Quantum Interpretation of the Proton Anomalous Magnetic Moment

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The role of the anomalous moment in the geometric Clifford algebra of proton topological mass generation suggests that the anomaly is not an intrinsic property of the free space proton, but rather a topological effect of applying the electromagnetic bias field required to define the eigenstates probed by the magnetic moment measurement. Quantum interpretations strive to explain emergence of the world we observe from formal quantum theory. This variant on the canonical measurement problem is examined in the larger context of quantum interpretations.

INTRODUCTION

The mystery of the wavefunction, inferred from measurement but not observable, is front and center in quantum interpretations, in our efforts to understand quantum mechanics as something more than abstract mathematical formalism. Contentions emerge as manifestations of the measurement problem.

"The measurement problem in quantum mechanics is the problem of how (or whether) wavefunction collapse occurs. The inability to observe this process directly has given rise to many different interpretations of quantum mechanics, and poses a key set of questions that each interpretation must answer."[1]

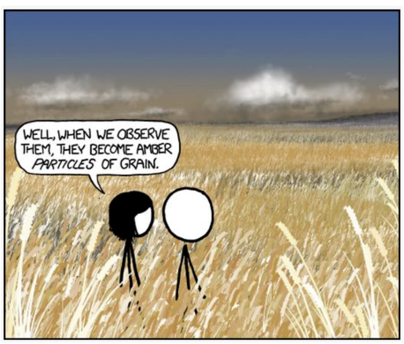

FIG. 1. A symptom of the measurement problem

At root the confusion arises from point particles. Points cannot collapse. One cannot understand wavefunction decoherence without self-coherence[2–5]. A single point particle has nothing to cohere with.

There arise two questions. How might one visualize a self-coherent geometric structure for the electron? What fields might one take to make manifest the geometric and topological properties of such a structure?

For the first we have Clifford algebra of the Pauli-Schrodinger and Dirac equations. In particular we have the geometric interpretation of that algebra, the background independent algebra of interactions of geometric primitives of physical space[6].

For the second we take the simplest possible option, and assign these geometric primitives the attributes of quantized electric and magnetic fields[7].

From these two constructs, geometry and fields, one can define a vacuum impedance structure[8–10], relate excitations of that structure to observables of particle physics, define a proton wavefunction, and perhaps gain some understanding of origins of both the proton Bohr magneton and the anomalous magnetic moment[11].

GEOMETRIC CLIFFORD ALGEBRA

For geometry the wavefunction presented here adopts the minimally complete 3D Pauli algebra of physical space - one scalar, three vectors, three bivector pseudovectors, and one trivector pseudoscalar - point, line, plane, and volume elements of Euclid, with the additional attribute of being orientable[6]. For fields it endows them with quantized electric and magnetic fields[7].

While this wavefunction can be easily intuitively visualized, it is not an observable[12, 13]. Observables are interactions, represented in geometric algebra by geometric products of wavefunctions. These products generate a 4D Dirac algebra of flat Minkowski spacetime[6]. Time (relative phase) emerges from the interactions.

Topological symmetry breaking is implicit in geometric algebra. Given two vectors a and b, the geometric product ab mixes products of different dimension, or *grade*. In the product $ab = a \cdot b + a \wedge b$, two 1D vectors have been transformed into a point scalar and a 2D bivector.

"The problem is that even though we can transform the line continuously into a point, we cannot undo this transformation and have a function from the point back onto the line..."[14].

Interactions of wavefunctions are represented by the geometric product. They break topological symmetry due to this property of grade increasing operations. With a little help from the topological duality between electric and magnetic charge[15–17], the remarkable power of geometric interpretation becomes evident in defining both vacuum and proton wavefunctions.

