Generalized Quantum Impedances: A Model for the Unstable Particles

Peter Cameron*
Strongarm Studios
Mattituck, NY USA 11952

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The discovery of exact impedance quantization in the quantum Hall effect was greatly facilitated by scale invariance. Both exact quantization and scale invariance follow from the the fact that the vector Lorentz force is neither conservative nor dissipative. This letter explores the possibility that quantum impedances may be generalized, defined not just for the Lorentz force, but rather for all forces, resulting in a precisely structured network of scale dependent and scale invariant impedances. If the concept of generalized quantum impedances correctly describes the physical world, then such impedances govern how energy is transmitted and reflected, how the hydrogen atom is ionized by a 13.6eV photon, or why the π_0 branching ratio is what it is. An impedance model of the electron is presented, and explored as a model for the unstable particles.

INTRODUCTION

Quantum impedances can be divided into two categories. The first has one member, the only massless particle that has been experimentally observed - the stable photon. The second contains all the massive particles, stable and unstable.

In the **first category**, the photon impedance is further divided into the scale invariant far-field and scale dependent near-field impedances. The far-field impedance is defined in terms of the ratio of magnetic permeability to electric permittivity as [1]

$$Z_0 = \sqrt{\frac{\mu_0}{\epsilon_0}} \simeq 376.73\Omega$$

In both near and far fields the amplitudes of the electric and magnetic components of the dipole impedance can be written as [2]

$$Z_E = Z_0 \left| \frac{1 + \frac{\lambda}{ir} + \left(\frac{\lambda}{ir}\right)^2}{1 + \frac{\lambda}{ir}} \right|$$

$$Z_M = Z_0 \left| \frac{1 + \frac{\lambda}{ir}}{1 + \frac{\lambda}{ir} + \left(\frac{\lambda}{ir}\right)^2} \right|$$

where λ is the photon wavelength and r is the length scale of interest. The impedances of a 0.511MeV photon are plotted in figure 1.

The photon impedance is strictly electromagnetic. Unlike the massive particles, the photon has no mechanical impedance.

In the **second category**, that of the massive particles, the impedance commonly encountered in the literature [3–12] is the scale invariant quantum Hall impedance

$$Z_H = \frac{h}{e^2} \simeq 25\,812.8\Omega$$

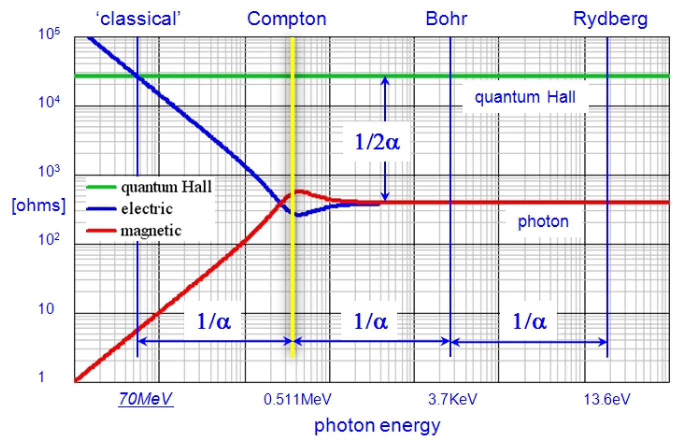

FIG. 1. Photon and electron impedances as a function of spatial scale as defined by photon energy

where h is Planck's constant and e is the charge quantum.

The quantum Hall impedance is plotted in figure 1. The role of the fine structure constant α in the impedance and energy ratios is a prominent feature of the figure.

This impedance is an electromechanical impedance. It provides one of the essential keys to understanding how to calculate quantum impedances for all forces [13, 14].

