Unmaking the Standard Model: Geometry and Fields

Peter Cameron and Michaele Suisse*
Strongarm Studios
Mattituck, NY USA 11952

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We present a wavefunction comprised of the eight fundamental geometric objects of a minimally complete Pauli algebra of 3D space - point, line, plane, and volume elements - endowed with electromagnetic fields. Interactions are modeled as geometric products of wavefunctions, generating a 4D Dirac algebra of flat Minkowski spacetime. The resulting model is naturally gauge invariant, finite, and confined. With regard to the U1 x SU2 x SU3 gauge group at the core of the Standard Model, natural finiteness and gauge invariance are benign. However, reflections from wavefunction geometric impedance mismatches yields natural confinement to the Compton wavelength, rendering both weak and strong nuclear forces unnecessary.

INTRODUCTION

As Professor Weinberg remarks in opening his essay on the making of the Standard Model [1],

"The study of what was not understood by scientists, or was understood wrongly, seems to me often the most interesting part of the history of science."

That essay makes no mention of two essential conceptual structures, no mention of two fundamental concepts absent from the dialog of particle physicists during the decades preceeding its writing.

One is the geometric interpretation of Clifford algebra, the background independent algebra of interactions of geometric primitives of physical space [2].

The other is that which governs amplitude and phase during interactions of these geometric objects, the background independent quantized impedances associated with all potentials, both geometric and topological [3].

What follows places these omissions in historical context, and explores consequences of their inclusion in worldviews of physicist and philosopher.

GEOMETRIC CLIFFORD ALGEBRA

Over fifty years have passed since the original geometric intent of Clifford algebra [4–6] was rediscovered by David Hestenes, expanded, and introduced to physics [2], and fifteen years since he was awarded the Oersted Medal by the American Physical Society for "Reformulating the Mathematical Language of Physics"[7]. The geometric interpretation remains unrecognized by mainstream physics, a profound measure of our inertia.

When realized, the power of geometric algebra suggests one might arrive at intuitive understanding of the Standard Model in which all of physics is geometry [8, 9]. According to Wheeler, "There is nothing in the world except empty curved space. Matter, charge, electromagnetism, and other fields are only manifestations of the curvature of space." [10]

However, the geometry of Standard Model point particles (quarks and leptons) is static, their attributes taken to be intrinsic, internal. It is only with the external gauge fields that dynamics enters geometry and the phase coherence defining quantum system boundaries is manifested. 'Internal' coherence is geometrically inaccessible.

While string theory moves beyond dimensionless points to mode structures of 1D strings and 2D branes, it is not unreasonable to suggest that a satisfactory model will ultimately require fundamental geometric objects corresponding to the full three dimensions of physical space.

As jumping to strings led to innumerable landscapes, and yet more so with branes, it would seem that stepping up to the full 3D Pauli algebra of our physical space would yield dynamics of landscapes upon landscapes upon landscapes, burying insight under the intractable wealth of possibilities.

However, with that jump the dynamics are now those of the 4D Dirac algebra of flat Minkowski spacetime. Couldn't be simpler. Dimensions of string theory become a subset of the degrees of freedom of the model. The perspective shifts from abstract higher dimensions to interactions of objects one can visualize in 3D space. Within the more limited constraints of the Standard Model, the perspective shifts from point particles to the structure of spacetime. The perspective shifts.

The wavefunction presented here is comprised of two constructs - geometry and fields. For geometry it 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. For fields it endows them with quantized electric and magnetic fields [3].

While this wavefunction can be easily and intuitively visualized, it is not an observable[11, 12]. Observables are interactions, represented in geometric algebra by geometric products of wavefunctions. These geometric products generate a 4D Dirac algebra of flat Minkowski spacetime. Time (relative phase) emerges from the interactions.

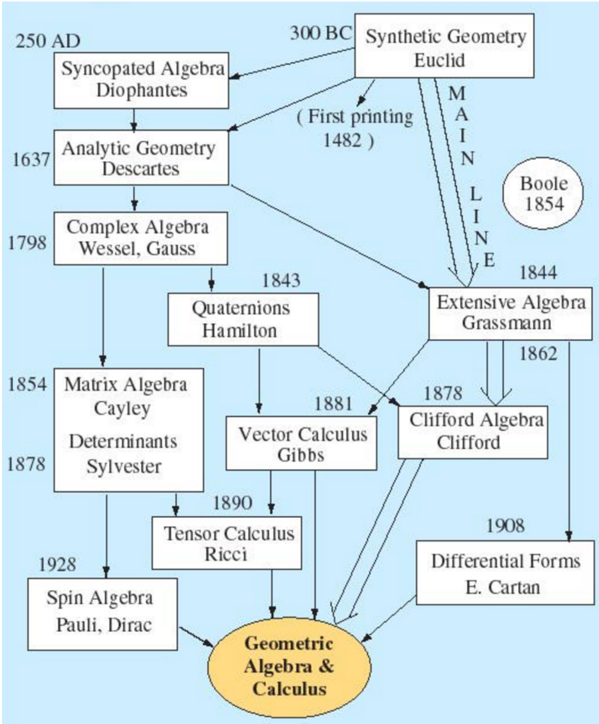

FIG. 1. Evolution of Geometric Algebra [15]

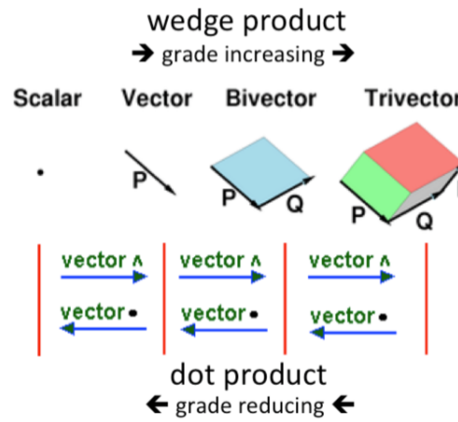

FIG. 2. Geometric algebra components in 3D Pauli algebra of space. The term grade is preferred to dimension, whose meaning is sometimes ambiguous and confused with degrees of freedom. The two products (dot and wedge or inner and outer) comprising the geometric product lower and raise the grade. Mixing of grades makes geometric algebra unique in the ability to handle geometric concepts in any dimension[18]

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Figure 1 illustrates an important point - geometric algebra (and its extension into geometric calculus) claims to encompass the better part of the particle physicist's mathematical toolkit[7, 13, 14].

