LINKING GAUGE THEORY GRAVITY WITH QUANTIZED IMPEDANCES

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ABSTRACT. The shared background independence of spacetime algebra and the impedance approach to quantization, coupled with the natural gauge invariance of phase shifts introduced by quantum impedances, opens the possibility that identifying the geometric objects of the impedance model with those of spacetime algebra will permit a more intuitive understanding of the equivalence of gauge theory gravity in flat space with general relativity in curved space.

INTRODUCTION

In the preface to the newly published second edition of his seminal text[1], Professor Hestenes makes four "bold and explicit... claims for innovation" in SpaceTime Algebra:

- STA enables a unified, **co-ordinate free** formulation for all of relativistic physics, including the Dirac equation, Maxwell's equation, and General Relativity.
- Pauli and Dirac matrices are represented in STA as **basis vectors** in space and spacetime respectively, with no necessary connection to spin.
- STA reveals that the **unit imaginary** in quantum mechanics has its origin in spacetime geometry.
- STA reduces the mathematical divide between classical, quantum, and relativistic physics, especially in the use of **rotors** for rotational dynamics and gauge transformations.

The preface encourages making such claims, lest the innovations be overlooked. "Modestly presenting evidence and arguing a case is seldom sufficient."[1] In this spirit, the following five bold and explicit claims are made for the Impedance Approach to quantization:

- IA is **background independent** - This fundamental connection with STA goes deep, to the **co-ordinate free** formulation essential for quantum gravity[2, 3, 4]. In STA, motion is described with respect to the object in question rather than an external coordinate system. Similarly, impedances are calculated from Mach's principle applied to the two body problem[5, 6]. Motion is described with respect to one of the two bodies. IA is background independent. There is no third body, no independent observer to whom rotations can be referenced, only spin.
- IA contains **gravity** - Matching quantized impedances at the Planck scale reveals an exact identity between electromagnetism and gravity [7]. By far the most imprecise of the fundamental constants, the gravitational constant G cancels out in the calculation.
- IA is **gauge invariant** - Impedances shift phase. Quantum impedances shift quantum phase. In gauge theories phase coherence is maintained by covariant derivatives. In IA coherent phase shifts are introduced by the impedances. IA is gauge invariant.
- IA is **finite** - In IA the quantization scale is taken to be the electron Compton wavelength. Low and high energy impedance mismatches provide natural cutoffs as one moves away from the quantizaton length. No need to renormalize. IA is finite.
- IA is **confined** - Reflections from the natural cutoffs of the impedance mismatches provide confinement to the vicinity of the quantization length.

The presence of gravity in IA in conjunction with the coordinate-free background independence common to STA and IA invites the conjecture[8] that scale dependent impedances (Coulomb, dipole, scalar Lorentz,...) of IA can be associated with the translation gauge field of gauge theory gravity [9, 10, 11, 12, 13, 14] and scale invariant impedances (quantum Hall/vector Lorentz, chiral, centrifugal, Coriolis, three body,...) with the rotation gauge field.

Let us see how this comes about, and what consequences might follow.

Historical Perspective on the Impedance Approach

Given the practical everyday utility of the impedance concept in technical applications, it is not surprising that one finds the most helpful historical introductions and expositions not in the academic literature, but rather in that of technologically advanced industries, where proper application of the concept is *essential for economic success* [15, 16, 17, 18].

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.

The most rudimentary example can be found at the foundation of quantum electrodynamics (QED), in the photon-electron interaction. The formidable breadth of the crack through which the impedance concept has fallen becomes apparent when one considers that the near field photon impedances [19] shown in figure 1 cannot be found in the physics textbooks of electricity and magnetism, QED, or QFT [20].

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 by examining energy flow between a 13.6 eV photon and the quantum Hall impedance of the electron. The figure illustrates the scale-dependent photon near-field dipole impedance that permits energy to flow without reflection 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.

