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Background Independent Relations between Gravity and Electromagnetism

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Abstract As every circuit designer knows, the flow of energy is governed by impedance matching. Classical or quantum impedances, mechanical or electromagnetic, fermionic or bosonic, topological,... To understand the flow of energy it is essential to understand the relations between the associated impedances. The connection between electromagnetism and gravitation can be made explicit by examining the impedance mismatch between the electrically charged Planck particle and the electron. This mismatch is shown to be the ratio of the gravitational and electromagnetic forces between these particles.

Keywords background independence · scale invariance · quantum impedance · network theory · scattering matrix · near field · Planck particle · state reduction · information theory

Introduction

This note presents a preliminary exploration of the role of background independent quantum impedances[1, 2, 3] in gravitation.

In that earlier work on impedances, the main players were the electron and the photon. It presented a model in which unstable particles were seen as resonant excitations of the network of electron impedances, the 'scattering matrix', by the photon.

The present note looks at the extreme high energy limit of the interaction of electron and photon with a third player, the Planck particle[4]. In what follows the Planck particle is presented, and its gravitational and Coulomb interactions with the electron are introduced.

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The impedance mismatch between Planck particle and electron is then shown, via the photon, to be equal to the ratio of the gravitational and electromagnetic forces at the level of one part per billion (the empirically determined Newtonian gravitational constant G is measured with an accuracy of about a part in ten thousand).

This suggests that the enormous difference in strengths between the gravitational and electromagnetic forces can be understood in terms of the equally enormous impedance mismatch to the Planck particle.

1 The Planck Particles

There are at least two ways to define Planck particles, one each for massive and massless particles.

For **massive particles** we equate the reduced Compton wavelength and the Schwarzschild radius

$$\frac{\hbar}{mc} = \frac{mG}{c^2} \tag{1}$$

Solving for the mass m gives the reduced Planck mass[5]

$$m_{Pl} = \sqrt{\frac{\hbar c}{G}} \simeq 2.1765 * 10^{-8} kg \simeq 10^{19} GeV \tag{2}$$

and the reduced Planck length

$$L_{Pl} = \frac{\hbar}{m_{Pl} c} = \sqrt{\frac{\hbar G}{c^3}} \simeq 1.6162 * 10^{-35} m \tag{3}$$

The Planck particle as thus defined is strictly mechanical. It has no electromagnetic properties.

The Planck particle may be similarly defined in terms of the **massless photon**, again as one whose wavelength and Schwarzschild radius are equal. For the photon it is the simple matter of the equivalence $E = mc^2$ of energy and mass. From that and $E = h\nu$ we have the photon wavelength

$$\lambda = \frac{c}{\nu} = \frac{hc}{E} = \frac{hc}{mc^2} = \frac{h}{mc} \tag{4}$$

and, excepting the factor of 2π, can proceed as for the massive particles with equation (1).

The Planck particle as thus defined is electromechanical, an electromagnetic black hole[6].

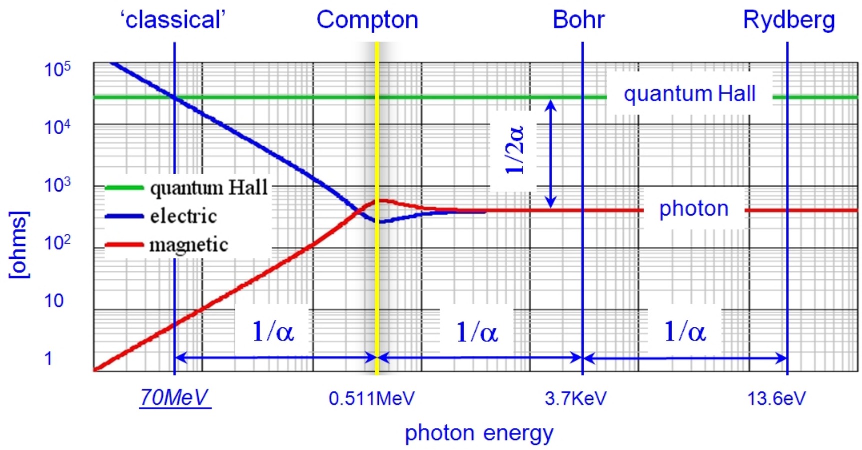

Fig. 1 Photon and quantum Hall impedances as a function of spatial scale as defined by photon energy. The role of the fine structure constant α is prominent in the figure.

2 The Interactions

The **gravitational force** between Planck particle and electron can be written as

$$F_{grav} = G\frac{m_e m_{Pl}}{{\lambda_e}^2} = 8.872\ 888\ 180 * 10^{-24} N \quad (5)$$

where m_e is the mass and λ_e the reduced Compton wavelength of the electron.

The **Coulomb force** between the electron and a Planck particle carrying the charge of a positron is

$$F_{Coul} = \frac{1}{4\pi\epsilon_0}\frac{e^2}{{\lambda_e}^2} = 1.547\ 138\ 633 * 10^{-3} N \quad (6)$$

The **ratio** of these two forces is

$$ratio_F = \frac{F_{grav}}{F_{Coul}} = 5.735\ 031\ 102 * 10^{-21} \quad (7)$$

3 The Impedances

Near and far field photon impedances[7] and the scale invariant quantum Hall impedance[8] are shown in the figure. The wavelength of the photon is the Compton wavelength of the electron. The energy of such a photon is 0.511MeV, the mass of the electron.

Similarly, we defined the Planck particle in two ways, one each for massive and massless particles, both with the same wavelength and energy. This is true in general. If the wavelength of a photon is the same as the Compton wavelength of a particle, then particle and photon have the same energy.