Clifford Algebra as originally conceived is the algebra of interactions between geometric objects. Grassman was "...a pivotal figure in the historical development of a universal geometric calculus for mathematics and physics... He formulated most of the basic ideas and... anticipated later developments. His influence is far more potent and pervasive than generally recognized."[16]

Grassman's work lay fallow until Clifford "...united the inner and outer products into a single *geometric* product. This is associative, like Grassman's product, but has the crucial extra feature of being *invertible*, like Hamilton's quaternion algebra."[17]

While Clifford algebra attracted considerable interest, with his early death in 1879 the absence of an advocate to balance the powerful Gibbs contributed to its eventual neglect. It was "...largely abandoned with the introduction of what people saw as a more straightforward and generally applicable algebra, the *vector algebra* of Gibbs... This was effectively the end of the search for a unifying mathematical language and the beginning of a proliferation of novel algebraic systems..."[14].

Geometric algebra resurfaced, unrecognized, as algebra without geometric meaning in the Pauli and Dirac matrices. It remains that the power of geometric interpretation has for the most part been lost in physics.

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..." [19].

Interactions of wavefunctions are represented by the geometric product. They break topological symmetry due to this property of grade increasing operations.

PROTON STRUCTURE

With a little help from the topological duality between electric and magnetic charge[20–22], the remarkable power of geometric interpretation becomes evident in calculating nucleon mode structure[23, 24].

The photon is our fiducial in measurements of the properties of space. 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 3, precisely spaced in powers of α, are inverted for magnetic charge[25]. The Compton wavelength $\lambda = h/mc$ is independent of charge.

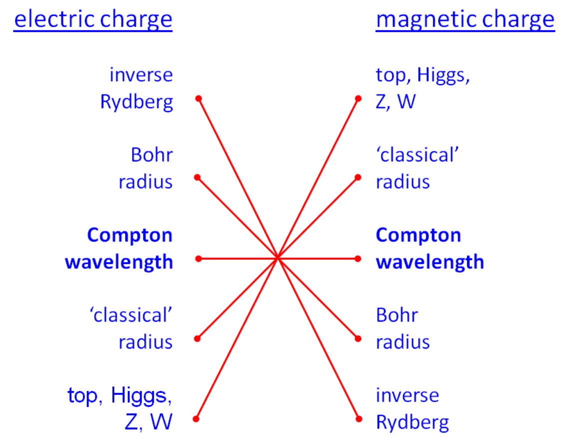

FIG. 3. Inversion of fundamental lengths by magnetic charge

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 3 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.

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 4 provides the needed filter, given the assumption that unstable particles contain at least one dark mode to drive decoherence.