The force operative in the quantum Hall effect is the vector Lorentz force. Impedance quantization is a possibility for all forces [6]. Quantizing with electromagnetic forces only and taking the quantization length to be the electron Compton wavelength gives the impedance network of figure 2, where the electron 'external dipole' impedance match to the photon is represented by the large blue diamonds. The nodes of the network are strongly correlated with the unstable particle coherence lengths [21, 22], suggesting that, as in the hydrogen atom, energy flows to and from the unstable particle spectrum via this network of electron impedances.

If impedance quantization is both a fact of nature and a powerful theoretical tool (as explicated later in this paper), how is it not already present in the Standard Model? One might suggest that the absence is simply an historical accident, a consequence of the order in which experimentalists revealed relevant phenomena [20]. The scaffolding of QFT was erected on experimental discoveries of the first half of the twentieth century, on the foundation of QED, which was set long before the Nobel prize discovery of the scale invariant quantum Hall impedance in 1980 [23].

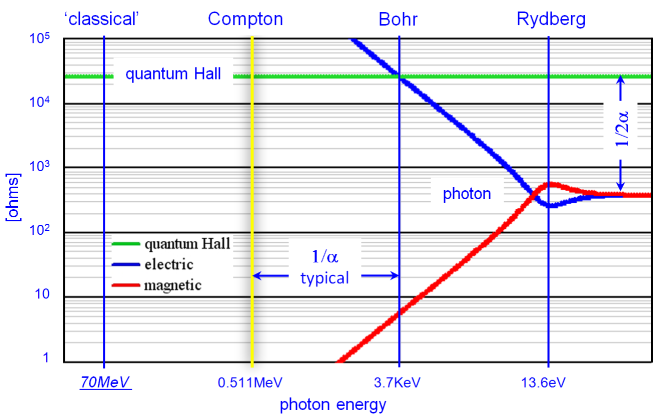

FIGURE 1. Electron quantum Hall and photon near and far field impedances vs. photon energy [19]

