Doppler-shifted Vacuum Photon Forces Responsible for Excess Energy required when Accelerating Relativistic Particles

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ABSTRACT: A kinetic energy equation for relativistic particles has been proposed giving a practical explanation for the excessive energy required to accelerate and maintain particle velocities in a particle accelerator. The equation supports the concept that this energy is absorbed by Doppler-shifted vacuum photons when colliding with charged particles. It is also shown that these colliding photons impose a practical limit to the maximum particle velocity achievable in the vacuum medium. Experimental data for 6.5 TeV protons accelerated in the LHC and the Planck cosmological parameters for vacuum energy and mass densities were used in the derivation of the equation. Energy calculations using this equation are shown to be in excellent agreement with published data from particle accelerator laboratories. The new proposed equation offers not just an alternative to the SRT energy equation but gives a physical insight to the interaction of relativistic particles with photons within the vacuum medium whilst avoiding the controversy of postulates regarding relativistic mass and kinetic energy.

KEYWORDS: Relativity, Particle Accelerators, Vacuum as a Medium, Particle/Photon Collisions, Doppler Effect, Geometric Mean.

Contents

1 Introduction

In particle accelerators the energy required to accelerate and maintain particles at relativistic velocities is significantly higher than predicted by Newtonian classical physics. To account for this phenomenon, special relativity theory (SRT) [1] postulates that particle mass/kinetic energy increases at relativistic velocities.

Although the SRT kinetic energy equation is in agreement with experimental observations, the concept of relativistic mass or relativistic kinetic energy has been, and still is, a controversial subject. Particle physicists have learnt to deal with this in their own way. However, physics educators still continue teach relativistic mass as a means to explain why particles cannot reach or exceed the velocity of light.

It is universally recognised that vacuum space is a medium interlaced with a sea of dynamic interacting quantum fields which include the electromagnetic field, photon field, and the Higgs field which is responsible for giving particles their mass. In quantum field theory (QFT), particles are seen as excitations in these underlying fields permeating all of space. This perspective contrasts sharply with the quantum-classical physics approach made here where particles are considered discrete entities moving through the vacuum medium.

The vacuum medium has been observed to have a vacuum energy density and mass density inferred from observations like the cosmic microwave background (CMB) by the Planck satellite and supernovae data [2]. By treating the vacuum as a medium using these two properties and applying the fundamental Newton–Laplace equation for the velocity of sound in a medium to determine the velocity of light it is estimated that $c = (U_{vac}/\rho_{vac})^{1/2} = 2.9979 \times 10^8$ m/s (U_{vac} can also be expressed as pressure P_{vac}). It is therefore suggested here that the vacuum of space could be viewed as a medium (see also reference [3]).

In a classical medium, the energy required to overcome drag forces on a moving particle is largely dissipated in the medium. This may also be the case when charged particles are passing through the medium of the vacuum.

To test this scenario a kinetic energy equation for relativistic particles has been derived using experimental data for 6.5 TeV protons in the Large Hadron Collider (LHC) [4], and the Planck Collaboration cosmological data for energy and mass densities of the vacuum medium [2]. No postulates regarding relativistic mass or relativistic kinetic energy were needed in the derivation of the equation.

A first attempt to derive an equation, based purely on the assumption that the vacuum behaves in the same way as a classical medium, was only successful for protons at low relativistic velocities. However, by adopting a semi-classical quantum approach, an equation has been derived to account for the extra energy required when accelerating particles to relativistic velocities:

$$E_{rel} = h\nu_{Comp}(\chi - 1).$$

This equation takes account of drag forces encountered by relativistic particles in collision with Doppler-shifted vacuum photons.

A number of research institutions are engaged in studies of frictional forces relating to quantum vacuum fluctuations [5] [6]

2 Derivation of the new kinetic energy equation

2.1 Photon force equations applied to protons in the LHC

A new equation was developed, using data from the LHC for a proton with energy 6.5 TeV [4], and results from the Planck Collaboration [2]. Values for these are given in the Appendix.