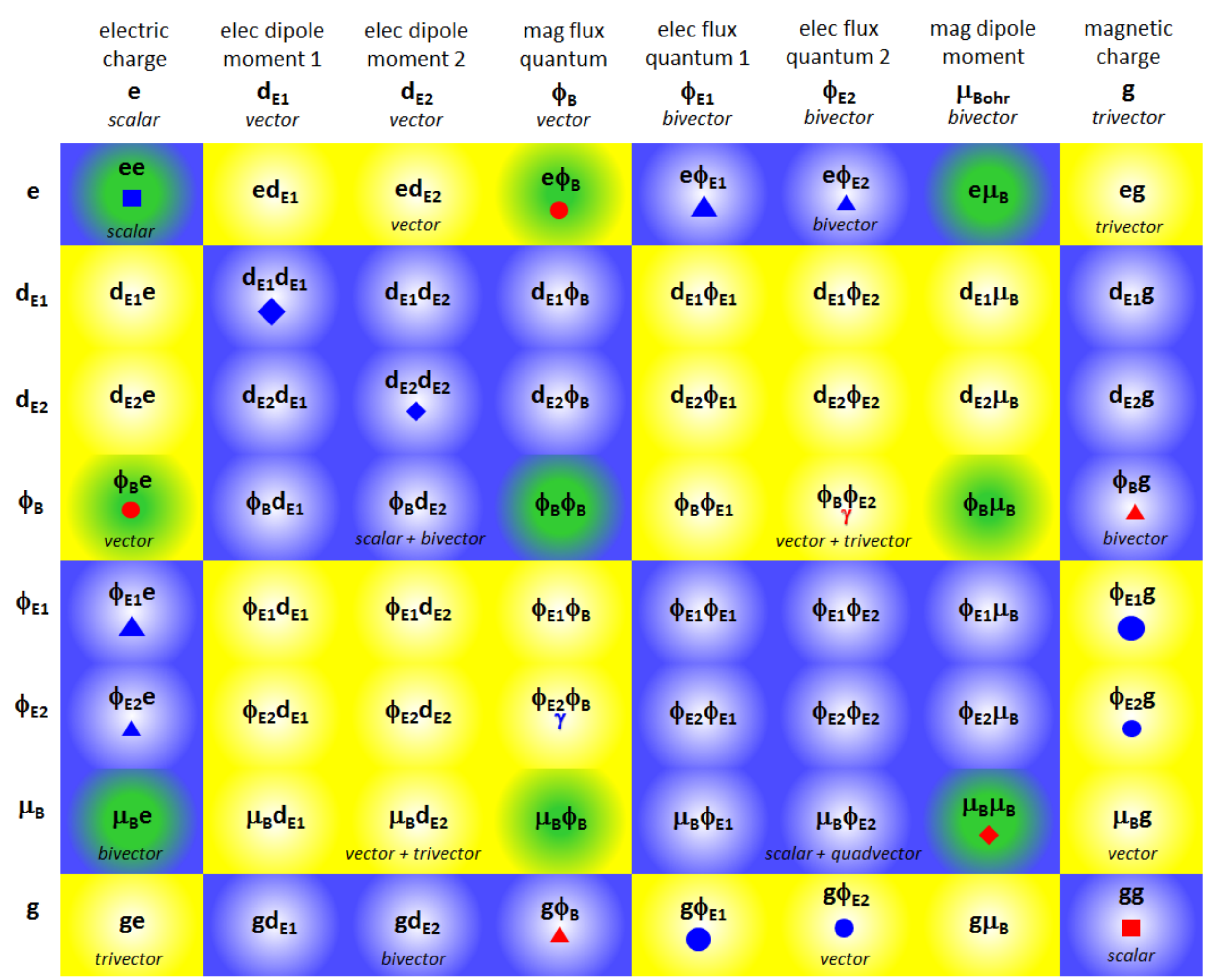

FIG. 4. As shown at top and left, a minimally complete Pauli algebra of 3D space is comprised of one scalar, three each vectors and bivectors, and one trivector. Attributing electric and magnetic fields to these fundamental geometric objects (FGOs) yields the wavefunction model [3]. In the manner of 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**[23]. The network comprised of modes indicated by symbols (triangle, square, dot, diamond) is shown in figure 9.

The speed of light (or free space impedance) can be calculated from excitation of virtual electron-positron pairs by the photon[26]. Just as the massless photon excites the vacuum impedance structure, so do the electromagnetic fields of all massive particles, stable and unstable.

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[27–30]. 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 4, gives us both transition modes (yellow background) and eigenmodes (blue background) of the proton.

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

FIG. 5. Eigenmodes of figure 4 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.

As shown in figure 5, eigenmode FGOs of figure 4 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.

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 4 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 4. 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 first 'quark', the scalar e emerging from the pair $e\overline{e}$, is unaccompanied. One wonders if it is observably different from the second, arising from the $\phi_B\overline{\phi}_B$ interaction in the company of bivector μ_B, or whether they differ from the third, emerging from $\mu_B\overline{\mu}_B$ accompanied by quadvector I.

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 [31–34], 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 [23].

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'[17].

Most remarkably, a plausible proton wavefunction emerges from the algebra, together with relative phase information of the coupled modes. The role of nucleon topological mass generation in observation of the anomalous moment is addressed in detail elsewhere[23, 24], the point being that the anomaly is a far-field property of the proton. In the near field the proton is spin 1/2, the nuclear Bohr magneton. To proceed we must introduce generalization of impedance quantization and its functional role in gauge theory.

GAUGE THEORY REQUIRES IMPEDANCES

Gauge theory is the theory of quantum phase coherence, of that which distinguishes quantum from classical. Phase is relative, not a single measurement observable. The boundary of a quantum system may be defined by absence of phase coherence with its surroundings. The existence of a quantum system is contingent upon coherence. With decoherence comes state reduction, wavefunction collapse, loss of phase information[27–30].

Gauge theory impedances shift phases. Inductive impedance advances phase, capacitive retards. Equally fundamental, impedance *matching* dictates the amplitudes. Wavefunction amplitude and phase are both governed by impedances. Gauge theories cannot be understood in full without impedance quantization.

Gauge Theory

While both Maxwell's electrodynamics and Einstein's general relativity are gauge theories, it was only with the invention of the wavefunction in the late 1920s that the gauge parameter assumed a central role in physics.

The evolution shown in figure 6 had two motivations - to unify electromagnetism and gravity, and develop working gauge theories of nuclear forces. With hindsight it is surprising that making the role of gauge theory more explicit in foundations of QED was not a priority.

"Gauge symmetry, however, played almost no role in QED. It was largely regarded as a complication and a technical difficulty that had to be carefully handled, especially as people were struggling with the quantization of quantum electrodynamics. This is partly due to the difference between local gauge symmetry and ordinary global symmetries of nature."[35]

The first impetus to the gauge program was given by Weyl[36], who gauged the scale of space in an effort to unite gravity with electromagnetism. Unlike phase, which is not a single measurement observable, spatial scale is an observable and cannot be gauged. The error was pointed out by Einstein (who quite liked the idea) via the path independence of observable atomic spectra.

