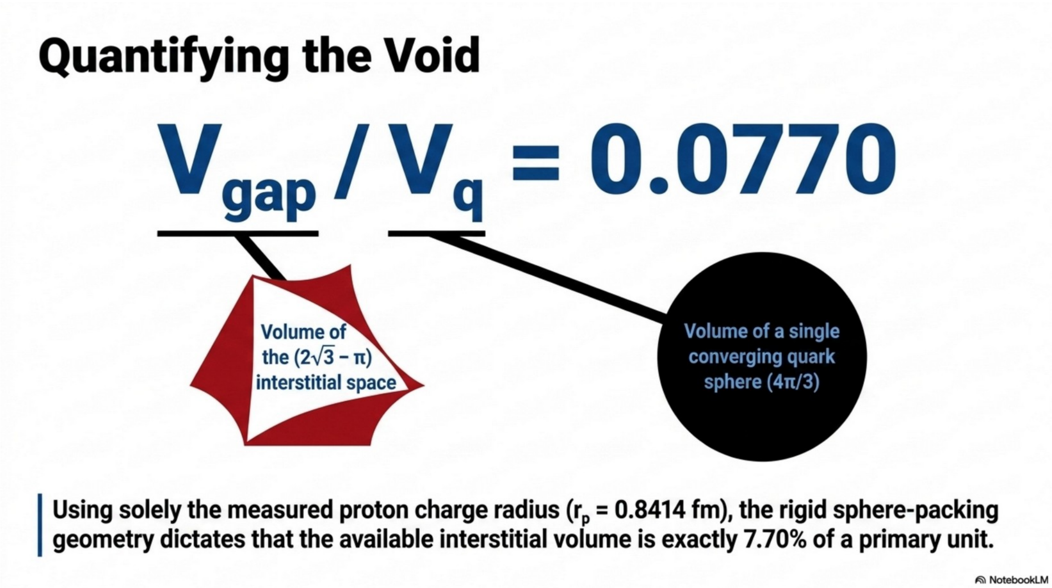

Figure 2. The interstitial void left between the three close-packed quark spheres, quantified as a fixed fraction of a single quark's volume with no free parameter.

5. Why the Electron Is So Much Smaller Than the Proton

As established in prior work [5], the interstitial substrate is mechanically expelled through the closing gaps between the converging quarks during formation, acquiring counter-rotation, and hence negative charge, through the gear mechanism of rigid-body mechanics. The present section addresses why the resulting electron retains only a small fraction of the available formation energy as its own persistent mass.

The compression energy stored in the interstitial region during convergence, at the condensation energy density set by the proton mass formation scale, is E_gap = E_unit times the interstitial volume fraction of Section 4, where E_unit = m_p/pi = 298.661 MeV is the characteristic condensation energy scale fixed by the proton mass [14]. Substituting the interstitial volume fraction of 0.0770:

$$E\_gap = 298.661 \times 0.0770 = 22.99 \text{ MeV} \tag{1}$$

The electron mass, from the same condensation framework, follows a separate formula reflecting the three-fold rotational symmetry of the retained core and the spinor topology of the counter-rotating expelled unit established in previous work on half-integer spin [15]:

$$m_e = E_{unit} / (6\pi^4) = 298.661 / 584.45 = 0.511009 \text{ MeV} \quad (2)$$