Starting from the premise that protons are moving at constant velocity in a vacuum medium, the vacuum photon drag forces have to be balanced by an external driving force. The momentum and force equations applied to this scenario are given by:

$$m_p v_{lhc} = h\nu/c, \tag{1}$$

where $h\nu/c$, corresponds to the sum of the momenta of the photons interacting with the proton, m_p is the inherent proton mass, c the velocity of light and v_{lhc} the proton velocity

The accumulated force exerted by the photons is given by:

$$F_{photon} = m_p v_{lhc}/T_{lhc} = h\nu/T_{lhc}c, \tag{2}$$

At 6.5 TeV v_{lhc} =0.9999999896c [4], $h\nu = m_p c^2$ =1.503 x 10 $^{-10}$ J, and ν = 2.2687 x 10^{23} Hz. This last value equals the Compton frequency ν_{Comp} for protons [7], and T_{lhc} is the total time (1200 s) taken by the proton orbiting the LHC [4].

Therefore, the accumulated drag force exerted by the colliding photons,

F_{photon} = 4.1786 x 10^{-22} N.

However, given the work done by the LHC is W_{lhc}= 1.0414 x 10^{-6} Joules (6.5 TeV), the average drag force on the proton is:

$$F_{lhc} = W_{lhc}/L_{lhc} = 2.89 \times 10^{-18} \text{ N} \tag{3}$$

To explain the cause for this large discrepancy between the calculated and measured forces, it is necessary to further examine the relationship between relativistic protons and vacuum photons,

2.2 Doppler-shifted Photons in Collision with Protons

Photons colliding with relativistic protons undergo Doppler-shifting and can either gain or lose energy through changes in frequency (anisotropic Doppler -shifting). Photons at the leading edge of protons of higher energy can gain a large amount of energy that is transferred from the proton - this process is called inverse Compton scattering [8]. Conversely, photons colliding at the trailing edge of the proton can actually transfer a small amount of energy and momentum to the proton – this process is referred to as Compton scattering [7].

2.3 Photon force distribution equation

To apply these principles to a relativistic proton interacting (colliding) with photons, the angular distribution of photon forces at the proton/photon interface must first be resolved along the axis and direction of travel. This interface is considered to be a thin circular disc transverse to the direction of proton motion.

Given the interacting photon flux (in Watts) in collision with a proton to be, $\Omega = h\nu/T_{lhc} = c\sigma_{int}U_{vac}$, the interactive disc cross-sectional area is:

$$\sigma_{int} = \Omega/cU_{vac} = 7.78 \times 10^{-13} \text{ m}^2 \tag{4}$$

where $U_{vac} = 5.3566 \times 10^{-10}$ J/m^3, the vacuum photon energy density[3] (N.B. it also has the units of pressure).

Vacuum photons exerting forces, F_{photon}, are incident on both sides of the disc interface (i.e. the proton). However, as seen in the rest frame of the proton, all incident photons within the cross-section σ_{int}, are subjected to Doppler shifting.

The Doppler equation for incident photons within the cross-section σ_{int} is given by:

$$\nu_{\phi} = \nu_{Comp}/\,(1 - \beta_{lhc}\cos\phi)\ , \tag{5}$$

and the incident Doppler-shifted photon angular force equation is given by:

$$F_{\phi} = F_{photon}/\,(1 - \beta_{lhc}\cos\phi) \tag{6}$$

where ϕ is the angle of incidence of interactive photons with the proton at the maximum relative velocity $\beta_{lhc,} = v_{lhc}/c, = 0.9999999896$. Figure 1 shows a graph of F_ϕ as a function of ϕ. The angular spectral range is from 0° at the leading edge of a moving proton to 180° at the trailing edge. As a reference, the initial incident photon force F_{photon}, is also shown.