WAVEFUNCTION AND S-MATRIX

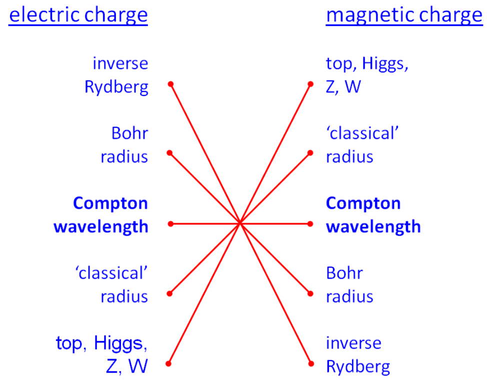

FIG. 2. Inversion of fundamental lengths by magnetic charge

The relativistic photon is our fiducial in measurements of geometry. Topological duality arises from the difference in coupling to the photon of magnetic and electric charge. If we take magnetic charge g to be defined by the Dirac relation $eg = \hbar$ and the electromagnetic coupling constant to be $\alpha = e^2/4\pi\epsilon_0\hbar c$, then e is proportional to $\sqrt{\alpha}$ whereas g varies as $1/\sqrt{\alpha}$. The characteristic coherence lengths of figure 2, precisely spaced in powers of α, are inverted for magnetic charge[18]. The Compton wavelength $\lambda = h/mc$ is independent of charge.

Magnetic charge g is 'dark', cannot couple to the photon, not despite its great strength, but rather because of it. The α-spaced lengths of figure 2 correspond to specific physical mechanisms of photon absorption and emission. Bohr radius cannot be inside Compton wavelength in the basic photon-charge coupling of QED, Rydberg cannot be inside Bohr,... Specific physical mechanisms of photon emission and absorption no longer work.