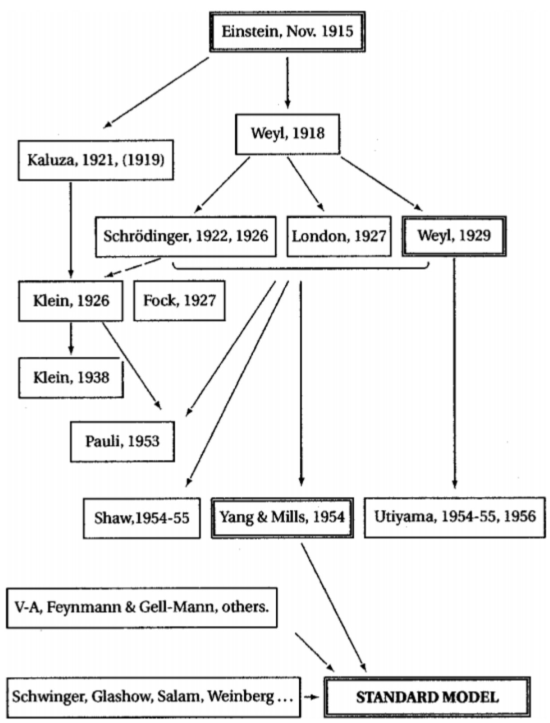

FIG. 6. Key papers in development of gauge theory beyond the U(1) gauge group of Maxwell's electromagnetism and its gauge boson, the photon.[37, 38]

Gauge invariance found a home in the quantum mechanics of the 1920s, with the gauge parameter corresponding not to spatial scale but quantum phase. In his 1929 paper Weyl elevated gauge invariance from a symmetry to a fundamental principle. Unfortunately, the label 'gauge' remained, and continues to cause confusion to this day. In the present context quantum interactions care not about scale invariance, but rather invariance of observables under phase transformations. 'Phase Invariance' would have been a better choice.

Possible connections between gravity and electromagnetism remained a distraction, prominent in the contributions of Schrodinger, London, and Weyl, and a motivation in the papers leading up to the embrace of the nuclear forces by Shaw, Yang and Mills, and Utiyama in 1954. Here is where confusion multiplies, where we enter into "what was not understood by scientists, or was understood wrongly,..." [1].

The need for nuclear binding forces was predicated upon the problem of confinement. What could hold protons together in the nucleus against electrostatic repulsion if not some sort of strong nuclear force? What might account for anomalously long lifetimes of unstable nuclei and flavor families, if not a weak nuclear force?

Straightforward connection between the simple U(1) of electromagnetism and nuclear forces remained for the most part unexplored, the possibility seemingly ruled out by experimental evidence. It was in some small part addressed for the weak force by Glashow, Weinberg, and Salam in the mid-1960s. Efforts to include the strong force in standard model unification remain unsuccessful. It is only with inclusion of impedance quantization, with inclusion of that which governs the flow of energy in all interactions, that such a unification becomes possible.

Impedance Quantization

Impedance may be defined as amplitude and phase of opposition to the flow of energy. When impedances are matched energy flows without reflection. Consider the bell of the trumpet, matching the player's lips to ambient atmosphere. That the force of the player can enter the room is a consequence of the impedance match [39].

Given the practical utility of the impedance concept in technical applications, it is not surprising that one finds the most helpful historical introductions and expositions not in academic literature, but rather in that of technologically advanced industries, where application of the concept is essential for economic success [40–43].

This inadvertent divorce of theoretical from practical has profound consequences for quantum field theory (QFT), where the Hamiltonian and Lagrangian formalisms focus upon conservation of energy and its flow between potential and kinetic, rather than upon that which governs the flow, the impedances.

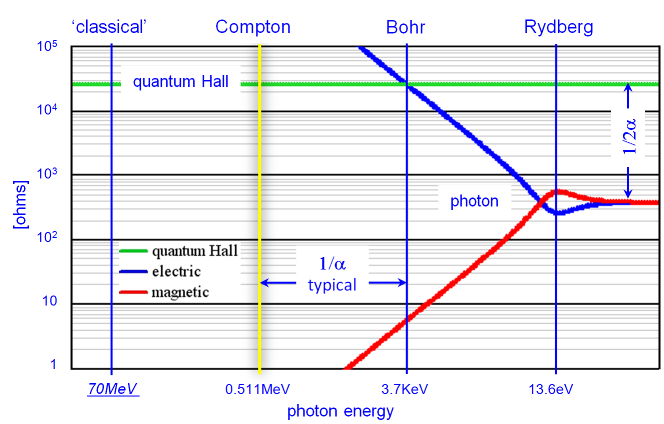

FIG. 7. Impedance match of a 13.6eV photon to the quantum Hall impedance of a single free electron [44, 45].

The most rudimentary example can be found at the foundation of QED, in the photon-electron interaction. The formidable breadth of the crack through which impedances have fallen becomes apparent when one considers that the near field photon impedances [44] shown in figure 7 cannot be found in the curriculum or textbooks of electricity and magnetism, QED, or QFT [46].

What governs the flow of energy in photon-electron interactions is explicitly absent from the formal education of the PhD physicist.

The significance can be seen in figure 7. The scale-dependent photon near-field dipole impedance permits energy to flow between Rydberg and Bohr, between photon and hydrogen atom. However, what is lacking in the impedance match is the corresponding scale-dependent electron dipole impedance. Both quantized impedances must be present for reflectionless energy transfer. Neither is explicit in the physics curriculum.

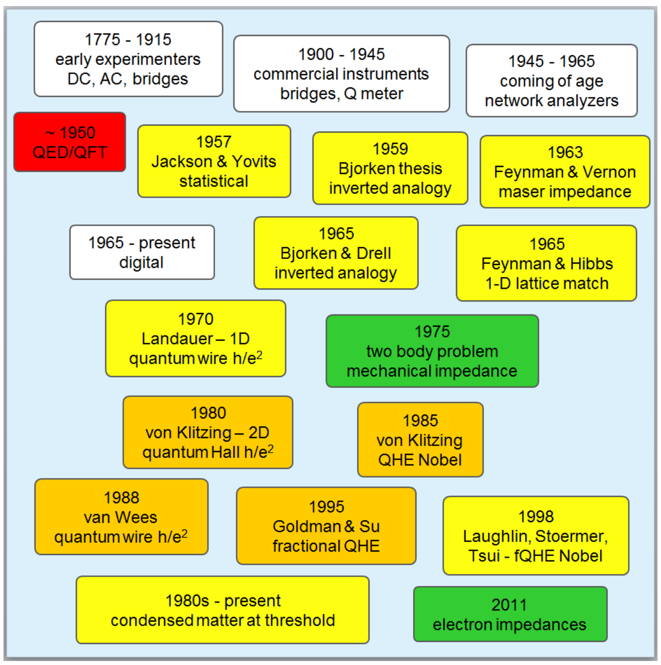

FIG. 8. Stages in development of theory and technology of classical impedances are highlighted in white, those of quantum impedances in yellow (theory) and gold (experiment), generalization of quantum impedances to all potentials in green, and the scaffolding of QFT in red [46].

