Magnetism as Circulating Charge: Why the Nuclear Electron Carries No Magnetic Moment

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July 20, 2026

Text and argument by the author; numerical computations with AI assistance (Claude, Anthropic).

Abstract

The classic objection that retired the proton–electron model of the nucleus in 1932 is the *magnetic-moment* problem: an electron confined inside a nucleus should carry a magnetic moment of order the Bohr magneton μ_B, whereas measured nuclear moments — the neutron's included — are of order the nuclear magneton $\mu_N \approx \mu_B/1836$, a thousand-fold too small. We show that in the RealQM/RealNucleus picture, where constituents are charge densities rather than point particles, this objection dissolves. In a charge-density theory the magnetic moment is a property of the *current*, $\boldsymbol{\mu} = \frac{1}{2}\int \mathbf{r}\times\mathbf{J}\, d^3r$ with $\mathbf{J} = (\hbar/m)\,\mathrm{Im}(\psi^*\nabla\psi)$, and a *real* density carries no current and hence no moment. RealNucleus computes the deuteron's confined electron as a *flat, real, node-less* charge density; it therefore carries *exactly zero* magnetic moment, and the nuclear moment is set by the protons alone — at μ_N-scale, not μ_B-scale. A direct numerical test confirms the enabling facts: a single global phase winding $e^{im\phi}$ gives a moment $\mu_z = -m\,\mu_B$ that is *quantized and independent of the density's spatial extent* (so caging cannot continuously suppress a winding), while only the winding-free ($m = 0$) real density gives zero. The same flatness that was shown to make the electron's *mass* irrelevant to nuclear binding thus also makes its *magnetic moment* vanish — one property answering two of the classical objections at once. We are explicit about what remains open: the free electron's own μ_B and the neutron's exact $-1.913\,\mu_N$ require a structured, self-consistent current and hence a complex/real-time solver, and the anomalous $g/2 = 1.00116\ldots$ is a separate debt.

Keywords: nuclear magnetic moment; nuclear electrons; RealQM; RealNucleus; circulating charge; charge-density current; flat electron; neutron.

1 The objection

When the proton–electron model of the nucleus was abandoned in 1932, two arguments did the work. One was the confinement energy (an electron localised to nuclear size should carry hundreds of MeV of kinetic energy); the other was the *magnetic moment*. The magnetic moment argument is the sharper of the two. An electron carries an intrinsic magnetic moment of about one Bohr magneton,

$$\mu_B = \frac{e\hbar}{2m_e} \;=\; 1836\,\mu_N, \qquad \mu_N = \frac{e\hbar}{2m_p}, \tag{1}$$

so any nucleus containing electrons should carry moments of order μ_B. Measured nuclear moments are instead of order μ_N: the neutron's is $\mu_n = -1.913\,\mu_N \approx -0.001\,\mu_B$. An electron inside would overshoot by a factor of roughly a thousand. In the standard picture the difficulty never arises, because the neutron is not $p + e$ but an elementary *udd* baryon whose moment comes from its charged quarks.

RealNucleus revives the proton–electron nucleus [1]: the neutron is a bound $p + e$ pair, the deuteron is $2p+1e$, and light nuclei are dual-Coulomb-confined arrangements of proton and electron charge densities. If that picture is to survive, it must answer the magnetic-moment objection. This note shows that it does — and that the answer is the *same* flat electron that answers the confinement-energy objection.

2 Magnetic moment as a property of the current

The decisive difference between a point-particle theory and a charge-density theory is where the magnetic moment comes from. For a point electron the dominant moment is *intrinsic* spin — a fixed $\sim \mu_B$ that the particle carries into any state, and which cannot be switched off by confinement. In a charge-density theory there is no such term *a priori*; the magnetic moment is generated entirely by the *current* in the density,

$$\boldsymbol{\mu} \;=\; \frac{1}{2}\int \mathbf{r}\times\mathbf{J}\,d^3r, \qquad \mathbf{J} \;=\; \frac{\hbar}{m}\,\mathrm{Im}(\psi^*\nabla\psi)\,. \tag{2}$$

The current is the electromagnetic reading of charge in motion, and it has one immediate and decisive property: for a *real* wavefunction ψ, the combination $\psi^*\nabla\psi$ is real, so $\mathbf{J} = 0$ identically. **A static, real charge density carries no current and therefore no magnetic moment.** Magnetism, in this framework, requires the complex, time-dependent structure of the wavefunction — specifically a phase that *winds in space*, which is the charge-density realisation of "charge moving in circles."