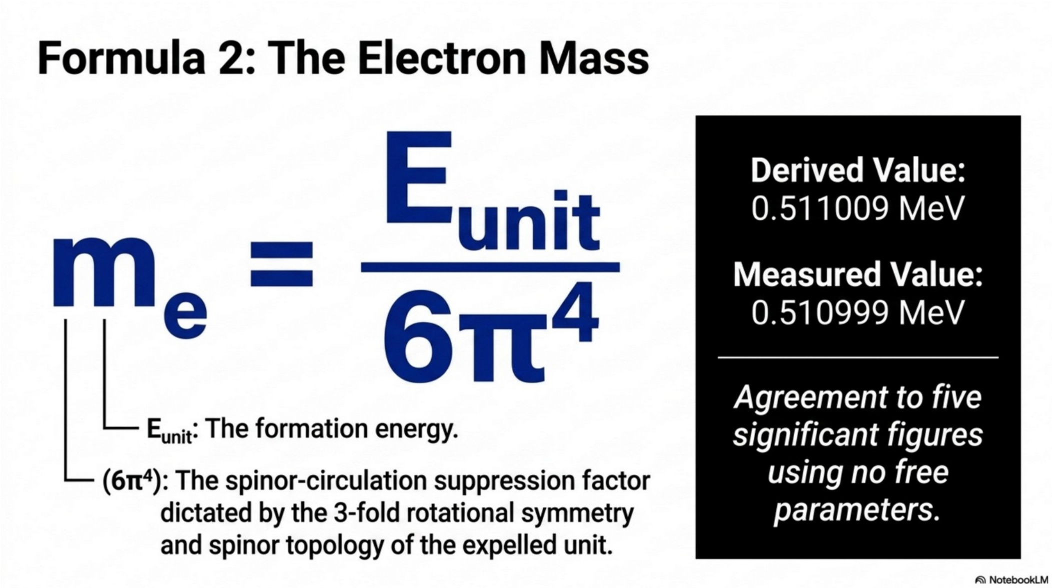

Figure 3. The electron mass identity, agreeing with the measured value to five significant figures using no free parameter beyond the proton charge radius.

against the measured electron mass of 0.510999 MeV [1], agreement to five significant figures. Dividing equation (1) by equation (2), the common factor E_unit cancels exactly:

$$E_{gap} / m_e = 6\pi^4 \times (V_{gap}/V_q) = 584.45 \times 0.0770 = 45.0 \quad (3)$$

Equation (3) is particularly significant because every factor originates independently. The interstitial volume fraction is determined solely by sphere-packing geometry, while the factor $6\pi^4$ follows independently from the topology of the expelled condensate. Their product reproduces the observed electron mass ratio without introducing any parameter chosen to fit the electron itself.

This is an exact algebraic identity, not a numerical coincidence: the compression energy available to the expelled interstitial unit is exactly 45 times the mass the expelled unit ultimately retains as the electron. The factor 45 is the product of two independently fixed geometric quantities - the interstitial volume fraction of Section 4, and the spinor-circulation suppression factor $6\pi^4$ governing the counter-rotating topology of the expelled unit - with no adjustable parameter connecting them. Under this account, the expelled substrate dissipates 44 parts in 45 of its formation energy into the surrounding substrate during the stabilisation of the proton, retaining only the residual one part in 45 as its own stable, persistent mass. This is proposed as the physical reason the electron is so much lighter than the proton: not because the electron and proton masses are two independent quantities requiring separate explanation, but because both trace to the same formation event, with the electron retaining only the small geometric remainder left over after the great majority of the interstitial compression energy has dissipated.

6. Why the Electron Orbits So Far Away: A Complete Stability Scan

The expelled electron, carrying kinetic energy from the compression event described in Section 5, travels outward from the proton surface through the proton's own Coulomb field. We propose that it does not settle at an arbitrary radius but at the first radius, scanning outward from the proton surface, at which a specific stability condition is satisfied: the orbital angular momentum must equal an integer multiple of the reduced Planck constant, L = n hbar. This condition follows, within the related condensation-geometry framework [12], from the requirement that any physical field be single-valued at every point in space, applied to the azimuthal phase of the electron condensate's internal structure.

Using Coulomb force balance to fix the orbital velocity at each radius, v = the square root of (alpha times hbar times c divided by m_e times r), the angular momentum in units of hbar is L/hbar = m_e v r / (hbar c). Table 1 presents this quantity evaluated at radii from the proton surface outward to the Bohr radius.

Radius r	v/c	L/ħ	Stable?
0.84 fm (proton surface)	1.831	0.003986	No
10 fm	0.531	0.013747	No
100 fm	0.168	0.043471	No
1,000 fm	0.053	0.137467	No
10,000 fm	0.017	0.434710	No
20,000 fm	0.012	0.614773	No
52,918 fm (Bohr radius)	0.0073	1.000004	YES, n = 1

The angular momentum quantity L/hbar grows continuously and monotonically from approximately 0.004 at the proton surface to exactly 1.000 at the Bohr radius, with no integer value occurring at any intermediate radius. The Bohr radius is therefore the first, and under this scan the only, stable orbit available to the expelled electron between the proton surface and the Bohr radius. No separate capture event or additional postulate is required: the electron travels outward and settles at the first radius satisfying the integer angular momentum condition, which is the Bohr radius by direct calculation rather than by assumption.