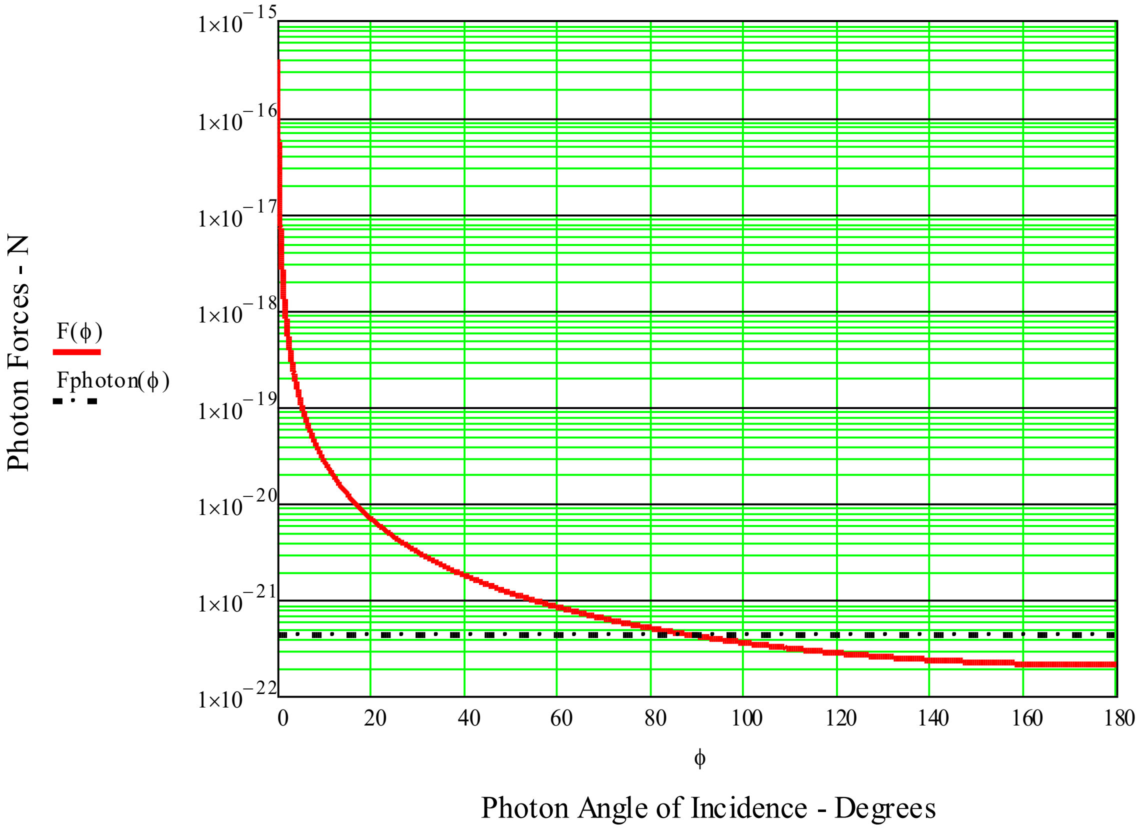

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Figure 1. Doppler–shifted photon forces on the proton as function of the angle of photon incidence. $F_\phi = F_{photon}/(1 - \beta_{lhc} \cos\phi)$.

The total effective drag force on the proton is therefore:

$$F_{proton} = \int_0^{180} F_\phi \, d\phi \,/180 = 2.89 \times 10^{-18} \text{ N} \qquad (7)$$

N.B. Due to rounding of numbers, this value is identical to that calculated for the force F_{lhc}, using Eq. (3).

2.4 Doppler shifted photon energy and the geometric mean

Given F_ϕ in Eq. (6) to be a function of Doppler-shifted photon frequency, it is considered more convenient to take the geometric mean (GM) of these frequencies between the limits, cos 0° =1 and cos 180° = -1, and calculate the total effective drag force on the proton. To do this the GM factor χ *is* defined as:

$$\chi_{lhc} = 1/[(1-\beta_{lhc})(1+\beta_{lhc})]^{1/2} = 1/(1-\beta_{lhc}^2)^{1/2}, \quad (8)$$

$$F_{proton} = F_{photon}\,\chi_{lhc} = 2.89 \times 10^{-18} \text{ N}, \quad (9)$$

where $\chi_{lhc} = 6.93 \times 10^3$.