A scope point must be made explicit here. RealQM in its established form is a *real-valued*, parabolic theory (ground states found by imaginary-time relaxation), and produces no current by construction; the complex, current-bearing form invoked by (2) is a time-dependent *extension* of that base theory, formulated separately [3]. This split is exactly what we exploit: the central result below — that the flat confined electron has *no* moment — holds already *within the real base theory*, since a real density has $\mathbf{J} = 0$; it is only the *nonzero* moments (the free electron's own μ_B, the neutron's residual) that require the complex extension, and those we treat as open. Nothing in the vanishing of the caged moment depends on the extension being complete.

A phase winding $\psi = R(\mathbf{r})\,e^{im\phi}$ about an axis produces a genuine azimuthal current and, through (2), an orbital magnetic moment. Its size is the subject of the next section.

3 The winding is quantised: a numerical test

Impose a phase winding $e^{im\phi}$ on a normalised electron density and evaluate (2). Writing s for the cylindrical radius, the current is $J_\phi = (\hbar/m)\,|R|^2\,(m/s)$, so $(\mathbf{r}\times\mathbf{J})_z = s\,J_\phi = (\hbar/m)\,m\,|R|^2$, and

$$\mu_z \;=\; -\frac{e}{2}\int (\hbar/m)\,m\,|R|^2\,d^3r \;=\; -\,m\,\mu_B, \tag{3}$$

since $|R|^2$ is normalised. **The moment is $-m\,\mu_B$ exactly, independent of the shape or extent of $|R|^2$**: the factors of s and $1/s$ cancel. The cancellation is not an accident but the gyromagnetic relation $\boldsymbol{\mu} = (q/2m_e)\mathbf{L}$ at work. A larger orbit has a proportionally larger lever arm ($\propto s$) but a proportionally slower winding velocity ($v_\phi = m/(m_e s) \propto 1/s$, since the phase wraps the same m times around a bigger circle), so the angular momentum $L_z = \int(\mathbf{r}\times\mathbf{p})_z|\psi|^2 = m\hbar$ is fixed by the winding number alone, regardless of the radial distribution. And m is not a free geometric parameter: single-valuedness of $e^{im\phi}$ forces it to be an integer. The moment is therefore fixed by a *topological* quantity (how many times the phase wraps), not by geometry — which is why caging cannot shrink it continuously, and why the only route to zero is $m = 0$, no winding at all. A direct grid evaluation confirms this and isolates that escape route (Table 1).

configuration	current pattern	μ_z/μ_B
free electron (broad, $\sigma = 5$)	single winding $m = 1$	-1.0000
caged electron (narrow, $\sigma = 0.5$)	single winding $m = 1$	-1.0000
caged electron (very narrow, $\sigma = 0.2$)	single winding $m = 1$	-1.0000
any real density	none ($m = 0$)	0.0000
caged, core+/halo− current	structured (counter-rotating)	$+0.212$

Table 1: Magnetic moment from imposed currents on normalised densities. A single global winding gives $-m\,\mu_B$ regardless of the density's spatial extent (rows 1–3): geometry does *not* suppress a winding. Only the winding-free real density gives zero. A *structured* current with opposed circulation in core and halo gives a non-quantised, tunable moment — the only route to a small nonzero value.

Two conclusions follow, one negative and one positive. *Negative:* caging cannot *continuously* suppress a magnetic moment — a single winding yields the full μ_B whether the electron is spread over five length units or squeezed into one fifth of one. The naive picture of "confinement shrinks the moment" is simply wrong. *Positive:* the only winding that gives zero is $m = 0$, the winding-free *real* density.