MECHANICAL IMPEDANCES

Mechanical impedance is defined as [15]

$$Z_{mech} = \frac{F}{v}$$

where F is the applied force and v is the resulting change in velocity. Taking the force F to be, for example, the centrifugal force

$$F_{centri} = \frac{mv^2}{r}$$

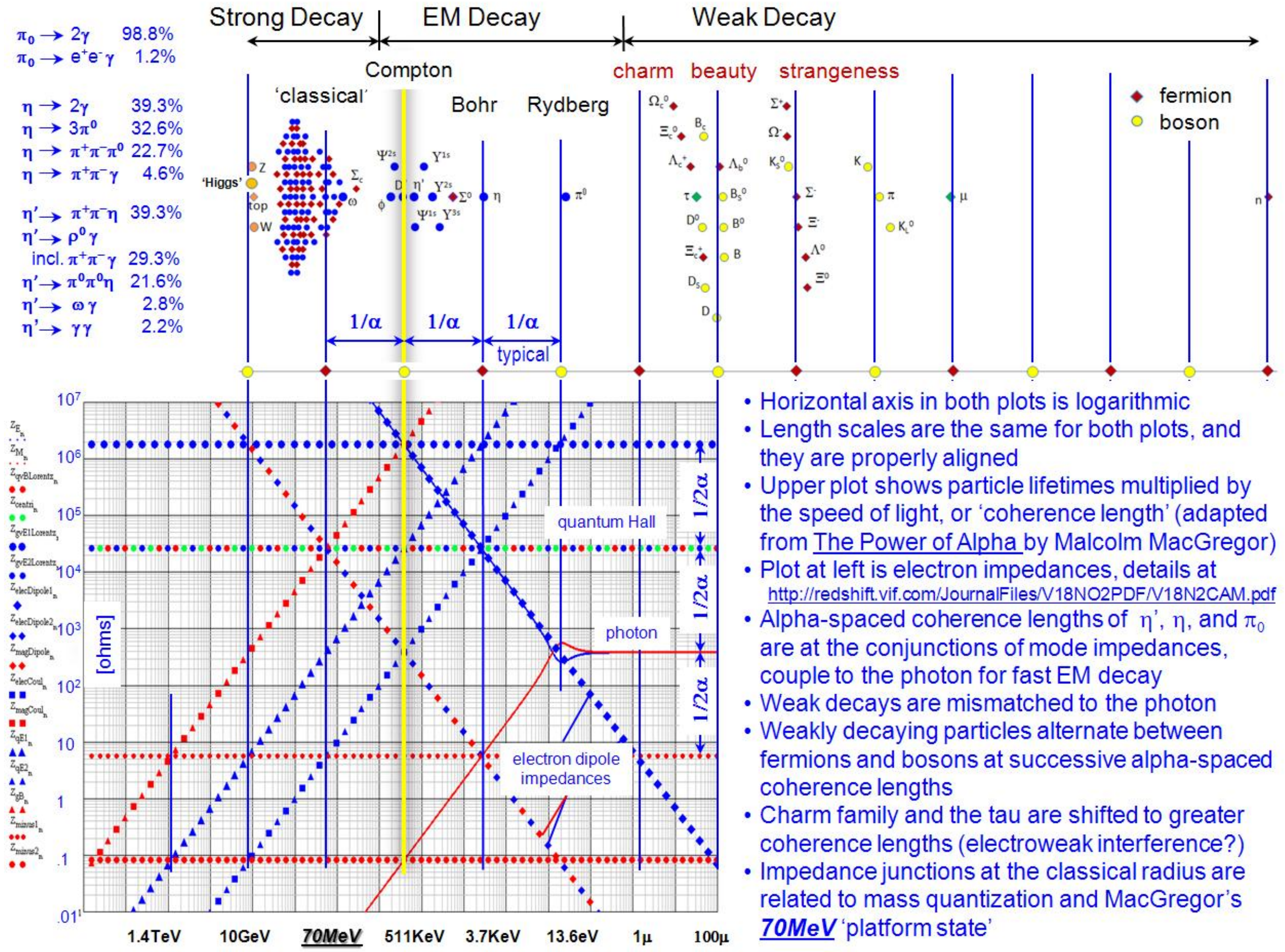

FIG. 2. A composite of 13.6eV photon impedances and a variety of electron impedances [14], measured branching ratios of the π_0, η, and η', the four fundamental quantum lengths shown in fig.1, and the coherence lengths of the unstable particles. Regarding dipole impedances, only the transverse dipole-dipole impedances are shown. Missing are the longitudinal dipole-dipole and longitudinal and transverse charge-dipole impedances.

gives

$$Z_{centri} = \frac{mv}{r}$$

where m and r are some as yet undefined mass and length parameters. Defining v by the deBroglie relation $v = \frac{h}{mr}$ yields

$$Z_{centri} = \frac{h}{r^2}$$

The units of mechanical impedance are [kg/s], those of electrical impedance [ohm] = [(kg/s)(m/Coul)^2]. Taking the second term on the right hand side, the line charge density term, to be a conversion factor between mechanical and electrical impedances gives

$$Z_{centri} = \frac{h}{r^2}\frac{r^2}{e^2} = \frac{h}{e^2} \simeq 25\,812.8\Omega$$

This impedance is numerically and symbolically identical to the scale invariant quantum Hall impedance, and is plotted in figure 2 (green dots).