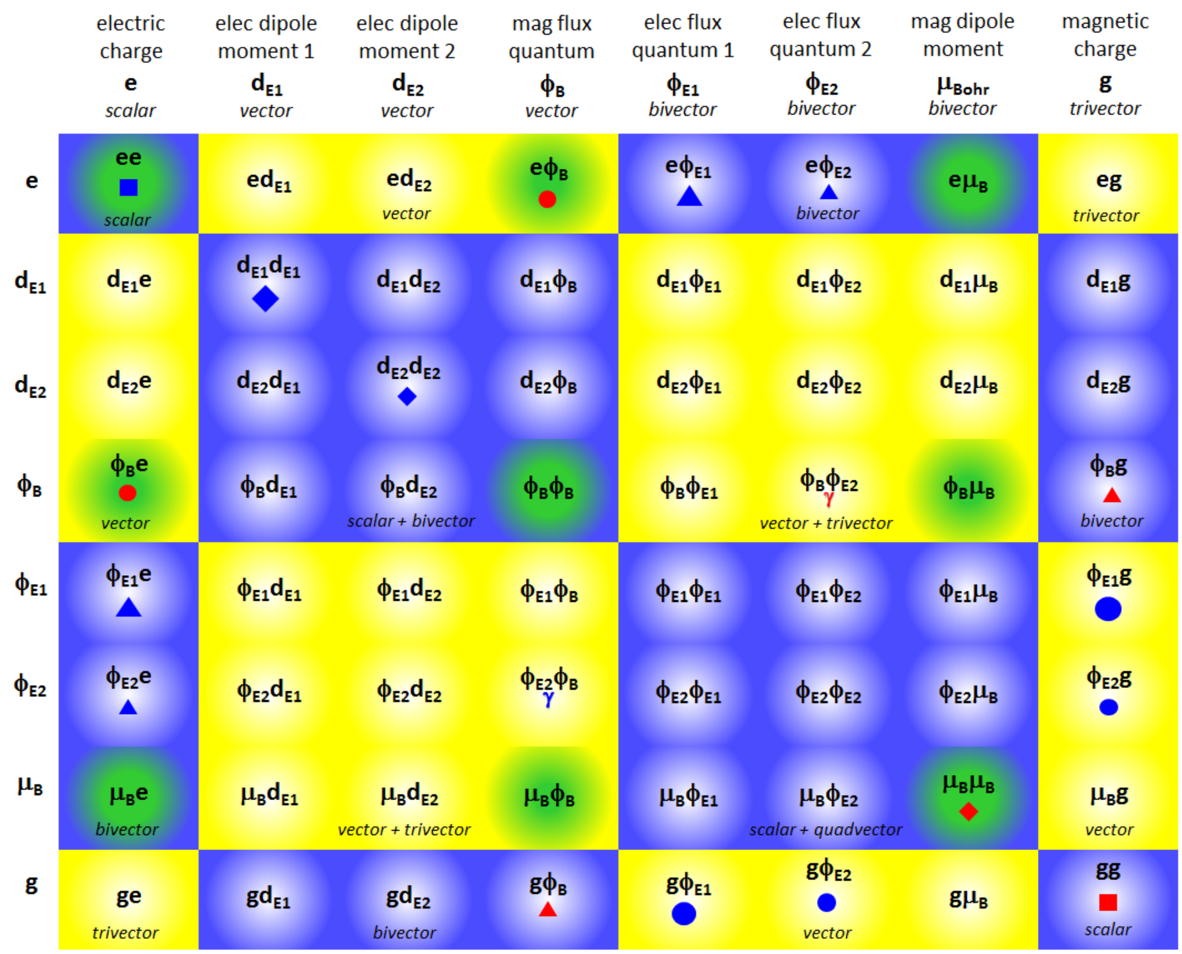

FIG. 3. **The S-matrix:** At top and left, a minimally complete Pauli algebra of 3D space is comprised of one scalar, three each vectors and bivectors, and one trivector. Attributing electric and magnetic fields to these fundamental geometric objects (FGOs) yields the wavefunction model [7]. In the manner of the Dirac equation, taking those at the top to be the electron wavefunction suggests those at the left correspond to the positron. Their geometric product generates the background independent 4D Dirac algebra of flat Minkowski spacetime, arranged in odd transition modes (yellow) and even eigenmodes (blue) by geometric grade. Time (relative phase) emerges from the interactions. **Modes of the stable proton are highlighted in green**[11]. Modes indicated by symbols (square, circle, diamond, triangle) are plotted in figure 4.