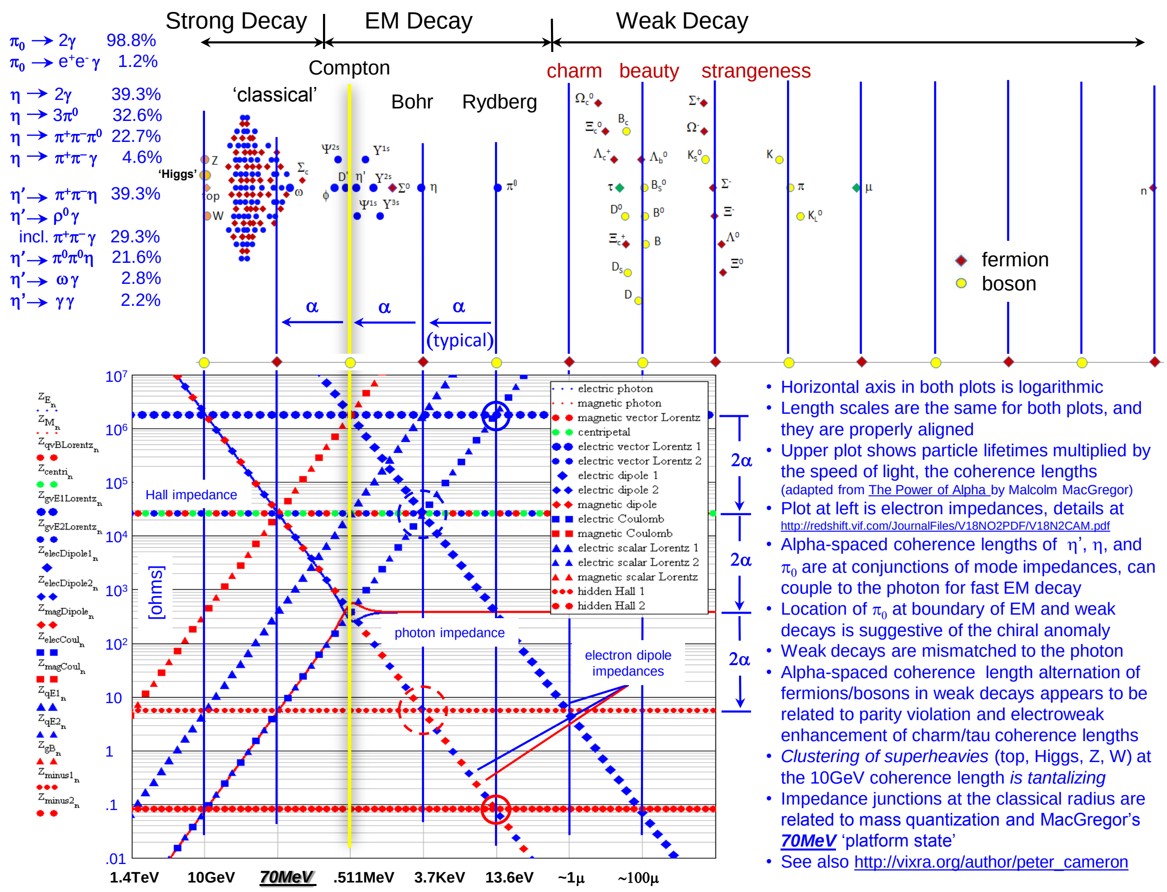

FIGURE 2. The 'One Slide' [35]

The discovery of exact impedance quantization was greatly facilitated by the scale invariance. This classically peculiar impedance is topological, the measured impedance being independent of the size or shape of the Hall bar, independent of the size or shape of the resistor that governs the flow of current. Prior to that discovery, impedance quantization was more implied than explicit in the literature [24, 25, 26, 27, 28, 29, 30]. Early mentions include the 1955 paper of Jackson and Yovits [24] and the 1957 paper of Landauer [25].

The 1959 thesis of Bjorken [26] presents an approach summarized [27] 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 [28]. As presented there, the units of the Feynman parameter are [sec/kg], the units of mechanical *conductance* [31].

It is not difficult to understand what led Bjorken astray, as well as those (including the present author) who have made more recent similar attempts [5, 32, 33, 34]. 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 [35] 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." [36].

With the confusion that resulted from misinterpreting conductance as resistance and lacking the concept of quantized impedance, the anticipated intuitive advantage [28] 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.

Like the first Rochester Conference on Coherence and Quantum Optics in 1960, the 1963 paper/thesis by Feynman and Vernon [29] on the "Interaction of Systems" was motivated by the invention of the maser. The authors devoted a thesis to concepts needed for impedance matching to the maser. Lacking again was the explicit concept of *quantized* impedance.

While the 1970 paper by Landauer [30] somewhat clarified his earlier work, the explicit concept of impedance quantization remained obscure.

Quantization of mechanical impedance in the hydrogen atom was introduced in a 1975 unpublished note [5]. However, the quantity with units [kg/sec] was interpreted as mass flow in the deBroglie wave, with confusion arising again due to the inversion in the SI system of units.

Had impedance quantization been discovered in 1950 rather than 1980, one wonders whether the concept 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, is paradigm-changing.

The Impedance Model

Given the experimental evidence of quantization in the photon and quantum Hall impedances and the realization that mechanical impedances can be calculated from Mach's principle applied to the two body problem [5], it is a short step to introduce the (inverse square of) line charge density needed to convert mechanical impedances [6] to electrical, where techniques for calculating electromagnetic interactions between the objects of Geometric Algebra are known.