N.B. Due to rounding of numbers, this value is also identical to that calculated for the force F_{lhc}, using Eq. (3).

Therefore, the total energy associated with proton/photon collisions:

$$E_{proton} = F_{proton}\,L_{lhc}. \quad (10)$$

Putting $E_{proton} = h\nu_{comp}$, the total kinetic energy associated the proton is given by:

$$E_{proton} = h\nu_{Comp}\,\chi = 1.041 \times 10^{-6} \text{ J} \quad (11)$$

Finally, to obtain the actual work done by the LHC on the proton, the initial, incident vacuum photon energy, $h\nu_{comp}$, must be subtracted from Eq.(11)

$$E_{lhc} = h\nu_{comp}\,(\chi_{lhc} - 1) = 1.041 \times 10^{-6} \text{ J}. \quad (12)$$

N.B. Due to the large differences between $h\nu_{comp}\chi_{lhc}$ and $h\nu_{comp}$ and the rounding of numbers, the result from Eq. (12) is identical to the result of Eq. (11).

2.5 Results from calculations using the generic version of Eq. (12)

The generic version of Eq. (12) isgiven by:

$$\text{Erel} = h\nu_{\text{Comp}}\,(\chi - 1) \quad (13)$$

where E_{rel} is the total work done when accelerating particles to relativistic velocities, $h\nu_{Comp}$ is the rest energy of the particle (= mc^2) and $\chi = 1/(1-\beta^2)^{1/2}$ is the geometric mean Doppler factor for vacuum photons incident at the leading and trailing edges of a relativistic particle.

Calculations were made to check the credibility of Eq. (13) in relation to experimentally measured laboratory results determined for 6.5 TeV protons and 574 TeV Pb ions at the LHC, and 46.6 TeV electrons at the Stanford Linear Accelerator Centre (SLAC). The results are shown in table 1.

Additional data used in calculations are given in the Appendix.

Table 1. Kinetic energy results using Eq. (13) compared to laboratory measured results

Lab.	Particle	KE measured, J	KE Eq. (13), J	ν_{Comp}, Hz	χ factor
LHC	Proton	1.041×10^{-6} (6.5 TeV)	1.041×10^{-6}	2.269×10^{23}	6.93×10^{3}
LHC	Pb ion	9.196×10^{-5} (574 TeV)	9.198×10^{-5}	4.666×10^{25}	2.98×10^{3}
SLAC	Electron	7.467×10^{-9}(46.6 GeV)	7.467×10^{-9}	1.234×10^{20}	9.12×10^{4}

Results from calculations using Eq. (13) and the SRT kinetic energy equation,

$$E_{srt} = mc^2(\gamma - 1) \;, \tag{14}$$

are plotted in Fig. 2 as a function of β for comparison .