4 Energetics: why the caged electron cannot afford a winding

Section 3 shows that geometry does not *continuously* shrink a winding — a winding of $m = 1$ gives μ_B at any size. But there remains the prior question of whether a caged electron can *sustain* a winding at all, and this is settled by energetics. A winding carries a kinetic cost,

$$\Delta T(m) \;=\; \frac{\hbar^2}{2m_e}\, m^2 \int \frac{|R|^2}{s^2}\, d^3r \;=\; \mathrm{Ry}\; m^2\, (a_0/\sigma)^2, \tag{4}$$

where σ is the density's cylindrical scale and the last form uses the $m = 1$ node-on-axis profile $|R|^2 \propto s^2 e^{-s^2/\sigma^2}$ (for which $\langle 1/s^2 \rangle = 1/\sigma^2$ exactly), with $\mathrm{Ry} = \hbar^2/2m_e a_0^2 = 13.6$ eV. The cost scales as $1/\sigma^2$, so it is minute for a spread-out free electron and enormous for a compact caged one (Table 2).

electron	scale σ	winding cost $\Delta T(m{=}1)$
free (Bohr scale)	$\sim a_0$	13.6 eV $\quad(\approx 1$ Ry$)$
caged (deuteron)	$\sim$2 fm	9.5 GeV
caged (deuteron)	$\sim$1 fm	38 GeV

Table 2: Kinetic cost of an $m{=}1$ winding, Eq. (4). For the free electron it is about one Rydberg — affordable, so the free electron can sustain a circulation. For the femtometre-caged electron it is of order GeV, thousands of times the $\sim$2.2 MeV deuteron binding — so a winding is forbidden and the electron collapses to the winding-free $m{=}0$ state. A winding is a gradient; it reintroduces exactly the kinetic cost the flat electron avoids.

The conclusion is robust, though the exact margin depends on a mass convention. Using the physical electron mass, the caged winding ($\sim$9.5 GeV at 2 fm) exceeds the deuteron binding by a factor $\sim 10^3$. Using RealNucleus's equal-mass device ($m_e \to m_p$ in the kinetic term) reduces it by 1836 to $\sim$5 MeV — still above the 2.2 MeV binding, so still forbidden, but only by a factor $\sim$2. Either way the caged electron cannot afford the winding and settles at $m = 0$; only the size of the margin is convention-dependent. Crucially this is the *same* statement as mass-irrelevance: the flat $m = 0$ electron avoids femtometre-scale gradients, and a winding is precisely such a gradient, so the property that removes the mass also forbids the current.

A self-consistent check. The estimate (4) is confirmed by relaxing the $m = 0$ and $m = 1$ states directly rather than assuming a profile. A radial imaginary-time relaxation in a harmonic well converges to $E(m{=}0) = 1.0000$ and $E(m{=}1) = 2.0000$ (in units of $\hbar\omega$), the exact two-dimensional oscillator values, so the winding cost is $\Delta E = 1 \cdot \hbar\omega$ computed, not posited. Scaled to physical confinement this is ≈ 27 eV for a free electron ($\sigma \sim a_0$) and ≈ 19 GeV for a caged one ($\sigma \sim 2$ fm) — the latter about 10^4 times the deuteron binding, forbidden by the same margin the estimate gives. The self-consistent relaxation therefore turns the energetic argument from an order-of-magnitude estimate into a computation: the caged electron settles in $m = 0$ and carries no moment. (The relaxation solver and the run are documented with the model implementation; the harmonic-vs-Gaussian difference between 19 and 9.5 GeV is an $O(1)$ profile factor, while the $\sim 10^4$ margin is not.)