With electromagnetic fields only, taking maximal symmetry between electric and magnetic, and taking the simplest geometric objects needed for a realistic model [6] gives

- quantization of magnetic and electric flux, charge, and dipole moment
- three objects - flux quantum (no singularity), monopole (one), and dipole (two)
- confinement to a fundamental length, taken to be the electron Compton wavelength
- the photon

In seeking to link IA to STA, one possibility is to explore the correspondence between the geometric objects of the two approaches, as shown in figure 3:

The calculated coupling impedances of the interactions between these geometric objects[6, 21, 37], the coupling impedances of the modes of the model, are shown in figure 2. Of immediate interest in terms of defining the components of the Dirac wavefunction are the modes intersecting at the electron Compton wavelength, including those of the .511 MeV photon. The energy of a photon whose wavelength is the electron Compton wavelength equals the .511 MeV rest mass of the electron.

item	marker	symbol	GA object
electric flux quantum	—	ϕ_E	bivector
magnetic flux quantum	—	ϕ_B	bivector
electric dipole	◆	d_E	vector
magnetic dipole	◆	μ_B	vector
electric monopole	■	q_E	scalar

FIGURE 3. Possible linking of a subset of the objects of IA with STA

The modes at the .511 MeV node that is matched to the 377 Ω photon impedance fall into one of three categories:

- self-interaction between the electric and magnetic flux quanta of the photon
- interaction between the flux quanta of the photon and the electron modes
- self-interaction of the excited electron modes

The three categories are stages in the transfer of energy from photon to electron. Results of the geometric products that describe these interactions are shown in figure 4.

In the **first stage** the coupled magnetic and electric flux quanta of the photon are propagating in free space [38]. The geometric product of the two flux bivectors delivers a pseudoscalar and a scalar.

In the **second stage**, which describes excitation of the electron by the photon, we have four interactions, each between one of the flux quanta of the photon and one of the geometric objects of the impedance model as shown in figure 3.

Here the two flux quanta of the free space photon start to decohere due to the opposing phase shifts of the capacitive and inductive impedances of the electron. Keller summarizes a possible interpretation of this process in the preface to his treatise on quantum theory in near-field electrodynamics [39].

"Matter-attached fields are unavoidably present in the near-field... and in the covariant notation their quantization leads to the scalar and longitudinal photons, and then by a certain unitary transformation to gauge and near-field photons."

mode	interaction	geometric product	resulting STA grades
photon	self	$\phi_E\phi_B$	pseudoscalar + scalar
photon-electron	mutual	$\phi_E\phi_B$	pseudoscalar + scalar
photon-electron	mutual	$d_E\phi_E$	pseudovector + vector
photon-electron	mutual	$\mu_B\phi_E$	pseudovector + vector
photon-electron	mutual	$q_E\phi_B$	bivector + scalar
stationary photon	self	$\phi_E\phi_B$	pseudoscalar + scalar
electric dipole	self	$d_E d_E$	bivector + scalar
magnetic dipole	self	$\mu_B\mu_B$	bivector + scalar
electromagnetic dipole	self	$d_E\mu_B$	bivector + scalar
scalar Lorentz	self	$q_E\phi_E$	bivector
Coulomb	self	$q_E q_E$	scalar

FIGURE 4. Grades of the photon-electron interaction at .511 MeV

In near-field electrodynamics *"The longitudinal electric field is always of crucial importance...this field involves the difference between the longitudinal and scalar photons"*. [40]

The 'certain unitary transformation'
$\begin{pmatrix} i & -i \\ 1 & 1 \end{pmatrix}$ is complex. Applying this transformation to the scalar and longitudinal photon wave functions delivers their 'real' sum (the gauge photon) and 'imaginary' difference (the near-field photon) [40]. The gauge photon carries the phase information (not a single measurement observable) that permits the instantaneous non-local projection of entangled photons into complementary eigenstates [22]. In the impedance model the associated impedance is scale invariant.

Assigning the experimental reality of non-local state reduction of entangled photons to the gauge photon implies the reality of the near-field photon in the excited states of the electron.

Keller's treatment doesn't employ STA. Presumably the geometric aspects of i in the transformation matrix are not yet understood, and certainly not by the present author. With that in mind, it should be noted that the above interpretation assumes that Keller's longitudinal and near-field photons can be identified with the corresponding pseudoscalars of STA shown in figure 4.