The essential point, missing from QFT and crucially relevant in models and theories of quantum interactions, is this: Impedances are quantized. Yet how, if impedance quantization is both fact of nature and powerful theoretical tool, is it not already present in the Standard Model?

This absence is most remarkable. Impedance is a fundamental concept, universally valid. The oversight can be attributed primarily to three causes. The first is historical [46], the second follows from the habit of setting fundamental constants to dimensionless unity, and the third from topological and electromagnetic paradoxes in our systems of units [3, 47, 48].

Historically, the foundation of QED (the template for QFT, highlighted in red in the figure) was set long before the Nobel prize discovery of the scale invariant quantum Hall impedance in 1980 [49]. Prior to that impedance quantization was more implied than explicit in the literature [50–57]. The concept of *exact* impedance quantization did not exist.

The second origin of overlooked impedance quantization is the habit of particle physicists to set fundamental constants to dimensionless unity. Doing so with free space impedance made quantization just a little too easy to overlook. And to no useful purpose. What matters are not absolute values of impedances, but rather their relative values, whether they are matched.

The third confusion is seen in an approach [52] summarized [53] as "...an analogy between Feynman diagrams and electrical circuits, with Feynman parameters playing the role of resistance, external momenta as current sources, and coordinate differences as voltage drops. Some of that found its way into section 18.4 of..." the canonical text [54]. As presented there, the units of the Feynman parameter are [sec/kg], the units not of resistance, but rather mechanical *conductance* [39].

It is not difficult to understand what led us astray [52–61]. The units of mechanical impedance are [kg/sec]. One would think that more [kg/sec] would mean more mass flow. However, the physical reality is more [kg/sec] means more impedance and *less* mass flow. This is one of many interwoven mechanical, electromagnetic, and topological paradoxes [48] to be found in the SI system of units, which ironically were developed with the intent that they "...would facilitate relating the standard units of mechanics to electromagnetism." [62].

With the confusion that resulted from misinterpreting conductance as impedance and lacking the concept of quantized impedance, the anticipated intuitive advantage [54] of the circuit analogy was lost. The possibility of the jump from a well-considered analogy to a photon-electron impedance model was not realized at that time.

Had impedance quantization been discovered in 1950 rather than 1980, one wonders whether it might have found its way into the foundation of QED at that time, before it was set in the bedrock. As it now stands the inevitable reconciliation of practical and theoretical, the incorporation of impedances into the foundations of quantum theory, opens new and exciting possibilities.