The method presented in the above example can be used to calculate quantum impedances for forces other than the centrifugal and vector Lorentz forces. The impedance plot of figure 2 shows results from such calculations [14].

THE HYDROGEN ATOM

The aim here is to see what insight into the hydrogen atom may be gained by exploring the role of quantum impedances in the transfer of energy from a 13.6eV photon to an electron.

In figure 2 the far field photon is the red line entering the impedance plot from the right at 377 ohms. The wavelength of the 13.6eV photon is the inverse Rydberg. At that scale the electric and magnetic flux quanta [16] decouple. The electric flux quantum is well matched to the larger of the two electric dipole impedances, as seen in the figure, where the electric dipole impedances are represented by large and small blue diamonds.

As the head of the **electric flux quantum** wavepacket arrives at the Bohr radius the packet is still feeding increasing energy in from out beyond the Rydberg. From figure 2 it can be seen that at the Bohr radius there is a conjunction (upper dashed circle) of the electron dipole impedance with the scale invariant electric and magnetic vector Lorentz impedances, the scale invariant centripetal impedance, and the scale dependent electric Coulomb and scalar Lorentz impedances. The details of the couplings between the modes associated with the impedances (phases, confinement mechanisms [17],...) remain to be investigated. At the outset it is tempting to say that one knows the outcome (the H atom is ionized) and can work backwards from there.

But where is the proton in this plot?

The **magnetic flux quantum**, unlike the electric flux quantum, arrives at the Bohr radius without benefit of an impedance match from the scale of the Rydberg, but presumably still phase-coherent. The excitation of the Bohr magneton (small red diamonds) at the Bohr radius is more of a shock excitation, more broadband.

The possible existence of at least one scale invariant magnetic impedance should be noted, present at the five ohm conjunction (lower dashed circle) of the magnetic flux quantum with the magnetic and the smaller of the two electric dipole impedances. Detailed calculations [14] suggest that the measured quantum Hall impedance is not just an electric impedance, but rather the sum of the scale invariant electric *and* magnetic impedances.

The impedance plot was generated with the electron in mind. It was only after the plot was generated that the photon was added. The 'Bohr correspondence' was a nice serendipitous surprise.

IMPEDANCE DRIVEN COHERENCE LENGTHS

The precise ordering of unstable particle lifetimes in powers of the fine structure constant [18–20] is arguably the most unappreciated and potentially useful organization of experimental data in the entire world of physics. Multiplying the lifetimes by the speed of light places them on the light cone, on the boundary between locality and non-locality, defining their coherence lengths. It also makes clear their relation to the impedance plot. That some strong correlation exists between coherence lengths and conjunctions of the network formed by the mode impedances can be seen from the figure.

Instead of a 13.6eV photon, suppose one looks at the interaction of a very high energy photon, several TeV, with this network. The multi-TeV photon successively excites the corresponding mode or modes of each of the impedances it encounters.

In the extreme short distance/high energy regime at the leftmost of the impedance plot the electric and magnetic impedances diverge, and the eigenmodes cannot couple to the photon. To the extent that the impedance model is in concordance with QED, the high energy impedance mismatch to the photon is a natural cutoff of the perturbation expansion, and the 'ultraviolet catastrophe' is absent. Similar reasoning applies in the long wavelength limit. The infrared divergences are cut off by the impedance mismatches.

Just the same, one has to confront the question of where the energy goes. The photon imparted several TeV to the network. Is it reflected back out through the network as a consequence of the exponentially increasing mismatch to the photon at ever smaller spatial scale? Does it see the virtual singularity at the Planck length? Conservation requires that, one way or another, this energy comes back out.