5 The flat electron carries no moment

This is where the RealNucleus computation supplies the answer. The deuteron's confined electron is not an arbitrary state: minimisation of the Coulomb energy under the free-boundary condition returns it as a *flat, node-less, real* charge density, caged by the two protons and satisfying charge continuity at a definite radius [1]. A flat real density is precisely the $m = 0$ case: ψ real $\Rightarrow \mathbf{J} = 0 \Rightarrow \boldsymbol{\mu} = 0$. **The nuclear electron carries no magnetic moment.**

The consequence is exactly what is observed. With the confined electron contributing nothing, the magnetic moment of a nucleus is set by its *protons*, and therefore comes out at *nuclear-magneton scale*, not Bohr-magneton scale. The factor-of-a-thousand overshoot that retired the proton–electron model does not occur, because the object that would have supplied it — an electron carrying its intrinsic μ_B into the nucleus — does not exist in a charge-density theory. There is no intrinsic term to carry; there is only the current, and the flat electron's current is zero.

One flatness, two objections. The flat confined electron was not introduced here to solve the magnetic-moment problem. It was already required, in the companion work [1], to make the electron's *mass* irrelevant to nuclear binding: a flat density has vanishing kinetic-energy gradient, so its mass drops out, and the deuteron's femtometre scale is set by the heavy proton rather than by confining a light electron at hundreds of MeV. That same flatness — real, node-less, currentless — now answers the magnetic-moment objection as well. The two classical arguments that retired nuclear electrons in 1932, the confinement energy and the magnetic moment, are answered by a single property of the confined-electron solution. This is not two patches but one fact read twice.

6 What remains open

We state plainly what this does and does not establish.

Established: the confined electron, computed as a flat real density, carries no magnetic moment, so RealNucleus predicts nuclear moments at μ_N-scale rather than μ_B-scale — the qualitative heart of the objection is removed, and by the same flatness that handles the mass.

Open, and requiring a complex/real-time solver:

- **The free electron's own moment — and why it is not an ordinary winding.** A free electron carries $\sim \mu_B$, and it is tempting to attribute this to an orbital winding of the kind used above. But that will not do, and the distinction is important. The ground state of a free or atomically-bound electron is *real* (the 1s state, $m = 0$): it has *zero orbital moment*, and in the standard account its μ_B is *intrinsic spin*, not orbital circulation. So the free electron's μ_B cannot come from an atomic-scale winding — if it circulates at all, it must be an *internal*, Compton-scale circulation ($s \sim \hbar/m_e c$), the Zitterbewegung structure, which is a far deeper and more speculative object than the atomic-scale current considered here. This means the clean, defensible result of this note is the *caged* side — the confined electron has no moment — while the *free* electron's μ_B is a genuinely open problem at the Compton scale, not settled by any atomic-scale winding calculation. We are careful not to conflate the two: suppressing the caged moment is solid; generating the free μ_B from circulation is a program.

- **The neutron's exact $-1.913\,\mu_N$.** This is small but nonzero, so it is not "electron contributes exactly nothing" but a proton-dominated value with a small residual. Table 1 shows a nonzero, non-quantised moment requires a *structured* current (opposed circulation in core and halo), which only a self-consistent complex solution can generate — not an imposed single winding.

- **The anomalous moment.** The precisely measured $g/2 = 1.00116\ldots$ is QED's crown jewel; a circulating-charge account would owe its own derivation of this correction. This is the hardest debt and is untouched here.

None of these is hidden, and none is answered by hand-waving. What is claimed is bounded and, we believe, correct: the *scale* objection — the thousand-fold overshoot that is the sharp form of the magnetic-moment argument against nuclear electrons — is removed, because a flat real confined electron has no current and hence no moment.

7 Conclusion

In a point-particle theory an electron's magnetic moment is intrinsic and cannot be switched off, so a nuclear electron wrecks the moment budget by a factor of a thousand. In a charge-density theory the moment is the current's, a real density has no current, and the confined electron — computed flat and real — has no moment. Nuclear moments then sit at μ_N-scale, as observed, and the same flatness that makes the electron's mass irrelevant to binding makes its magnetic moment vanish. The magnetic moment, long the sharpest weapon against nuclear electrons, turns out to depend on treating the electron as a point that carries spin; read as a charge density that carries current, a caged flat electron carries nothing. What remains — the free electron's μ_B, the neutron's exact value, the anomalous g-factor — is well-posed and is the province of a complex, current-bearing extension of the solver.

References

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