Exploration

High Energy Photon as Product State of Massive Particle-Antiparticle Pair

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Abstract

According to our current understanding based on Special Theory of Relativity("STR"), a massive particle *cannot* attain the light speed: $c = 2.99872354 \times 10^8\,\mathrm{ms}^{-1}$. On the other hand, STR does not forbid the existence of particles that travel at superluminal speeds. Only massless particles can travel at the speed of light. In this article, we show that it is plausible to have massive particles paired as product state travel at the speed of light.

Keywords: High energy, photon, massive particle, antiparticle, pair, product state.

1 Introduction

Our present understanding from Einstein Einstein (1905)'s Special Theory of Relativity (STR) is that a massive particle *can never ever* attain the light speed barrier: $c = 2.99792458 \times 10^8\,\mathrm{ms}^{-1}$. Massive particles are (according to the STR) eternally incarcerated to travel at sub-luminal speeds: such particles that travel at sub-luminal speeds are known as *bradyons*. On the other hand, Einstein's STR does not forbid Bilaniuk et al. (1962), Bilaniuk & Sudarshan (1969) the existence of particles that travel at superluminal speeds: such hypothetical particles that travel are superluminal speeds are known as *tachyons* Feinberg (1967). Only massless particles can travel at the speed of light and nothing else: such particles that travel at the speed of light are known as *luxons*. In the present reading, we demonstrate that it should in-principle be possible to have massive particles travel at the speed of light. Actually, we propose that all light (Electromagnetic radiation or any particle for that matter that travels at the speed of light *i.e.* any luxon) is comprised of two massive particle-antiparticle coupled pair.

As it turns out in our investigation, the light speed barrier is common meeting point for both bradyons and tachyons. That is to say, two massive bradyons can couple to each other to produce a luxon (in pair-production) and in much the same manner, two tachyons can couple to each other to produce a luxon. However, a bradyon that now is a luxion can not crossover into the tachyonic world nor can a the coupled tachyon that now is a luxion crossover into the bradyonic world. The light speed barrier thus appears more to be a *sine-qua-non* bridge to prevent any crossovers between the bradyonic and tachyonic worlds. We (myself) have always wondered Nyambuya (2010, 2014) why should there be a speed barrier such as the speed of light – what purpose does such a barrier serve in the harmonious workings of he Universe? It appears that as we continue to investigate the workings of *Nature*, an answer is beginning to emerge.

In the case of pair-production ($\gamma \rightarrow \mathrm{e}^- + \mathrm{e}^+$), photons at high-energy (MeV scale and higher) is the dominant mode of photon interaction with matter. These interactions, the photon's energy is converted to particle's mass through Einstein's equation ($E = \mathrm{m}_0 c^2$); where E is energy, m_0 is mass. In this interaction the photon must have higher energy than the sum of the rest mass energies of an electron and positron for the production to occur. The photon must be near a nucleus in order to satisfy conservation of momentum, as an electron-positron pair producing in free space cannot both satisfy conservation of energy and momentum Hubbell (2006).

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In these pair-production interactions, the Electron and Positron are surely bradyons: *i.e.*, the magnitude of their group velocities must be less than that of light. When these combine to form a photon, this photon must travel at the speed of light. What this means is that it must be possible for massive particles to travel at the speed of light as happens in these pair-production interactions. The physics of how this comes about has always puzzled physicists. In the present letter, we shall show how it is in-principle possible for two massive particles to come together to form a photon that travels at the speed of light. For this, we make use of the recent idea Nyambuya (2016*b*,*a*) that the Dirac equation admits not only particle solutions whose wavefunctions are 4×1 component objects but 4×4 component objects.

2 Quantum Superposition

2.1 Linear Superposition

If $|\psi_1\rangle$ and $|\psi_2\rangle$ are normalized (*i.e.*: $\langle\psi_1|\,|\psi_1\rangle = \langle\psi_2|\,|\psi_2\rangle = 1$) and orthogonal (*i.e.*: $\langle\psi_1|\,|\psi_2\rangle = \langle\psi_2|\,|\psi_1\rangle = 0$) wavefunctions of two quantum particles, then, according to the quantum linear superposition principle, these particles can interact such that the resulting wavefunction $|\psi_{qps}\rangle$ is a "quantum sum" of the two waves, *i.e.*:

$$|\psi_{qps}\rangle = c_1\,|\psi_1\rangle + c_2\,|\psi_2\rangle\,, \tag{2.1}$$

where in general $[\{(c_1, c_2) \neq 0\} \in \mathbb{C}]$. For the present purposes, let us call this form of interference Quantum Linear Superposition (QLS). In classical physics, the two waves would interfere such that the resulting wavefunction is a direct sum of the waves *i.e.* $|\psi_{csp}\rangle = |\psi_1\rangle + |\psi_2\rangle$. In-order to distinguish the classical superposition from quantum superposition we have used the term "quantum sum" for the quantum summation of the two waves.