In the **third stage** we have the self-interacting modes of the electron model that were excited by the impedance matched photon. These modes comprise an even sub-algebra of STA. The complete algebra appears only in the photon-electron interaction of the second stage.

In the impedance approach the 'electron' is a coupled mode family obeying linear superposition. The correlation of the network nodes with the coherence lengths shown in figure 2 suggests that the elementary particle spectrum consists of excited modes of the impedance network, that the network comprises the 'structure of the vacuum' as cited earlier [38]. Any of them, when taken as components of the Dirac wave function, should deliver meaningful results.

The initial conjecture [8] relating IA and STA was based upon the distinction between scale invariant (rotation gauge field) and scale dependent (translation gauge field) impedances. With the one known exception of the massless photon, which is unique in having both scale invariant far-field and scale dependent near-field impedances, the invariant impedances cannot communicate energy/information, only quantum phase. This distinction plays a fundamental role in entanglement, non-locality, and state reduction [22], the black hole information paradox [41], the chiral anomaly [42], time asymmetry [43], the extreme early Big Bang [44] and at the foundational level in interpretations of quantum mechanics [45].

The centrifugal impedance shown in figures 2 (green dots) and 5 (green line) is scale invariant. Scale invariant impedances cannot be shielded [43]. The vector Lorentz impedance of the Aharonov-Bohm effect is one example. The question here is what role invariant impedances might play in gravitation. The equivalence principle as stated by Heisenberg [46] reads

"...gravitational forces can be put on the same level as centrifugal or other forces that arise as a reaction of the inertia..."

THE PLANCK PARTICLE

Just as the energy of a photon whose wavelength is the electron Compton wavelength equals the electron rest mass, the energy of a photon whose wavelength is the Planck particle Compton wavelength is the rest mass of the Planck particle and its associated event horizon. This is the 'electromagnetic black hole', the simplest Planck particle eigenstate. A more detailed model can be had by taking the quantization length to be not the electron Compton wavelength, but rather the Planck length, resulting in the network of figure 5.

