Transluminal Energy Quantum (TEQ) Model of the Electron

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ABSTRACT

A transluminal energy quantum (TEQ) is proposed that forms an electron by its circulatory motion. The TEQ is particle-like with a helical wave-like motion. It carries electric charge, energy, momentum and angular momentum but no mass, and easily passes through the speed of light *c*. An electron is modeled by a –e charged TEQ circulating at 1.2×10^{20} hz, the Compton frequency mc^2/h, in a closed double-looped helical trajectory whose circular axis' double-looped length is one Compton wavelength h/mc. In the electron model the TEQ's speed is superluminal 57% of the time and subluminal 43% of the time, passing through *c* twice in each trajectory cycle. The TEQ's maximum speed in the electron model's rest frame is 2.515*c* and its minimum speed is .707*c*. The TEQ's spatio-temporal helical parameters for the electron model produce the Dirac equation's electron spin $s_z = \hbar/2$ as well as the Dirac equation's magnetic moment $M_z = -e\hbar/2m$, *zitterbewegung* frequency $2mc^2/h$, *zitterbewegung* amplitude $\hbar/2mc$ and internal forward speed *c*, while the TEQ's two helicities correspond to the electron and the positron. In the electron model, the TEQ moves on the mathematical surface of a self-intersecting torus (spindle torus). http://www.superluminalquantum.org

INTRODUCTION

Dirac's (1928a; 1928b) theory of the relativistic electron did not include a model of the electron itself, and assumed the electron was a point-like particle. Schrödinger (1930) analyzed the results of the Dirac equation for a free electron, and described a high-frequency *zitterbewegung* or jittery motion which appeared to be due to the interference between positive and negative energy terms in the solution. Barut and Bracken (1981) analyzed Schrödinger's *Zitterbewegung* results and proposed a spatial description of the electron where the *zitterbewegung* would produce the electron's spin as the orbital angular momentum of the electron's internal system, while the electron's rest mass would be the electron's internal energy in its rest frame. Barut and Thacker (1985) generalized Barut and Bracken's (1981) analysis of the internal geometry of the Dirac electron to a proper-time relativistic formalism. Hestenes (1973; 1983; 1990; 1993) reformulated the Dirac equation through a mathematical approach (Clifford algebra) that brings out a geometric trajectory approach to understanding *zitterbewegung* and to modeling the electron, such as identifying the phase of the Dirac spinor with the spatial angular momentum of the electron. A trajectory approach to the Dirac theory has also been utilized by Bohm and Hiley (1993), who describe the electron's spin angular momentum and its magnetic moment as due to the circulatory motion of a point-like electron. However, none of the above work in modeling the electron's jittery motion has a superluminal aspect.

The objectives of the present paper are to 1) present the transluminal energy quantum (TEQ) model of the electron having experimental and theoretical features of the Dirac equation's electron, 3) relate the TEQ electron model to the Heisenberg uncertainty relations, and 4) suggest approaches for testing the TEQ electron model.

A TRANSLUMINAL APPROACH TO MODELING THE ELECTRON

The present approach models the electron as a transluminal helically moving energy quantum. The electron model has several features of the Dirac electron's *zitterbewegung*. Point-like entities are postulated called transluminal energy quanta (TEQs), which are distinct from electrons themselves, and which individually compose an electron. A TEQ has energy *E*, with its associated frequency *f* and angular frequency $\omega = 2\pi f$, linear momentum $\vec{P}$ with its associated wavelength λ and wave number $k = 2\pi / \lambda$, angular momentum, and electric charge, but no mass. One TEQ forms an electron. An electron's TEQ oscillates between subluminality and superluminality. TEQs move in helical trajectories, which may be open (for a photon) or closed (for an electron). Movement of a TEQ along its trajectory produces an electron. The type of helical trajectory and the associated charge determines whether an electron or a positron is produced. More information about the transluminal energy quantum electron model presented below is presented in Gauthier (2006; 2007).

THE TRANSLUMINAL ENERGY QUANTUM (TEQ) MODEL OF THE ELECTRON

If the open helical trajectory of the photon model is converted into a closed, double-looped helical trajectory, the quantum gets an electric charge $-e$, and several helical parameters corresponding to an electron's experimental and theoretical properties are set, we get the superluminal/subluminal quantum model of the electron. Besides having the electron's experimental spin value and the magnetic moment of the Dirac electron, the superluminal/subluminal quantum model of the electron, described below, quantitatively embodies the electron's *zitterbewegung*.