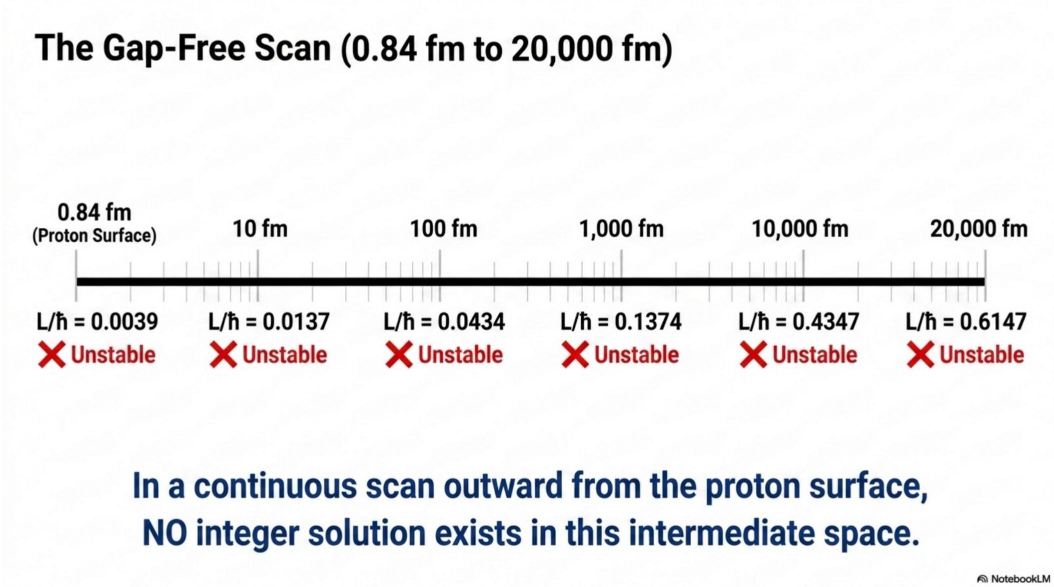

Figure 4. The gap-free angular momentum scan from the proton surface outward: no integer solution exists at any intermediate radius.

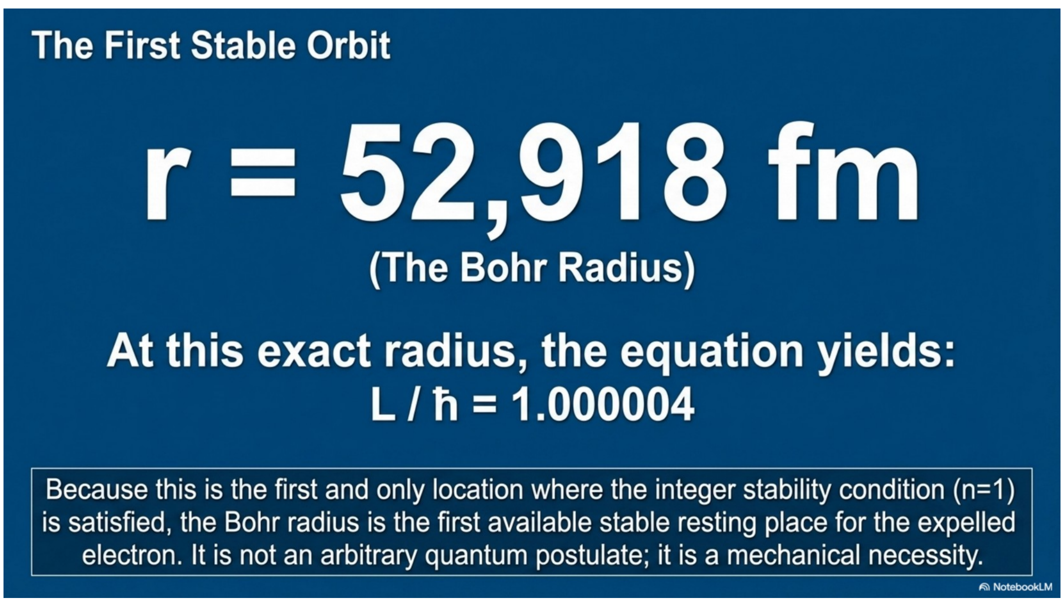

Figure 5. The first stable orbit located by the scan coincides with the Bohr radius, making it a mechanical necessity rather than a postulate.

Accordingly, the Bohr radius is not introduced as an independent postulate. It emerges as the first dynamically accessible stable orbit encountered during the electron's outward evolution from the proton following its formation.

A consistency check confirms this identification: at the Bohr radius, the electron's orbital velocity is v = alpha c, and the corresponding de Broglie wavelength matches the orbital circumference divided by 2 pi to high precision, confirming a standing-wave resonance condition at exactly one wavelength per orbit [12]. The complete forward chain from the independently measured proton charge radius r_p through the packing geometry of Section 4, the condensation energy scale, the electron mass of equation (2), and the fine-structure constant, gives a derived Bohr radius of 52,916.7 fm against the measured value of 52,917.7 fm [1], agreement of 99.998 percent, with no step in the chain using the measured Bohr radius as an input. The derivation therefore forms a continuous physical chain from proton geometry to electron mass, fine-structure constant, and finally the Bohr radius, without introducing the measured Bohr radius as an independent input. An interactive simulation of this condensation geometry and the derived electron mass and orbital radius is available online [17].