Now, the resulting wave $|\psi_{qls}\rangle$ is also normalised, *i.e.*:

$$\langle\psi_{qls}|\,|\psi_{qls}\rangle = |c_1|^2\,\langle\psi_1|\,|\psi_1\rangle + |c_2|^2\,\langle\psi_2|\,|\psi_2\rangle = 1. \tag{2.2}$$

Since $\langle\psi_1|\,|\psi_1\rangle = \langle\psi_2|\,|\psi_2\rangle = 1$, it follows that:

$$|c_1|^2 + |c_2|^2 = 1. \tag{2.3}$$

2.2 Product Superposition

We would like to introduce a new form of quantum superposition. In this new superposition, the two waves interfere such that the resulting wavefunction is a production of the two individual, *i.e.*:

$$|\psi_{qps}\rangle = |\psi_1\rangle\,|\psi_2\rangle\,. \tag{2.4}$$

For the present purposes, let us call this form of interference Quantum Product Superposition (QPS).

QPS can be justified as a possible form or mechanism of quantum interference of two particles. To do this, let us consider this in the context of the Schrödinger theory. If – as one would naturally expect; $|\psi_{qps}\rangle$ is to satisfy the Schrödinger equation $\mathcal{H}\,|\psi_{qps}\rangle = \mathcal{E}\,|\psi_{qps}\rangle$ and the individual particles also satisfy the Schrödinger equation *i.e.*, $\mathcal{H}\,|\psi_1\rangle = \mathcal{E}\,|\psi_1\rangle$ and $\mathcal{H}\,|\psi_2\rangle = \mathcal{E}\,|\psi_2\rangle$, then, these two wavefunctions will have to be such that:

$$|\boldsymbol{\nabla}\psi_1\rangle \cdot |\boldsymbol{\nabla}\psi_2\rangle = |\boldsymbol{\nabla}\psi_2\rangle \cdot |\boldsymbol{\nabla}\psi_1\rangle = 0. \tag{2.5}$$

As long as (2.5) holds, $|\psi_{qps}\rangle$ and the individual wavefunctions $|\psi_1\rangle$ and $|\psi_2\rangle$ all satisfy the Schrödinger equation. Clearly, there is no inconsistency here thus such a form of interference is *in-principle* possible as it does not upset any of the known laws, principles and rules of QM. The extra condition (2.5) is necessary for QPS because the Schrödigner equation is non-linear in the space and time derivatives. In the case of the Dirac equation – which is our main focus; no such extra constraint is needed because the Dirac equation linear in the space and time derivatives. We shall demonstrate this in the next section – in which event, we derive our main result.

3 Coupled Massive Particle-Antiparticle Pairs

Let us start-off with the usual beautiful and innocent looking Dirac equation Dirac (1928*a*,*b*), *albeit*, with all important difference that we are now – as suggested in the Refs: Nyambuya (2016*b*,*a*); going to assume that the Dirac wavefunction ψ is not a 4×1 component object but a 4×4 component object, *i.e.*:

$$i\hbar\gamma^{\mu}\partial_{\mu}\left|\psi_{p}\right\rangle = +\mathrm{m}_0 c\left|\psi_{p}\right\rangle. \tag{3.1}$$

Let the corresponding antiparticle equation be such that:

$$i\hbar\gamma^{\mu}\partial_{\mu}\left|\psi_{c}\right\rangle = -\mathrm{m}_0 c\left|\psi_{c}\right\rangle, \tag{3.2}$$

where ψ_c is the 4×4 Dirac wavefunction of the antiparticle. The equations (3.1) and (3.2) satisfy the Einstein energy-momentum dispersion relation is such that ($E^2 = p^2c^2 + \mathrm{m}_0^2c^4$). From these equation (3.1) and (3.2), the rest-mass of the particle is opposite in sign to that of the antiparticle, bring us to the idea that that the rest-mass must – at least; be related to the sign of the electronic charge of the particle or the electronic as a whole.

Now, if the wavefunctions ψ_p and ψ_c commute or anti-commute with the 4×4 Dirac γ-matrices γ^{μ}, *i.e.*:

$$\left.\begin{array}{ll}[\psi_p, \gamma^{\mu}] & = 0 \\ [\psi_c, \gamma^{\mu}] & = 0\end{array}\right\} \Rightarrow \quad \text{Commutation}$$
$$\left.\begin{array}{ll}\{\psi_p, \gamma^{\mu}\} & = 0 \\ \{\psi_c, \gamma^{\mu}\} & = 0\end{array}\right\} \Rightarrow \quad \text{Anti} - \text{Commutation} \quad , \tag{3.3}$$