Zitterbewegung refers to the Dirac equation's predicted rapid oscillatory motion of a free electron that adds to its center-of-mass motion. No size or spatial structure of the electron has so far been observed experimentally. High energy electron scattering experiments by Bender *et al*. (1984) have put an upper value on the electron's size at about 10^{-18} m. Yet Schrödinger's *zitterbewegung* results suggest that the electron's rapid oscillatory motion has a magnitude of $R_{zitt} = \frac{1}{2}\hbar / mc = 1.9 \times 10^{-13}\,\mathrm{m}$ and an angular frequency of $\omega_{zitt} = 2mc^2 / \hbar = 1.6 \times 10^{21} / \sec$, twice the angular frequency $\omega_0 = mc^2 / \hbar$ of a photon whose energy is that contained within the rest mass of an electron. Furthermore, in the Dirac equation solution the electron's instantaneous speed is *c*, although experimentally observed electron speeds are always less than *c*. An acceptable model of the electron would presumably contain these *zitterbewegung* properties of the Dirac electron.

In the present superluminal quantum model of the electron, the electron is composed of a charged superluminal point-like quantum moving along a closed, double-looped helical trajectory in the electron model's rest frame, that is, the frame where the superluminal quantum's trajectory closes on itself. (In a moving inertial reference frame, the superluminal quantum's double-looped helical trajectory will not exactly close on itself.) The superluminal quantum's trajectory's closed helical axis' radius is set to be $R_0 = \frac{1}{2}\hbar / mc = 1.9\times10^{-13}\,\mathrm{m}$ and the helical radius is set to be $R_{helix} = \sqrt{2}R_0$. The electron model structurally resembles a circulating photon model having angular frequency $\omega_0 = mc^2/\hbar$, wavelength $\lambda_C = h/mc$ (the Compton wavelength) and wave number $k = 2\pi/\lambda_C$. The electron's quantum moves in a closed double-looped helical trajectory having a circular axis of circumference $\lambda_C/2$. After following its helical trajectory around this circular axis once, the electron's superluminal quantum's trajectory is 180° out of phase with itself and doesn't close on itself. But after the superluminal quantum traverses its helical trajectory around the circular axis a second time, the superluminal quantum's trajectory is back in phase with itself and closes upon itself. The total longitudinal distance along its circular axis that the circulating superluminal quantum has traveled before its trajectory closes is λ_C.

In its rest frame, the electron's superluminal quantum carries energy $E = \hbar\omega_0 = mc^2$. Unlike the photon's superluminal quantum which is uncharged, the electron's superluminal quantum carries the electron's negative charge –*e*.

The above closed, double-looping helical spatial trajectory for the superluminal quantum in the electron model can be expressed in rectangular coordinates by:

$$
\begin{aligned}
x(t) &= R_0(1+\sqrt{2}\cos(\omega_0 t))\cos(2\omega_0 t) \ , \\
y(t) &= R_0(1+\sqrt{2}\cos(\omega_0 t))\sin(2\omega_0 t) \ , \\
z(t) &= R_0\sqrt{2}\sin(\omega_0 t) \ ,
\end{aligned}
\tag{1}
$$

where $R_0 = \frac{1}{2}\hbar / mc$ and $\omega_0 = mc^2/\hbar$. These equations correspond to a left-handed photon-like object of wavelength λ_C, circulating counterclockwise (as seen above from the +*z* axis) in a closed double loop. An image of the transluminal energy quantum (TEQ) model of the electron is shown in Figure 1.

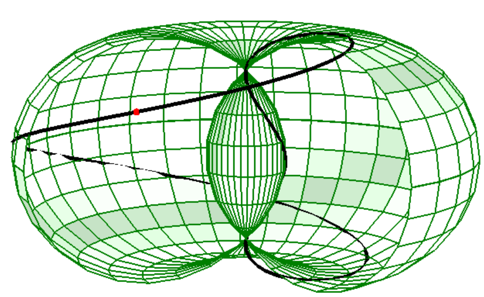

FIGURE 1. The closed double-looped helical trajectory of the electron model's transluminal energy quantum (TEQ) along the mathematical surface of a self-intersecting torus (spindle torus).

The velocity components of the superluminal/subluminal quantum are obtained by differentiating the position coordinates of the superluminal quantum in equation (1) with respect to time, giving:

$$
\begin{aligned}
v_x(t) &= -c[(1+\sqrt{2}\cos\omega_0 t)\sin 2\omega_0 t + \frac{\sqrt{2}}{2}\cos 2\omega_0 t \sin\omega_0 t]\ , \\
v_y(t) &= c[(1+\sqrt{2}\cos\omega_0 t)\cos 2\omega_0 t - \frac{\sqrt{2}}{2}\sin 2\omega_0 t \sin\omega_0 t]\ , \\
v_z(t) &= c\frac{\sqrt{2}}{2}\cos\omega_0 t\ .
\end{aligned} \tag{2}
$$

From equation (2) it is found that the maximum speed of the electron's quantum is 2.515*c*, while its minimum speed is .707*c*. A graph of the speed of the electron's quantum versus the angle of rotation in the y-z plane as the electron's transluminal energy quantum circulates in its closed double-looped helical trajectory is shown in Figure 2. The quantum completes each trajectory cycle in 12.56 or 4π radians.