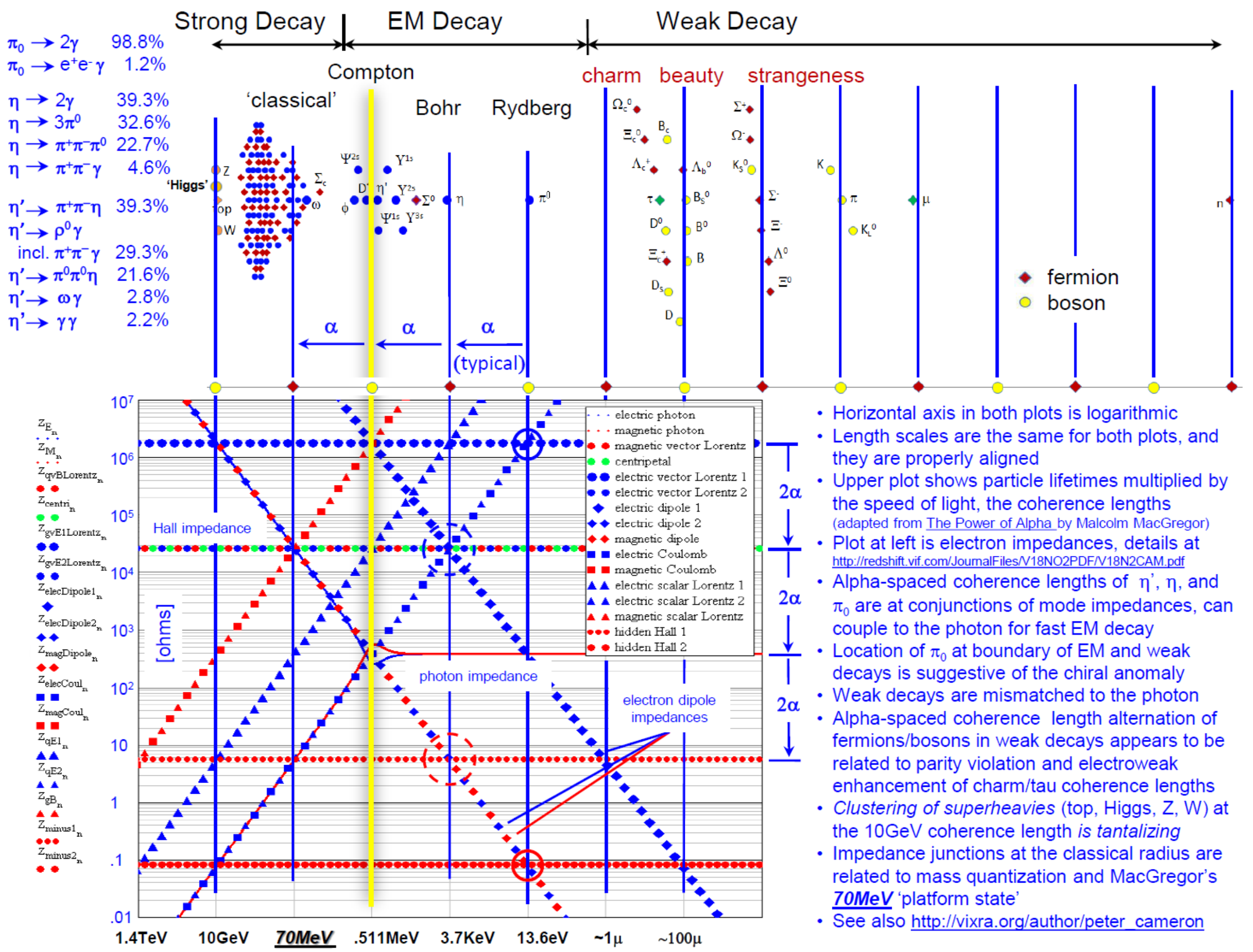

FIG. 4. Correlation between coherence lengths (light cone boundary) of the unstable particle spectrum[19–21] and nodes of the energy/scale dependent impedance network of a subset of the modes of figure 3[22]. Impedances are matched at the nodes, permitting the transfer of energy between modes essential for particle decay. Precise calculation of π_0, η, and η' branching ratios shown at the upper left and resolution of the chiral anomaly follow from impedance matching considerations [23].

If one takes the Compton wavelength of figure 2 to be that of the electron, then nodes of the impedance network of a subset of the mode structure shown in figure 3 are correlated with unstable particle lifetimes as shown in figure 4[22].

The speed of light (or vacuum impedance) can be calculated from excitation of virtual electron-positron pairs by the photon[8, 9], from the scalar mode shown at the upper left of figure 3. One might consider the possibility that a more detailed understanding results from taking the complete impedance network of the mode structure of figure 3 to comprise a model of the vacuum impedance, an impedance representation of the S-matrix [11].

The extraordinary fit between the impedance network of figure 4 and the particle spectrum lifetimes follows from the fact that the electron is the lightest charged particle, by far the most easily excited by the photon, and the virtual electron-positron pair the natural candidate for lowest order coupling to the 'vacuum impedance'.

PROTON STRUCTURE AND SPIN

Distinguishing dark and visible modes plays an essential role in sorting out proton structure. The predominance of unobserved dark modes (containing magnetic charge, electric flux quantum and/or electric dipole) in figure 3 provides the needed filter, given the assumption that unstable particles contain at least one dark mode to drive decoherence.

Dark fundamental geometric objects (FGOs) couple differently to the vacuum impedance and therefore experience different phase shifts. Modes containing one or more dark FGOs decohere from differential phase shifts[2–5]. To identify the mode structure of the proton we need only consider modes comprised exclusively of visible FGOs, a tremendous simplification. Restricting attention to these modes, highlighted in green in figure 3, gives us both transition modes (yellow background) and eigenmodes (blue background) of the proton.

proton eigenmodes - the Bohr magneton

As shown in figure 5, eigenmode FGOs of figure 3 entering the geometric products number three scalars, two vectors, and three bivectors. Those emerging from the geometric products number three scalars, two bivectors, and one quadvector - an even subalgebra of the Dirac algebra, itself again a Pauli algebra, a wavefunction. Electric charge is conserved in the interaction.