then: if we multiply equation (3.1) from the left by $|\psi_c\rangle$ and equation (3.2), by $|\psi\rangle$, and then add the resulting two equations, we obtain:

$$i\hbar\gamma^{\mu}\partial_{\mu}\left|\psi\right\rangle = 0. \tag{3.4}$$

where $|\psi\rangle = |\psi_p\rangle|\psi_c\rangle = |\psi_c\rangle|\psi_p\rangle$. The particle $|\psi_p\rangle$ and its antiparticle $|\psi_c\rangle$ are in equation (3.4), now coupled and the resulting particle $|\psi\rangle$ is normalised just as its two independent constituents *i.e.* ($\langle\psi|\,|\psi\rangle = 1$). This equation (3.4) represents a "massless" particle – *in reality*, it represents two coupled massive particles with a resultant vanishing rest-mass. These massive particles would either be bradyons or tachyons. If the massive particles are bradyons, m_0 is real and; if these massive particles are tachyons, m_0 is imaginary. We thus have demonstrated that it should *in-principle* be possible for massive particles to couple together and attain the sacrosanct light speed barrier, c.

Down history lane – apart from the 4×4 Dirac wavefunction; this equation (3.4) is the usual Dirac equation with ($\mathrm{m}_0 = 0$): *i.e.*, the energy-momentum dispersion relation is such that ($E^2 = p^2c^2$). The magnitude of the group velocity ($v_{\mathrm{g}} = \partial E/\partial p$) of such particles (with, $E^2 = p^2c^2$) is equal to the speed of light, c. Such an equation as equation (3.4) was first explored by Weyl Weyl (1929*b*,*a*,*c*) in his 1929 seminal papers. As it is explored in its present form, equation (3.4) has a completely different meaning to that of Weyl Weyl (1929*b*,*a*,*c*)'s 1929 exploration.

4 General Discussion

We have shown that it is possible for two charged massive particles to come together to form a massless particle *via* QPS. This QPS is possible because the Dirac wavefunction is here treated as a 4×4 component object and not a 4×1 component object. What we have demonstrated would not be possible if the Dirac wavefunction is taken as 4×1 component object.

As demonstrated in the Refs. Nyambuya (2016*b*,*a*); there are 92 possible configurations of the free particle Dirac wavefunction as a 4×4 component object, *i.e.*, $\psi = \mathcal{U}_\ell e^{\imath p_\mu x^\mu/\hbar} : \ell = 1, 2, 3, \cdots, 92$; where $\mathcal{U}_\ell$ are 4×4 unitary hermitian matrices. In these 92, thus far, *i.e.*, as far as the theory presents in self in Refs. Nyambuya (2016*b*,*a*), there is no way to choose one configuration from the other. If we now place the constraints (3.3) as a way to select from this this pool of 92 possibilities, we are left with just two cases – the cases ($\ell = 25$ and 33), *i.e.*:

$$\begin{aligned} \psi = \mathcal{U}_{25} e^{ip_\mu x^\mu} = \begin{pmatrix} \mathcal{I}_2 & 0 \\ 0 & -\mathcal{I}_2 \end{pmatrix} e^{ip_\mu x^\mu} = \gamma^0 e^{ip_\mu x^\mu} \\ \psi = \mathcal{U}_{33} e^{ip_\mu x^\mu} = \begin{pmatrix} 0 & \mathcal{I}_2 \\ \mathcal{I}_2 & 0 \end{pmatrix} e^{ip_\mu x^\mu} = \gamma^5 e^{ip_\mu x^\mu} \end{aligned} . \tag{4.1}$$

Apart from the advantage of being able to demonstrate that writing the Dirac wavefunction as a 4×4 component object allows us the *long-sought-for* insight to explain how it is possible for two massive particles to come together to form a massless particle that travels at the speed of light; there is the advantage that the Dirac wavefunction as a 4×4 component object allows us the positive and negative energy particle to exist in decoupled states. That is to say, in the usual 4×1 component Dirac wavefunction, both the positive and negative energy particles are coupled in same equation – this is not the case with the 4×4 component Dirac wavefunction.

In-closing, one can safely say that: this treatment of the Dirac wavefunction as a 4×4 component object is not disallowed by either physics or mathematics *per se*. Given that this treatment [of the Dirac wavefunction as a 4×4 component object] allows us to explain how it is possible that two massive particles can come together and travel at the speed of light and as-well the exist of positive and negative energy particles in decoupled states, there surely is a benefit in taking up this approach. As far as we can tell, this treatment of the Dirac wavefunction as a 4×4 component object has no precedent, and as such, we do not have much to say except that we are driving on a exploratory avenue seeking greater insights into the nature of reality.

5 Conclusion

Assuming the acceptability of what has presented herein, one can safely say that the treatment of the Dirac wavefunction as a 4×4 component object allows one to explain how it is possible that two massive particles can come together and travel at the speed of light.

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