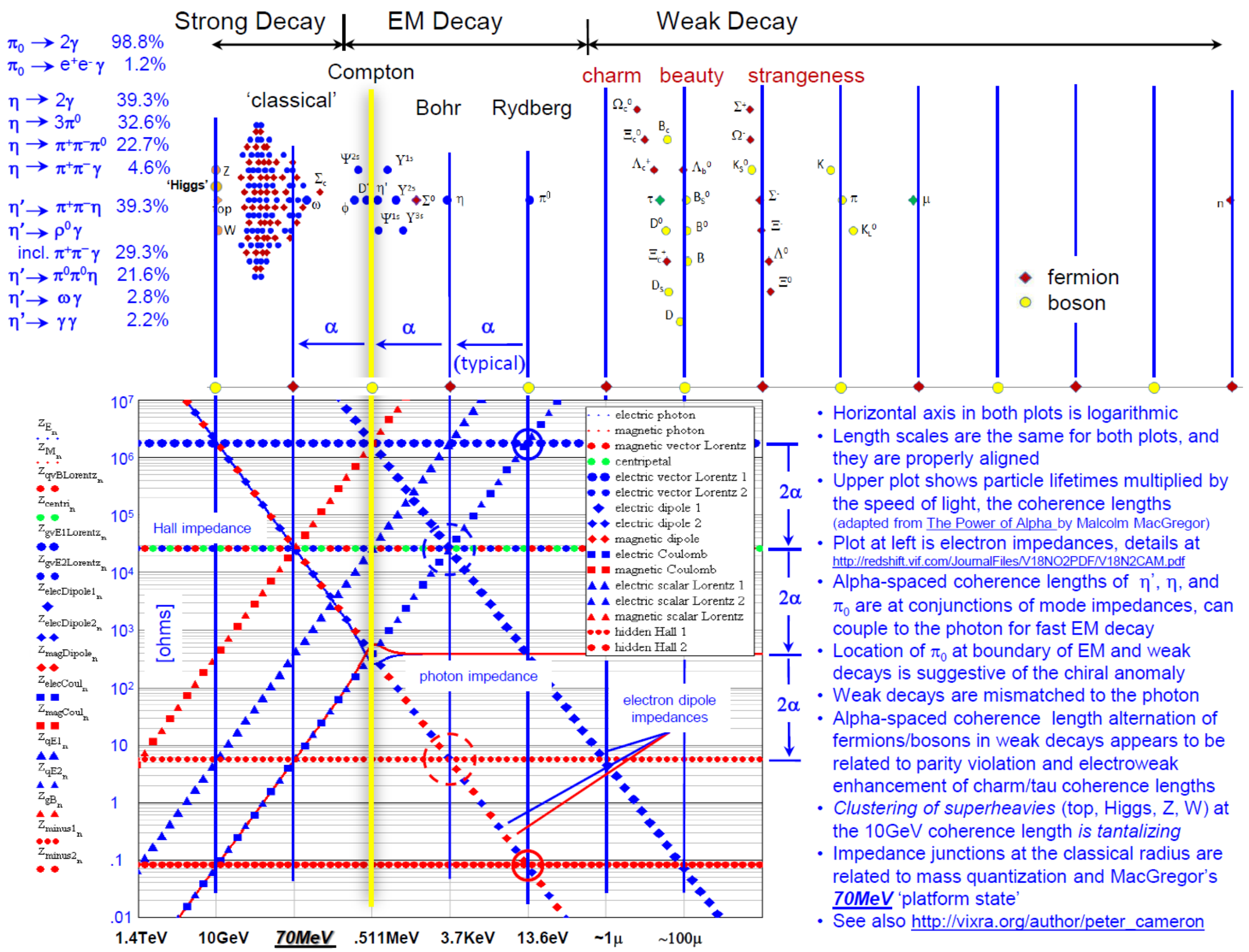

FIG. 9. Correlation between coherence lengths (boundary of the light cone) of the unstable particle spectrum and nodes of the energy/scale dependent impedance network of a subset of the modes of figure 4 [64]. Impedances are matched at the nodes, permitting the transfer of energy between modes essential 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 [65].

THE UNSTABLE PARTICLE SPECTRUM

Impedance quantization is possibile for all forces [3, 63]. Quantizing with electromagnetic forces only and taking the quantization length to be the electron Compton wavelength gives the impedance network of figure 9. Nodes of the network are strongly correlated with unstable particle coherence lengths [27, 64], suggesting that energy flows to and from the unstable particle spectrum via this network of electron impedances.

In QFT one is permitted to define but one fundamental length (customarily the short wavelength cutoff). The impedance approach is finite, divergences being cut off by mismatches as one moves away from the fundamental length of the model, the Compton wavelength. With FGOs confined to that scale by the mismatches, interaction impedances can be calculated as a function of their separation, the 'impact parameter'. Strong correlation of the resulting network nodes with unstable particle coherence lengths[44, 66–69] follows from the requirement that impedances be matched for energy flow between modes as required by the decay process.

S-matrix and the Impedance Representation

Chapter 11 of Hatfield's textbook on quantum field theories of point particles and strings opens with this statement of S-matrix universality[70]:

"One of our goals in solving interacting quantum field theories is to calculate cross sections for scattering processes that can be compared with experiment. To compute a cross section, we need to know the S-matrix element corresponding to the scattering process. So, no matter which representation of field theory we work with, in the end we want to know the S-matrix elements. How the S-matrix is calculated will vary from representation to representation."

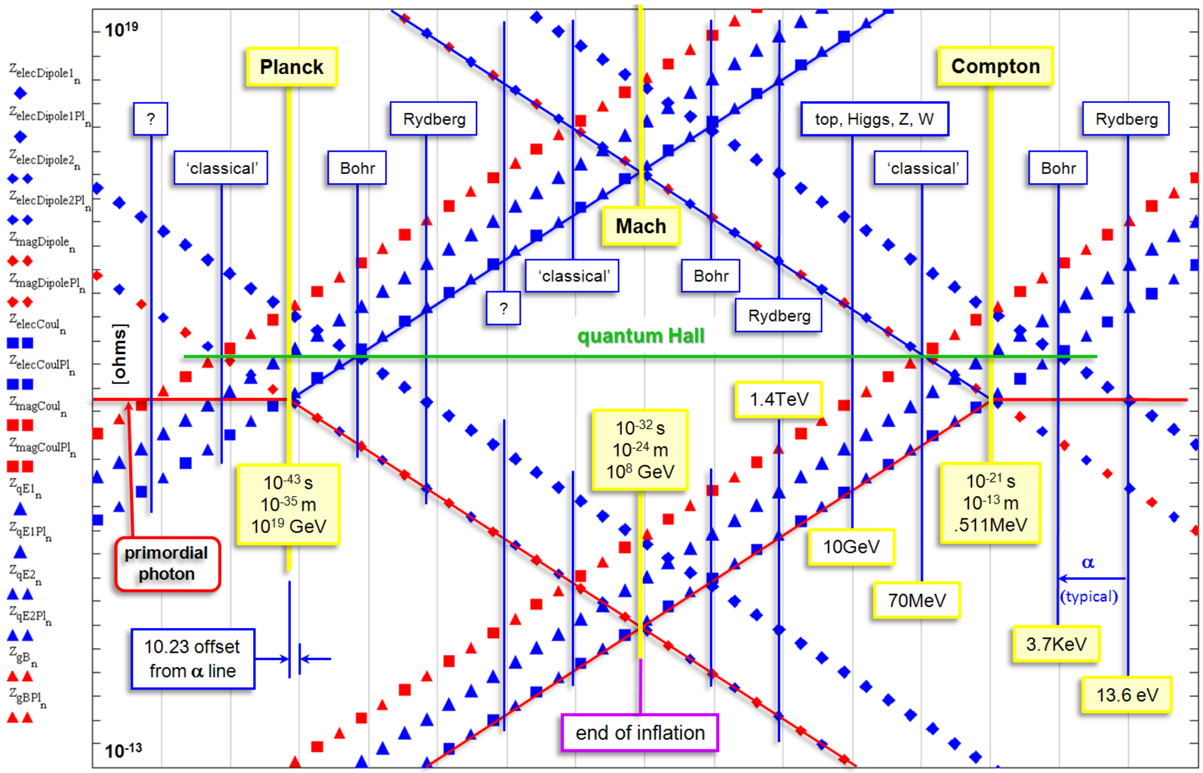

FIG. 10. A subset of impedance networks of the electron and Planck particle, showing both a .511 Mev photon entering from the right (included here not to imply relevance to the Big Bang but rather for illustrative purposes only), and the primordial photon entering from the left[78]. The end of inflation in the impedance approach (as in the cosmological Standard Model) comes at $\sim 10^{-32}$ seconds, at the intersection of the two impedance networks, referred to here as the 'Mach scale' [79].