eigenmode FGOs			
mode	*entering FGOs*	*emerging FGOs*	E&M FGOs
ee	two scalars	scalar	**e**
$\boldsymbol{\phi_B\phi_B}$	two vectors	scalar + bivector	$\mathbf{e + \mu_B}$
$\boldsymbol{\mu_B e}$	bivector + scalar	bivector	$\boldsymbol{\mu_B}$
$\boldsymbol{\mu_B\mu_B}$	two bivectors	scalar + quadvector	**e + I**

FIG. 5. Eigenmodes of figure 3 having only visible Pauli FGOs entering the geometric products, showing emerging grades and corresponding electromagnetic FGOs of the model, which again comprise a Pauli wave function.

The connection of the three emergent scalars with three quarks seems obvious. The only scalar in our wavefunction model is electric charge. Given that the top and left Pauli algebras of figure 3 correspond to electron and positron wavefunctions, then all three scalars follow from three particle-antiparticle geometric products ($e\overline{e}$, $\phi_B\overline{\phi}_B$, and $\mu_B\overline{\mu}_B$), one for each of the three grades entering the products. All are found on the diagonal of figure 3. Also prominent on the diagonal is the Coulomb mode $g\overline{g}$ of magnetic charge, part of the mode structure of the superheavies (top, Higgs, Z, W,...).

The two bivectors μ_B emerging from geometric products $\phi_B\overline{\phi}_B$ and $\mu_B e$ might be identified with Yang-Mills axial vectors. With relevance to the proton spin controversy [24–27], the 938 MeV rest mass of the emergent $\mu_B\overline{\mu}_B$ mode corresponds to stored electromagnetic field energy not of the measured moment, but rather the spin 1/2 proton Bohr magneton, suggesting the anomaly is not a property of the proton near field [11].

The grade-4 quadvector $I = \gamma_0\gamma_1\gamma_2\gamma_3$ defines spacetime orientation as manifested in the phases, with γ_0 the sign of time orientation. The γ_μ are orthogonal basis vectors in the geometric Dirac algebra of flat 4D Minkowski spacetime, not matrices in 'isospace'[28].

proton transition modes - the anomaly

The FGOs entering the geometric products to generate the transition modes of figure 3 are shown in figure 6, as well as grades of the FGOs emerging from the products and their corresponding identities in the impedance representation[11].

In figure 6 the Chern-Simons term $\phi_B e$ is the quantum Hall impedance of the charge 'orbiting' in the field of the flux quantum, driven by the impinging photon. The two spin zero (vectors have no spin) flux quanta ϕ_B are indistinguishable bosons, can be taken to couple the bivector (GA equivalent of a Yang-Mills axial vector) Bohr magneton μ_B to the charge scalar e.

transition mode FGOs			
mode	*entering FGOs*	*emerging FGOs*	E&M FGOs
$\boldsymbol{\phi_B e}$	vector + scalar	vector	$\boldsymbol{\phi_B}$
$\boldsymbol{\phi_B\mu_B}$	vector + pvector	vector + pscalar	$\boldsymbol{\phi_B + g}$

FIG. 6. Transition modes of figure 3 having only 'visible' FGOs entering the geometric products, showing the grades of emerging FGOs and corresponding electromagnetic FGOs.

FGOs entering transition mode products include one scalar, two vectors, and one bivector. These comprise a minimally complete 2D geometric algebra. Their geometric products yield two vector flux quanta ϕ_B and the pseudoscalar magnetic charge g. With the pseudoscalar we've gained a dimension. Via the interactions we have the 2+1 dimensions of topological mass generation[29].

At the scale of the .511 MeV Compton wavelength there exist modes of the vacuum impedance model shifted in energy by powers of α, a consequence of the impedance nodes being arranged in such powers. Scalar Lorentz coupling of emergent magnetic charge g to flux quantum ϕ_B (rightmost column of figure 6) yields a route to the 70 MeV mass quantum and the muon mass[30].