Electromagnetic decays appear to be the most straightforward route out of the network for the energy in excited eigenmodes. The α-spaced coherence lengths of the π_0, η, and η' are at the conjunctions of mode impedances, and can couple to the photon for fast electromagnetic decay. Their branching ratios are shown in the upper left corner of the figure.

The coherence length of the π_0 is the inverse Rydberg. As the 13.6eV photon coupled to the electric dipole impedance at that length scale, so the dipole mode of the π_0 couples almost as well to the photon pair.

However in the case of the π_0, additional modes are excited at the Rydberg scale, a magnetic mode junction at a tenth of an ohm (indicated by the lower solid circle) and an electric mode at a couple megohms (upper solid circle). They are mismatched to the Landauer/Hall electron impedance by that factor of $\frac{1}{2\alpha}$, resulting in suppression of the $e^+e^-\gamma$ decay relative to 2γ.

A simple impedance matching calculation of the π_0 branching ratio agrees with experiment at better than three parts per thousand. The result can be used in the calculation of the η branching ratios within two percent on each the four decays shown in the figure, though with the proviso that unexplained factors of two previously introduced [14] intrude here as well. Presumably one could use the π_0 and η results to calculate the η' branching ratios, though the complexity grows formidably as one goes deeper into the decay chains. Numerically, the relative values of the η and η' branching ratios shown in the figure are remarkably similar. This follows from the similarity of the impedance structures that result in these ratios.

Weak decays are not so straightforward. That they are slower than electromagnetic decays follows from their mismatch to the photon. It is tempting to speculate that the weak 'force' is just an impedance mismatch.

In weak decays, the alternation between fermions and bosons at successive alpha-spaced coherence lengths is remarkable. At the extreme right of fig.2, the neutron sits on a fermion line. Then three unoccupied lines before encountering the muon, again a fermion on a fermion line. Then the pion and kaons, bosons on a boson line. Then the fermionic strange baryons on a fermion line, with the bosonic kshort intruding. The beauty bosons sit on a boson line, with the neutral lambda b intruding. One might conjecture that this fermion/boson alternation is related to parity violation.

At charm and the tau the alternation breaks down and both charm and tau are shifted to greater coherence length, leaving a gap between EM and weak decays. This raises the question of how both effects, the breakdown of fermion/boson alternation and the shift to greater coherence length, might be calculated in terms of electroweak interference.

What have not yet been addressed are the longitudinal dipole-dipole and longitudinal and transverse charge-dipole impedances. These impedances will likely prove to be of interest in understanding weak decays.

Strong decays are yet more obscure. The biggest problem might be that QCD doesn't play well with high energy spin physics [21–23].

The approach presented here views the unstable particles as excited states of the electron. The model takes the electron Compton wavelength as a fundamental length. In the case of the electromagnetic and weak decays the coherence lengths are greater than the Compton wavelength. For strong decays that is not the case. This implies that the short-lived resonance excitations cannot be coherent over the entire electron.

In the impedance model weak and electromagnetic decays are coherent, the coherence manifesting in α-spacing of coherence lengths. Strong decays are incoherent.

THE 70MeV MASS QUANTUM

There is a comprehensive phenomenology of the particle mass spectrum [18–20] based upon the 70MeV platform state. It will be interesting to see to what extent the impedance model and that phenomenology agree.

In the model the mass of the electron is calculated at the limit of experimental accuracy (though one might argue that the mass is given by defining the Compton radius to be a fundamental length), the mass of the muon at one part in one thousand, the pion at two parts in ten thousand, the kaon at one part in one hundred, and the nucleon at seven parts in one hundred thousand [16, 24]. All, including the 70MeV mass quantum, follow directly from electric and magnetic flux quantization.

CONCLUSION

The question of fundamental importance is not whether the model presented here is a good model. The question is whether the concept of generalized quantum impedances is scientifically correct, and also whether it is a useful concept with practical applications [8–12, 25–29].

Nothing in the impedance model appears to be in disagreement with either the small sample of experimental data to which it has been applied, or with the Standard Model. As in the case of the 70MeV mass phenomenology, it will be interesting to see if the model can be more deeply connected with both theory [17, 30] and data. Certainly the coherence length clustering of the four superheavies - W, Z, Higgs, and top - at the 10GeV conjunctions of mode impedances is intriguing in this regard.

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* petethepop@aol.com

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