Calculating mode impedances of interactions shown in figure 4 yields an impedance representation of the S-matrix [3, 23, 71–74]. Transformation between impedance and scattering matrices is standard fare in electrical engineering[75–77]. As we endeavor to make clear, when seeking to understand details of the elementary particle spectrum significant advantages accrue for the physicist working in the impedance representation.

GRAVITY AND THE BIG BANG

Just as the energy of a photon whose wavelength is the Compton wavelength of the electron is equal to the rest mass of the electron, the energy of a photon whose wavelength is the Compton wavelength of the Planck particle is the rest mass of the Planck particle and its associated event horizon. This is the 'electromagnetic black hole', the simplest eigenstate of the Planck particle.

A more detailed model of the Planck particle can be had by quantizing the 3D Pauli wavefunction not at the electron Compton wavelength, but rather the Planck length, resulting in the network of figure 10 [79].

Calculating the impedance mismatch between electron and Planck particle gives an identity between electromagnetism and gravity[80]. The gravitational force between these two particles is identically equal to the mismatched electromagnetic force they share. The Newtonian gravitational constant G (by far the most imprecise of the fundamental constants) cancels out in the calculation, suggesting that both gravity and rest mass are of electromagnetic origin, and that gravity is nothing more than impedance mismatched electromagnetism.

That the impedance approach of flat 4D Minkowski spacetime delivers an exact result at the event horizon of the Planck particle (and beyond to the singularity, completely decoupled by the infinite impedance mismatch to the dimensionless point) is perhaps surprising. One wonders what correspondence exists between this result and the dictates of general relativity near the event horizon, how the two might be found to be in agreement.

The discovery that Gauge Theory Gravity in flat space is equivalent to General Relativity in curved space [14, 17, 81–84] is both astounding and a paradigm shift of itself. Why work in curved space all these years if one can work so much more easily in flat space? How did it get this way?

Like the absences of impedance quantization and the geometric interpretation of Clifford algebra from mainstream modern physics, this is another historical accident. When Einstein and company were searching for a mathematical framework in which to cast a theory of gravity the geometric interpretation was in abeyance. They did not have those tools at hand, worked with tensor calculus (a subset of geometric algebra/calculus, as shown in figure 1) in curved space.

Whether one describes gravity as the effect of mass curving space or quantum phase shifts in flat space, the claim is that they yield equivalent results[85], that gauge theory gravity and general relativity are one.

Connections between the impedance model and geometric algebra go deep, to the coordinate-free background independence essential for quantum gravity[86]. Geometric algebra uses a coordinate-free representation. Motion is described with respect to a coordinate frame defined on the object in question rather than an external coordinate system. Similarly, mechanical impedances are calculated from the two body problem[58]. Motion is described with respect to a coordinate frame on one of the bodies, the 'observer'. The two body problem is inherently background independent. There is no independent observer to whom rotations can be referenced, only fermionic and bosonic spin, the one topological and the other geometric.

It is precisely this shared background independence of geometric algebra and the impedance model that permits scale invariant impedances (quantum Hall, chiral, centrifugal, Coriolis, three body,...) of the impedance model to be associated with the rotation gauge field of gauge theory gravity, and scale dependent impedances (Coulomb, dipole, scalar Lorentz,...) with the translation gauge field[87]. In the case of forces associated with invariant impedances, the resulting motion is perpendicular to the applied force. They are non-local, can do no work, cannot communicate information, but rather only quantum phase, not a single measurement observable.

Gauge invariance is maintained via covariant derviatives. Equivalently, phase shifts generated by quantum impedances encode the phase information. The same gauge theory, seen from complementary perspectives.

Just as mass is of electromagnetic origin in the impedance approach[47], so must be gravity. However, two essential properties of gravity seem upon first consideration to rule out an electromagnetic origin [88].

First, unlike electromagnetic forces, it appears that gravity cannot be shielded. However, scale invariant impedances cannot be shielded[27, 89]. Consider for instance centrifugal force, or the Aharonov-Bohm effect of the vector Lorentz force.

Second, unlike the bipolarity of electromagnetism, gravity appears to have only one sign. We observe only attractive gravitational forces. Here the distinction between near and far fields plays a pivotal role. For the interaction between two electrons, gravity is forty-two orders of magnitude weaker than the Coulomb force, a consequence of the impedance mismatch.

If we take a characteristice length to be the electron Compton wavelength (about 10^{-12} meters), or equivalently the wavelength of a .511MeV photon, then the wavelength of the mismatched 'gravity photon' will be about forty-two orders of magnitude greater, or about 10^{30} meters. The radius of the observable universe is about 10^{26} meters.

The point is that our material existence appears to be in the extreme near field of the 'gravity photons' of *almost* all of the mass in the universe. In the near field there exist both transverse and longitudinal electromagnetic fields. The *almost* arises due to the $\pi/2$ phase shift of those gravity photons whose average energy is above a few GeV. The phase shift due to field oscillation in the transition from near to far field reverses the effective longitudinal direction at around the present age of the universe. The high energy portion of matter becomes repulsive on the scale of the universe.