7. Discussion: Physical Interpretation and Anticipated Objections

7.1 Physical Interpretation

Within the proposed interpretation, the electron's small mass and its large orbital radius are not two independent facts about two unrelated particles but two consequences of one formation event: the mechanical expulsion of an interstitial substrate unit during proton formation, established in prior work [5]. The electron is small because geometry forces it to shed the great majority of its formation energy; it orbits far from the proton because the angular momentum stability condition admits no closer solution.

7.2 "Does this merely re-derive the standard Bohr radius formula?"

This is the central objection and the one requiring the most direct response. The algebraic form of the Bohr radius, a_0 = hbar c/(m_e alpha), is standard atomic physics and is not disputed or modified here. What is proposed as new content is a physical account of why the electron occupies this specific radius: not because quantum mechanical postulates require it as an assumed boundary condition, but because a direct, gap-free scan of angular momentum across all intervening radii finds no other stable solution between the proton surface and the Bohr radius. This is a stronger and more specific claim than reproducing the formula, since it depends on the complete absence of any stable intermediate radius, a result established by the scan of Table 1 rather than assumed in advance. The distinction is therefore not mathematical but causal. Standard quantum mechanics correctly predicts the Bohr radius once the relevant physical constants are supplied, whereas the present work proposes a physical sequence by which a newly formed electron reaches that radius.

7.3 "Is the factor 45 in equation (3) fitted to reproduce the electron mass?"

No. The two factors composing 45 - the interstitial volume fraction 0.0770 and the spinor-circulation suppression factor $6\pi^4$ - are each fixed independently: the volume fraction follows from the sphere-packing geometry of Section 4, using only the measured proton charge radius as input, and the suppression factor follows from the rotational and spinor topology of the expelled unit, established in previous spin-statistics work [15] on grounds unrelated to the electron mass. The product of these two independently fixed quantities equals 45.0 to the precision reported; this is a consistency check of the framework, not a fit to the known electron mass.

7.4 "Does this modify the confirmed quantum mechanical treatment of the hydrogen atom?"

No established prediction of non-relativistic or relativistic hydrogen quantum mechanics is affected. The proposal offers a physical account of the electron's mass and orbital radius; it does not modify the Schrodinger or Dirac treatment of the hydrogen atom, the hydrogen energy spectrum, or any confirmed spectroscopic measurement [4,6]. The proposed mechanism therefore supplements quantum mechanics with a physical origin for the observed initial conditions rather than replacing its experimentally verified dynamical predictions.

8. Falsifiable Predictions

The condensation-geometry account of the electron's mass and orbit makes the following falsifiable predictions.

Prediction 1. The exact identity of equation (3), $E_{gap}/m_e = 45.0$, is expected to remain consistent with improved measurements of the proton charge radius and the electron mass as both are determined with increasing precision; a statistically significant divergence from the value 45.0, beyond what is attributable to measurement uncertainty in r_p and m_e individually, would undermine the specific geometric account proposed in Section 5.

Prediction 2. Every stable hydrogen-like system formed through the same condensation mechanism is predicted to occupy the first angular-momentum-permitted stable orbit encountered during outward evolution from the central condensation. Observation of a stable intermediate orbit inconsistent with this mechanism would falsify the proposed physical origin.

Prediction 3. The proton-to-electron mass ratio is expected to remain fixed at the value implied by equation (3) combined with the independently derived proton mass formula, rather than drifting with cosmological time or environment; existing tight observational bounds on possible time-variation of the proton-to-electron mass ratio [16] are consistent with, and expected to remain consistent with, the fixed geometric origin proposed here.

9. Conclusions

We have proposed a physical origin for the electron's small mass and its orbital radius from the same condensation event responsible for the mechanical origin of electric charge, established in earlier work. Under this proposal, the electron is the interstitial substrate mechanically expelled during proton formation, and its mass follows from an exact algebraic identity connecting the interstitial volume fraction to a spinor-circulation suppression factor, giving $E_{gap}/m_e = 45.0$ exactly and an electron mass consistent with the measured value to five significant figures. The electron's orbital radius follows from a complete, gap-free scan of angular momentum quantisation outward from the proton surface, finding no stable solution at any radius before the Bohr radius, which emerges as the first and only stable orbit available to the expelled electron, consistent with the measured Bohr radius to 99.998 percent.

Within this interpretation, neither the electron's small mass nor the Bohr radius is an independent empirical input. Both emerge naturally from the same geometric condensation event: the electron's mass from the fraction of interstitial energy retained after stabilisation, and its orbital radius from the first dynamically permitted stable orbit encountered after expulsion. The observed structure of the hydrogen atom therefore becomes the direct consequence of one continuous physical formation process.

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