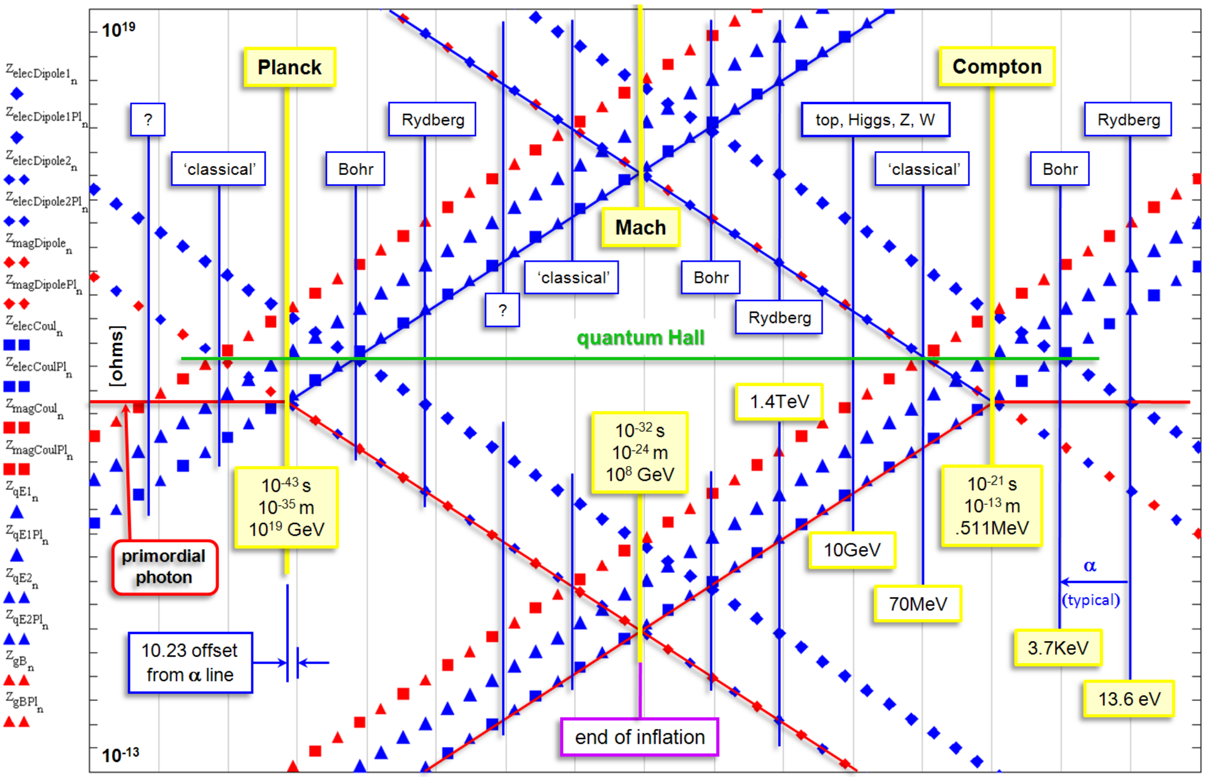

FIGURE 5. An impedance template for the Big Bang - a subset of the electron and Planck particle impedance networks, showing a .511 Mev photon entering from the right and the'primordial photon' from the left. The green line represents both quantum Hall and centrifugal impedances [7, 41, 44].

Calculating the impedance mismatch between electron and Planck particle gives an identity between electromagnetism and gravity [7, 41]. The calculation proceeds in the same manner as the impedance match of the 13.6 eV photon near-field impedance to the quantum Hall impedance at the Bohr radius, by attempting to match the .511 MeV photon near-field impedance to the quantum Hall impedance at the Planck length. Similar calculations can be done with any of the coupled impedances of figure 5.

The gravitational force between these two particles is equal to the impedance mismatched electromagnetic force they share. This result suggests that both gravity and rest mass are of electromagnetic origin. While strong classical arguments have been advanced against electromagnetic theories of gravity [47], preliminary examination suggests that such arguments fail when the full consequences of quantum phase coherence are taken into consideration.

IA delivers exact results at the Planck particle event horizon (and beyond to the singularity, completely decoupled by the infinite mismatch to the dimensionless point). Relativistic curvature corrections are unneeded. The impedance model is flat space.

MASS

At the nine digit limit of experimental accuracy, the exact identity between gravity and electromagnetism that was found by impedance matching to the Planck particle [7] limits the energy transfer between these two particles to the rest mass of the electron. In this sense the electromagnetic interaction with the Planck particle can be considered a route to the 'origin of mass', and the Planck particle almost but not quite virtual. The Casimir effect comes to mind.

The impedance model offers a simple second route to mass. The model is comprised of self-interacting electromagnetic fields in flat space, configured as geometric objects in the flat spacetime algebra of gauge theory gravity, and confined by impedance mismatches as one moves away from the quantization scale. The mode impedances of the self-interacting geometric objects are shown in figures 2 and 5.

The second 'origin of mass' in the impedance model is the stored energy of the electromagnetic fields. Calculating that energy [48] at the relevant quantization scales gives the electron mass at the limit of experimental accuracy, the muon mass at one part per thousand, the pion at two parts in ten thousand, and the nucleon at seven parts in one hundred thousand. The pion and muon calculations invoke a supersymmetry of sorts. The nucleon calculation is admittedly a bit of a kludge, but interesting none-the-less.

GRAVITY

The relatively recent discovery that Gauge Theory Gravity in flat space is equivalent to General Relativity in curved space [9, 10, 11, 12, 13, 14] is both astounding and a paradigm shift of itself. Why work in curved space all these years if one can work so much more simply in flat space? How did it get this way?