In accord with that calculation, if one takes μ_B entering the interaction (leftmost column of figure 6) to be not the electron Bohr magneton but rather that of the muon and ϕ_B to be similarly confined to the muon Compton wavelength, then the energy of the bivector magneton in the field of the vector flux quantum, the energy of the $\phi_B\mu_B$ transition mode, is the muon mass.

Most remarkably, the anomalous magnetic moment of the proton is impedance matched to the Coulomb modes of the proton shown in figure 5 and both the Chern-Simons impedance of topological mass generation and the dipole impedance of a photon whose energy is the rest mass of the muon. With sufficient photon energy, the muon radiates the proton mass, the point being that the anomaly appears to be in the far-field of the proton, a property of the muon. and the spin 1/2 nuclear Bohr magneton a near-field property. At low energy the proton appears with the anomaly. At high energy the direct interaction is with the nuclear Bohr magneton[11].

The muon, the next lightest elementary particle, appears to provide both the proton anomalous moment and a route to topological mass generation of the nucleons, this with no further input by hand to the five fundamental constants of the model[7].

Index	Interpretation	Authors	non-local?	probabilistic?	hidden variables?	wavefcn real?	wavefcn collapse?	universal wavefcn?	observer role?	unique history?
30	Objective Collapse	GRW 1986, Penrose 1989	Yes	Yes	No	Yes	Yes	No	No	Yes
30	Transactional	Cramer 1986	Yes	Yes	No	Yes	Yes	No	No	Yes
30	Quantum Impedances	Cameron & Suisse 2013	Yes	Yes	No	Yes	Yes	No	No	Yes
25	Relational	Rovelli 1994	No	Yes	No	No	Yes	No	No	agnostic
23	Quantum Logic	Birkhoff 1936	agnostic	agnostic	No	agnostic	No	No	No	Yes
17	Ithaca	Mermin 1996	No	Yes	No	No	No	No	No	No
15	Consistent Histories	Griffiths 1984	No	agnostic	No	agnostic	No	No	No	No
15	Copenhagen	Bohr & Heisenberg 1927	No	Yes	No	No	Yes	No	Yes	Yes
9	Qbism	Caves, Fuchs, Schack 2002	No	Yes	No	No	Yes	No	Yes	No
6	Orthodox	von Neumann 1932	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
-3	Many Worlds	Everett 1957	No	No	No	Yes	No	Yes	No	No
-18	de Broglie – Bohm	de Broglie 1927, Bohm 1952	Yes	No	Yes	Yes	No	Yes	No	Yes

FIG. 7. Comparison of Interpretations. The Index parameter quantifies strength of agreement between a given interpretation and the rest of the table. Values are calculated by adding a point for entries that agree with a given interpretation, subtracting for entries that disagree, and giving half values for agnostics. Appearance over the course of nearly a century of growing numbers of interpretations and contentions demonstrates lack of proper physical understanding of fundamental phenomena[12].

QUANTUM INTERPRETATIONS

Interpretations of the formalism and phenomenology of quantum mechanics address distinctions between knowledge and reality, between epistemic and ontic, between how we know and what we know. It's a pursuit that straddles the boundary between philosophy and physics. There are many areas of contention. Figure 7 shows a sample of contentions and interpretations[12].

In each of these areas quantum interpretations seek to address the same basic question - how to understand the measurement problem?[31, 32] How does one get rid of the shifty split[33] of the quantum jump[34], develop a smooth and continuous real-space visualization of state reduction dynamics?[5] What governs the flow of energy and information in wavefunction collapse?

The point here is that, unlike other interpretations, the present approach has a working electromagnetic geometric model. The wavefunction can be visualized in our 3D physical space. It is this that may permit resolution of the contentions of quantum interpretations.