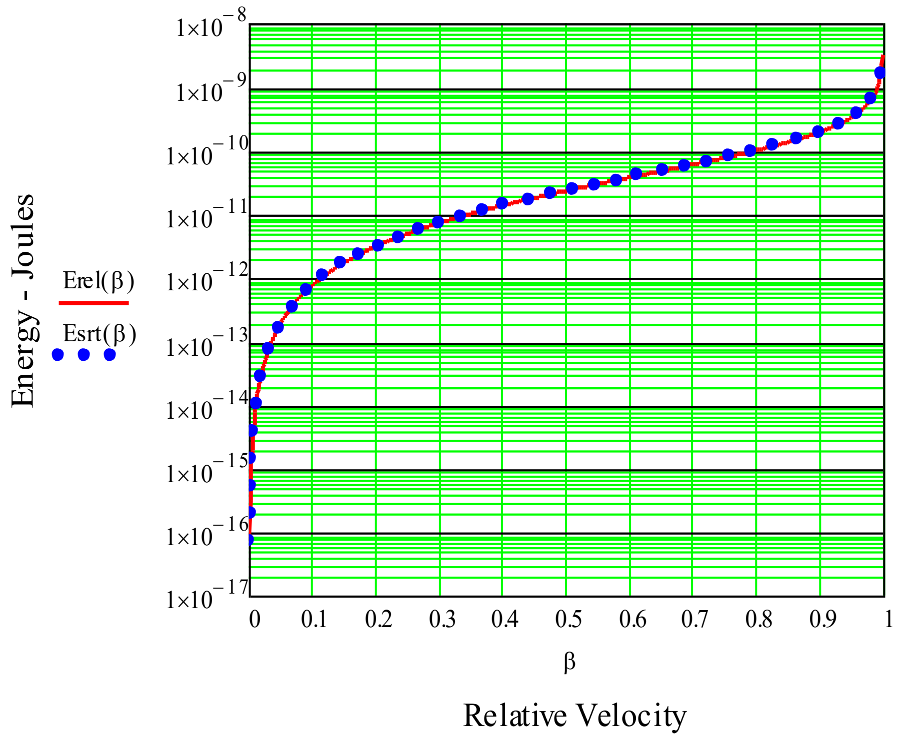

Figure 2. Comparison of E_{rel} and E_{srt}, plotted as a function of β for protons

Unsurprisingly, Eq. (13) has a similar format and gives the same results as the SRT equation, Eq. (14). However, there is a significant difference in both the derivation and the interpretation of Eq. (13) in relation to the SRT equation.

2.6 Limitation to particle velocity in the vacuum medium

According to SRT, particle velocity cannot equal or exceed the velocity of light, because the particle's mass (or kinetic energy) would become infinite. The speed of sound in a medium is determined by the ratio of the density and elasticity of the medium in which it travels. Interestingly, as was shown earlier, the speed of light also appears to be controlled by the medium properties of the vacuum (ρ_{vac} and U_{vac}).

Following this line of thought, Fig. 3 shows both the classical drag force

$$F_{class} = 1/2\, \rho_{vac}\, v^2 \sigma_{int} \;, \tag{15}$$

and the induced Doppler-shifted force

$$F_{dopp} = \rho_{vac}\, c^2 (\chi - 1)\, \sigma_{int} \,, \tag{16}$$

as a function of β. $\rho_{vac} = 5.96 \times 10^{-27}$ kg/m^3 is the mass density of the vacuum [2], $\sigma_{int} = 7.5\text{x } 10^{-13}$ m^2 is the interactive cross-section, and v (= βc) is the velocity of the proton,

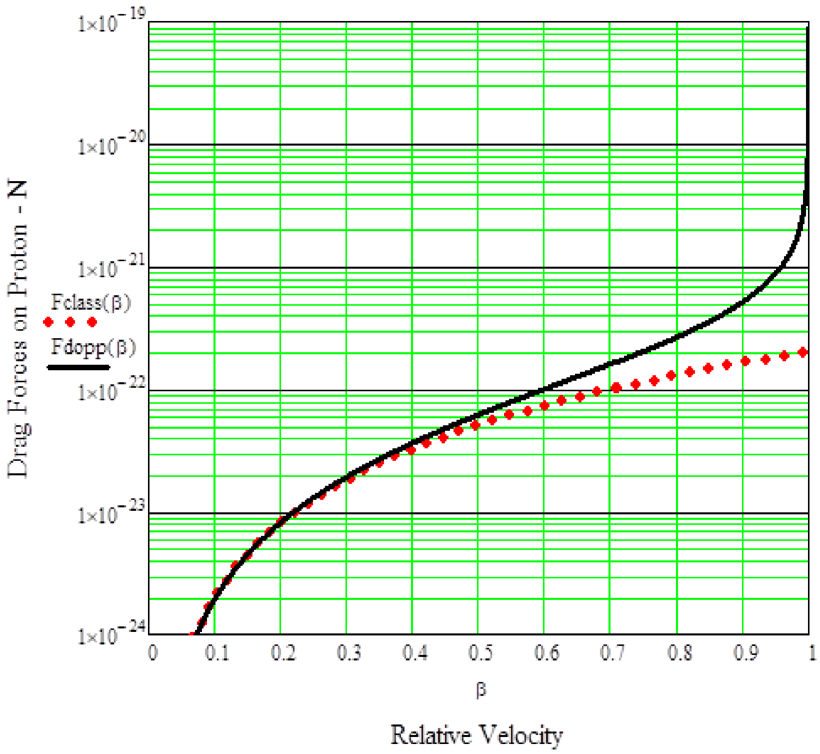

Figure 3. Vacuum photon drag forces on a relativistic proton, F_{class} and F_{dopp}, as a function of β.