Like the absence of impedances from QED, this is another historical accident. It arose because the geometric algebra of Grassman and Clifford was lost with the early death of Clifford and the ascendancy of the simpler Gibbs' vector formalism in the late 19th century. Clifford algebra persisted in various forms without geometric insight until rediscovered and expanded by Hestenes starting in the 1950s. Einstein and company did not have that tool at hand, worked with tensor calculus (which is a subset of geometric algebra/calculus, as is the Dirac algebra of quantum mechanics) in curved space. Whether one describes gravity as the effect of mass curving space or quantum phase shifts, the claim here is that they yield equivalent results.

Just as mass is of electromagnetic origin in the impedance approach, so must be gravity. What then of the graviton? Which of Keller's photons [49] is the graviton?

Some guidance comes from two essential characteristics of gravity that, upon first consideration, would seem to rule out an electromagnetic origin [47]. First, unlike electromagnetic forces, it appears that gravity cannot be shielded. However, as mentioned earlier in the context of both the centrifugal force and the Aharonov-Bohm effect of the vector Lorentz force, scale invariant impedances cannot be shielded [22, 43]. And second, gravity appears to have only one sign. We observe only attractive gravitational forces. However again it seems these impedances have a particular characteristic that is relevant here. These impedances are DC. As such, they can account for the attractive-only character of gravity. In the case of observables it seems that they act by retarding the phases [50], or the space bending if you will. In the case of the 'dark matter/energy' of the impedance model [6] the possibility exists that either or both the phase or/and its effect upon such matter/energy would be repulsive rather than attractive.

Given that linear superposition applies to this quantum network of nonlinear coupled modes (!), it would seem that any of the scale invariant impedances would be equal to the tasks outlined above, as appropriate for a given set of initial conditions. The phase shifts of Gauge Theory Gravity could be communicated by any of the scale invariant impedances. Yet a paradox remains, apparently topological and one of many. The scale invariant impedances can do no work, can only communicate quantum phase. And we all know gravity can do work.

Discussion

Mentioned earlier was the use of the inverse square of line charge density $[m^2/Coul^2]$ to convert mechanical impedances to electrical [6]. This is a bivector with the attribute of charge, where the charge appears not in the numerator, as one would expect in such a conversion, but rather in the denominator. This is yet another example of the many interwoven mechanical, electromagnetic, and topological paradoxes [35] to be found in the SI system of units.

The impedance plots of figures 2 and 5 are static, showing amplitudes but not phases. To solve the dynamics one might employ iterative mathematical modeling of the phases and couplings of the networks, the output of which will hopefully converge upon the structure and dynamics of the experimentally observed elementary particle spectrum as shown in figure 2, and a deeper understanding of the relationship between electron and Planck particle shown in figure 5. At one point it was hoped that this could be accomplished in flat space with the vector algebra of Gibbs. However the topological paradoxes suggest that Geometric Algebra will be essential.

Conclusion

Dating back to the emergence of life from the oceans, the concepts of mass and gravity have been directly wired into our perceptions of the world by our physical structure. Since the time of Newton they have become facts both experimental and theoretical. Electromagnetism, on the other hand, has entered the body of knowledge only with the technology of the past few centuries, and offers much less intuitive guidance.

Trusting and following the rigorous logics of both the geometric algebra of Grassman and Clifford and the foundations of Mach's intuitions regarding the origins of mass have led most unexpectedly to an electromagnetic model that offers the possibility of a formalism bringing together electromagnetism, nuclear forces, and gravity. One hopes that this possibility will be recognized, and eagerly awaits the work by mathematical physicists with geometric algebra as informed by impedance quantization. Please. If it exists, show us that formalism.

One awaits as well the integration of impedance quantization in the toolbox of the nano-engineer, the quantum chemist, the biologist,... In practical terms, the economic future of impedance quantization appears to be in AMO/condensed matter physics [52].

ACKNOWLEDGEMENTS

The author thanks Michaele Suisse for helpful discussions and innumerable literature searches, and family and friends for unfailing support and encouragement.

In closing, it seems appropriate to repeat a quote attributed [51] to Einstein:

"To understand the electron would be enough."

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