The near and far field amplitudes of the electric and magnetic components of the dipole impedance seen by the photon can be written as [7]

$$Z_E = Z_0 \left| \frac{1 + \frac{\lambda}{ir} + \left(\frac{\lambda}{ir}\right)^2}{1 + \frac{\lambda}{ir}} \right| \tag{8}$$

$$Z_M = Z_0 \left| \frac{1 + \frac{\lambda}{ir}}{1 + \frac{\lambda}{ir} + \left(\frac{\lambda}{ir}\right)^2} \right| \tag{9}$$

where λ is the photon wavelength, r is the length scale of interest, and $Z_0 \simeq 377\Omega$ is the free space impedance seen by the photon in the far field. These are the photon impedances plotted in the figure, where on the scale of this page the Planck particle sits about a page width to the left of the electron Compton wavelength. The singularity is to the left at infinity, totally mismatched, decoupled from the event horizon at the Planck length, as well as from the photon and electron.

There are two possibilities, both giving the same result, for calculating the impedance mismatch between the electron and the Planck particle, either by matching them directly or via the intermediary of the photon. The simpler approach for the present purpose, and the one in greater harmony with QED, utilizes the photon. There are at least two ways to go about this:

- match the near field impedance of a .511MeV photon to the scale invariant quantum Hall impedance of the Planck particle at the Planck length
- match the dipole mode of the electron to a 10^{19}GeV photon at the Planck length.

The first approach assumes that one of the Planck particle impedances can be taken to be the quantum Hall impedance[1], which is well documented in the literature. It requires that the Planck particle be given the attribute of electric charge, in this case the charge of the positron.

The second approach requires introduction of the quantum dipole impedance of the electron[2]. Both produce the same result. In the interest of simplicity and brevity, only the first will be presented here.

Looking first at the **electric component** of the photon near field impedance as shown in equation (8), and taking λ to be the .511MeV photon wavelength and r the Planck length gives

$$Z_E = 9.001\ 802\ 075 * 10^{24}\Omega \tag{10}$$

and

$$ratio_{Z_E} = \frac{Z_0}{\alpha Z_E} = 5.735\ 031\ 103 * 10^{-21} \tag{11}$$

At the part-per-billion level this is the ratio of the gravitational to Coulomb force calculated in equation (7).

$$\frac{ratio_{Z_E}}{ratio_F} = 1.000\ 000\ 001 \tag{12}$$

[1] the equality between the quantum Hall impedance and an inertial impedance associated with the centrifugal force was presented earlier[2, 3]

The accuracy is surprising at first glance, given the much larger experimental uncertainty in the gravitational constant G. However G is present in both numerator and denominator of this ratio of ratios and cancels out. This ratio of gravitational and electromagnetic forces is *independent* of the value of G. The roles of this in scale, conformal, Weyl, and/or gauge invariance[9] and their relations to background independence remain to be investigated.

The same calculation for the **magnetic component** of the photon near field impedance gives

$$Z_M = 1.576\ 636\ 854 * 10^{-20} \Omega \tag{13}$$

and

$$ratio_{Z_M} = \frac{Z_M}{\alpha Z_0} = 5.735\ 031\ 103 * 10^{-21} \tag{14}$$

so that, as for the electric component of the impedance

$$\frac{ratio_{Z_M}}{ratio_F} = 1.000\ 000\ 001 \tag{15}$$

It should be noted, as implied in the acknowledgements to this note, that if one takes the numerical value of the fine structure constant to be defined by

$$\alpha = \frac{e^2}{2\epsilon_0 hc} \tag{16}$$

rather than the experimentally determined value, then the identity between the impedance mismatch and the ratio of the forces is exact.

4 Discussion

The reader might object that the Planck particle exists only in theory, that if such a particle could somehow be produced it would not be stable, would immediately radiate its energy away. However, the possibility of interaction with the virtual Planck particle remains, just as interaction with the vacuum permits renormalization of QED in theory, or observation of the Aharanov-Bohm effect in practice.

The reasoning presented in the previous sections was adopted in the interest of making the simplest possible presentation of the role of quantum impedances in gravitation. It therefore employed only those impedances found in the commonly accepted body of physics knowledge, namely the photon and quantum Hall impedances. Attributing the full family of generalized quantum impedances to the Planck particle[10] opens many possibilities.

That step to generalized quantum impedances requires a model[2,3] that is arguably not needed for the present purpose. The reader is encouraged to explore that model in the hope that the logical foundation of the calculations presented here will become more transparent, in the hope that the utility of the concepts of quantum impedances in such diverse areas as state reduction[11], AdS/CFT[12,13], gravity wave detectors[14], or nanoelectronics[15] will motivate further interest. Particularly compelling in this context is the black hole information paradox[16].

Conclusion

Classical or quantum, mechanical or electromagnetic, fermionic or bosonic, topological,... The flow of energy is governed by impedance matching.

If the gravitational mass of the electron follows from mismatched electromagnetic interaction with the virtual Planck particle, then this will be true for all massive particles, each via its own routes through the impedance networks.

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Thanks are also due to the referee who pointed out an easily derived exact relationship between the ratio of the forces and the ratio of the electron and Planck particle masses, shown here in terms of electromagnetic impedances as well.

$$\frac{F_{grav}}{F_{Coul}} = \frac{m_e}{\alpha m_{Pl}} = \frac{Z_0}{\alpha Z_E} = \frac{Z_M}{\alpha Z_0}$$

The role of the fine structure constant will be explored in a note to follow[10].

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