For low values of β the two curves are closely connected; the vacuum appears to behave like a classical medium. At higher values of β, the photon Doppler Effect clearly dominates.

It is highly significant; due to the self–regulating feedback of the 'Doppler shift' with velocity, it is the enhanced Doppler photon frequency and hence forces that are strongly controlling proton velocity - rather than its relativistic mass. In the limit where $\beta = 1$, the drag forces on the proton become infinite.

3 Conclusions and Comments

By accepting the vacuum to be a medium endowed with photons, it was shown that excessive energy is required when particles are travelling at relativistic velocities. This energy is considered to be largely absorbed by vacuum photons undergoing a Doppler-shifted collision with the particle (inverse Compton scattering).

In essence, Eq. (13) may be seen to be just a reflection of the SRT kinetic energy equation, Eq. (14); however, there are significant differences in both the derivation and the interpretation of this new equation.

- Equation (13) was derived without the need for postulates and the controversy surrounding relativistic mass.
- Results from calculations are shown to be in agreement with published laboratory experimental results.
- The theoretical speed limit of charged particles is explained by the enhanced Doppler-shifted vacuum photon frequencies during collision with a relativistic particle. These frequencies, and associated forces, serve to provide a self–regulating feedback mechanism.
- In the limit, with $\beta=1$, Doppler-induced frequencies and drag forces on a particle with mass become infinite.
- Fig. 1 shows the force effects of Doppler-shifted photon anisotropy around the moving proton; this photon phenomena is in agreement with the observed Doppler-effects caused by object motion through the CMB [9].
- Given the scenario that in the vacuum drag forces exist which act on particles in motion through a sea of vacuum photons; could it be possible to regard photon-induced forces as a possible source for the invisible glue, the dark matter of the universe?
- It is also suggested that the ultra-high frequency photons observed in photon-photon interactions when the cross-sections (σ_{int}?) of two counter rotating protons overlap in the LHC [10] are Doppler- shifted photons that have scattered from the leading edge of the relativistic protons?

The findings from this study are in conflict with the SRT kinetic energy equation for relativistic particles. However, complimentary to this study, other authors have also successfully applied the concept of Doppler-shifting of electromagnetic waves to confirm the results of Michelson-Morley and Ives–Stilwell type experiments (see for example[3] [11]). Calculations in these studies were also made without the need to invoke postulates (time dilation or length contraction).

In conclusion the analysis presented here, and by others, suggest Doppler-shifting of photons (as electromagnetic waves) are responsible for the relativistic phenomena observed in nature. Applying results from these findings to new theories and other theories hampered by restraints imposed by SRT, may serve to advance our understanding of the universe?

4 Appendix

The following data for protons accelerated from 450 GeV to 6.5 TeV in the LHC [3], together with Plank Collaboration results [2], have been used in the derivation of Eq.(13)

Large Hadron Collider:

- Time to reach 6.5 TeV (1.0414 x10 $^{-6}$ J), taken to be 20 minutes
- Distance travelled by a proton in LHC, L_{lhc}, taken to be 3.6 x 10^{11}m
- Velocity of light, c = 2.99792458 m/s
- Injection proton velocity, v_{in} = 0.999997818c
- Extraction proton velocity, v_{lhc} = 0.9999999896c
- Proton mass, m_p = 1.67262x10^{-27} kg
- Planck's constant, h = 6.626 x 10^{-34} Js

Planck Collaboration Results:

- Mass density of the vacuum, ρ_{vac} = 5.96 x 10^{-27} kg/m^3
- Energy density of the vacuum, U_{vac} = 5.3566 x 10^{-10} J/m^3

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