In the extreme near field the scale dependent impedances appear scale invariant, due to the flatness of the phase as the amplitude goes to zero. One might conjecture that this is what permits the scale dependent impedances to appear to have the 'cannot be shielded' property of the scale invariant impedances. Hopefully the topological character of geometric algebra will provide a proper formalism for such a conjecture.

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, including reality and observability of the wavefunction and wavefunction collapse, determinism and the probabilistic character of wavefunction collapse, entanglement and non-locality, hidden variables, realism versus the instrumentalism of 'shut up and calculate', the role of the observer,...[11].

In each of these areas quantum interpretations seek to address the same basic question - how to understand the measurement problem?[90, 91] How does one get rid of the shifty split[92] of the quantum jump[93], develop a smooth and continuous real-space visualization of state reduction dynamics?[27] 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 permits resolution of the contentions of quantum interpretations.

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. 11. Comparison of Interpretations. The Index parameter quantifies strength of agreement between a given interpretation and the rest of the table. Values in the Index column 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 a growing number of quantum interpretations and contentions demonstrates the lack of proper physical understanding of fundamental phenomena[11].

The Measurement Problem

Contentions in quantum interpretations are for the most part 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."[94]

At root the confusion arises from modeling electrons and quarks as point particles. Points cannot collapse. One cannot understand the decoherence of wavefunction collapse without understanding self-coherence. Presence of the point particle in the Standard Model leaves self-coherence lost in mathematical abstraction, rather than presenting the impedance-driven coherence and decoherence of interacting electromagnetic modes visualized in 4D spacetime.

Reality and Observability of the Wavefunction

The wavefunction is comprised of fundamental geometric objects shared by geometric algebra and the impedance model, the eight component Pauli algebra of 3D space. The wavefunction is not observable. Interactions of wavefunctions generates the observable S-matrix of the elementary particle spectrum[23, 70–74]. 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[28, 29], from differential phase shifts between the coupled modes of a given quantum system. The phase shifts are generated by interaction impedances of wave functions [27]. 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?" [30]

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. For quantum mechanics to be deterministic would require phase to be a single measurement observable, a global symmetry rather than local.

Deterministic aspects are present in the sense that ensemble probabilities are determined by the impedance matches[65]. 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 state space (later to be identified with Hilbert space) to the theory. He defines states as "...the collection of all possible measurement outcomes." [95] 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) [96].

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." [97] 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[89, 98]. The invariant impedances are topological. The associated potentials are inverse square.

Hidden Variables

Early on in the development of quantum theory, the probabilistic character prompted Born[99, 100] 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 single measurement observables!), then it follows that the "...additional parameters not yet introduced into the theory..." are the phase shifters, the quantum impedances.

Observer Role

Quantum impedances are background independent. The method of calculating quantum impedances derives from consideration of the two body problem and Mach's principle[58, 78]. There is no independent observer in the two body problem.

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 in fact it makes no sense to talk of a role for 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

The electron is not a point particle. It gives that appearance if one doesn't appreciate the possibility that electron geometric structure, when endowed with electric and magnetic fields and excited by the photon, might generate the remainder of the massive particle spectrum. By far the lightest of all charged elementary particles, the electron impedance network is the natural candidate for this role[85], in some sense might be considered the structure of the vacuum[26].

The impedance model requires that five fundamental constants be input by hand - speed of light, Planck's constant, electric charge quantum, permittivity of free space, and electron Compton wavelength. There are no adjustable parameters. With these constants one can assign quantized electromagnetic fields to the fundamental geometric objects of the 3D Pauli algebra of physical space, and calculate quantized interaction impedances of the resulting wavefunctions[3].

There are no gluons or weak vector bosons to bind the constituents. The modes are confined by the impedance mismatches, by reflections as one moves away from the quantization scales as defined by the impedance nodes. Mismatches also remove infinities associated with singularities. The impedance approach is finite and confined.

The serendipitous commonality of fundamental geometric objects between the impedance model and geometric Clifford algebra lends a formal structure to the impedance approach that maximizes the utility of both, providing simple yet powerful mathematical tools to the physicist and physical intuition to the mathematician, philosopher, and layperson.

Thus far applications of generalized quantum impedances have been primarily conceptual. Sage advice [101] suggests that the most fertile field for impedance quantization will be in condensed matter - in atomic, molecular, and optical physics[46]. If there is practical value in the approach presented here, AMO is likely the place where it will be found. Though harking back to Wheeler [71], impedance matching might prove equally useful in understanding both fission and fusion.

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APPENDIX

Clarifying Terminology in Geometric Algebra

There is possibility for confusion in the terminology of geometric algebra.

terminology difference between Pauli and Dirac algebras					
3D Pauli	scalar	vector	pseudovector	pseudoscalar	_
	e	**d_E, ϕ_B**	**ϕ_E, μ_B**	**g**	_
GA grade	0 - scalar	1 - vector	2 - bivector	3 - trivector	4 - quadvector
4D Dirac	**e**	**d_E, ϕ_B**	**ϕ_E, μ_B**	**g**	**I**
	scalar	vector	bivector	pseudovector	pseudoscalar

FIG. 12. Bivector and trivector are pseudovector and pseudoscalar of the Pauli algebra. Trivector and quadvector are pseudovector and pseudoscalar of the Dirac algebra.

As shown in the figure, the highest grade element of an algebra is the pseudoscalar of that algebra. In the Dirac algebra, this results in the bivector being interposed between vector and pseudovector of the Pauli algebra, and opens possibilities for endless confusion. For this reason we favor the scalar/vector/bivector/trivector/quadvector nomenclature, but at times the use of conventional pseudovector or pseudoscalar tags seems well advised. At such times both appelations will be shown.

* electronGaugeGroup@gmail.com

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