Reality and Observability of the Wavefunction

The wavefunction is comprised of fundamental geometric objects of geometric algebra, the eight component Pauli algebra of 3D space. The wavefunction is not observable. Wavefunction interactions generate the observable S-matrix of the elementary particle spectrum[11, 35–39]. By conservation of energy, the reality of observable interactions would seem to require that the things that interact, the wavefunctions, are real.

Reality and Observability of Wavefunction Collapse

Collapse of the wavefunction follows from decoherence[2–4], from differential phase shifts between the coupled modes of a given quantum system. The phase shifts are generated by interaction impedances of wave functions[5]. What emerges from collapses are observables. The reality of observables would seem to require that the collapse is real, however the smooth and continuous dynamics of wavefunction collapse are not observable, only the end result.

Determinism and Probabilistic Wave Function Collapse

"... the Schrodinger wave equation determines the wavefunction at any later time. If observers and their measuring apparatus are themselves described by a deterministic wave function, why can we not predict precise results for measurements, but only probabilities?"[2]

The probabilistic character of quantum mechanics follows from the fact that phase is not a single measurement observable. The measurement extracts the amplitude. The internal phase information of the coherent quantum state is lost as the wave function decoheres. To be deterministic would require phase to be a single measurement observable, a global symmetry rather than local.

Ensemble probabilities are determined by the impedance matches[23]. This *unobservable determinism*, as required by gauge invariance, removes some of the mystery from 'probabilistic' behavior.

Superposition of Quantum States

Investigating the meaning of the newly discovered quantum states of Heisenberg and Schrodinger, Dirac led the way in introducing Hilbert state space to the theory. He defines states as "...the collection of all possible measurement outcomes." [40] According to Dirac,

"*The superposition that occurs in quantum mechanics is of an essentially different nature from any occurring in the classical theory"* (italics in original) [41].

What distinguishes quantum superposition from classical is linear superposition of states, of wavefunctions, as opposed to superposition of fields. The wavefunction is comprised of coupled electromagnetic modes, their fields sharing the same energy at different times. The state into which they collapse is determined by time/phase shifts of impedances they see.

Entanglement

"Entanglement is simply Schrodinger's name for superposition in a multiparticle system." [42] For a system of wavefunctions to be entangled means they are quantum phase coherent, that the entangled wavefunctions share that unobservable property.

non-Locality

The scale invariant impedances (photon far-field, quantum Hall/vector Lorentz, centrifugal, chiral, Coriolis, three body,...) are non-local. With the exception of the massless photon, which has both scale invariant far-field and scale dependent near-field impedances, the invariant impedances cannot do work, cannot transmit energy or information. The resulting motions are perpendicular to the applied forces. They only communicate phase, not a single measurement observable. They are the channels linking the entangled eigenstates of non-local state reduction. They cannot be shielded[43, 44]. The invariant impedances are topological. The associated potentials are inverse square.

Hidden Variables

Early in development of quantum theory, probabilistic character prompted Born[45, 46] to comment "...anybody dissatisfied with these ideas may feel free to assume that there are additional parameters not yet introduced into the theory which determine the individual event."

If one takes the 'hidden' variables to be quantum phases (not observable!), it follows that the "...additional parameters not yet introduced into the theory..." are phase shifters, the quantum impedances.

Observer Role

Both geometric algebra and quantized impedances are background independent. The one is 'first person', the other two body[47]. Neither has independent observers.

In the present work the two bodies are taken to be two interacting wavefunctions, and wavefunctions to be not observable. If it makes sense to talk of an observer role, then the observer must be either or both of the two wavefunctions. Which is to say the observer is a wavefunction. Which is to say observers are not observable.

This paradox suggests that it makes no sense to talk of an observer in the quantum mechanics of single measurements, that it is an emergent concept having no place in the conceptual foundations of the present approach.

SUMMARY AND CONCLUSION

While the readily visualized wavefunction presented here might lead one to suggest that present contentions of quantum interpretations will eventually be fully resolved, perhaps more consequential for interpretations is the blurring of identity that follows from the highly interconnected character of the vacuum impedance network that controls the flow of energy. The apparent delocalization of the proton anomalous moment and its relocation in the muon provides a possible example.

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