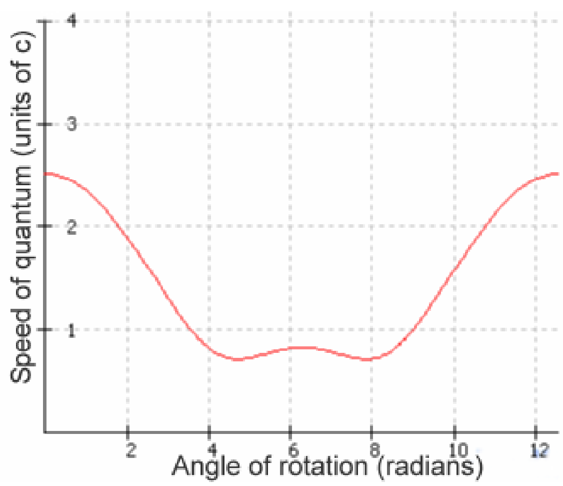

FIGURE 2. Speed of the transluminal energy quantum (TEQ) along its double-looped helical trajectory.

The circulating quantum spends approximately 57% of its time (measured in the electron model's rest frame) traveling superluminally along its trajectory and 43% of its time traveling subluminally. The quantum twice passes through the speed value *c* while completing one closed helical trajectory. This passage of the quantum from superluminal speeds through *c* to subluminal speeds and back again to superluminal speeds is not a problem from a relativistic perspective. This is because it is the point-like electric charge -*e* that is moving at these speeds and not the average center of mass/energy of the electron model, which remains at rest in the electron model's rest frame.

SIMILARITIES BETWEEN THE DIRAC EQUATION'S FREE ELECTRON SOLUTION AND THE TEQ MODEL OF THE ELECTRON

The TEQ model of the electron shares a number of quantitative and qualitative properties with the Dirac equation's electron with *zitterbewegung*:

1) The *zitterbewegung* internal frequency of $\omega_{zitt} = 2mc^2/\hbar = 2\omega_0$.

2) The *zitterbewegung* radius $R_0 = \frac{1}{2}\hbar/mc = R_{zitt}$. Using the equations (1) the rms values of x, y and z, which are the values of Δx, Δy and Δz in the Heisenberg uncertainty relation, are all calculated to be $R_0 = \hbar/2mc$, where R_0 is the radius of the closed helical axis of the superluminal electron model. This is the also value of the amplitude of the electron's jittery motion found by Schrödinger (1930). These rms results are predictions of the electron model, and are only obtained when the radius of the superluminal quantum's helix is $R_0\sqrt{2}$ as used in equation (1). This value $R_0\sqrt{2}$ is the helical radius required to give the electron model's z-component of its magnetic moment a magnitude equal to the Dirac equation's magnitude of one Bohr magneton μ_B.
3) The z*itterbewegung* speed-of-light result for the electron.
4) The prediction of the electron's antiparticle, having opposite helicity to the electron model's helicity.
5) The calculated spin of the electron.
6) The calculated Dirac magnetic moment of the electron $M_z = -\mu_B$. In the electron model, $M_x = 0$ and $M_y = -.25\mu_B$, which differs from the Dirac result.
7) The electron's motion is the sum of its center-of-mass motion and its *zitterbewegung.*
8) The non-conservation of linear momentum in the *zitterbewegung* of a free electron, a result first pointed out for the Dirac electron by de Broglie (1934).

THE HEISENBERG UNCERTAINTY PRINCIPLE AND THE TEQ ELECTRON

The TEQ electron is modeled as a helical photon-like object moving in a circle at the *zitterbewegung* angular frequency $\omega_{zitt} = 2mc^2/\hbar$ with a forward velocity *c* and Compton momentum $p_C = h/\lambda_C = mc$ (where λ_C is the Compton wavelength h/mc of the photon-like object composing the electron). This circle (see Figure 2) is the circular axis (of radius $R_{zitt} = \frac{1}{2}\hbar/mc$) of the electron model's helix. The rms values for position in the electron model in the x, y and z directions all give $R_{rms} = \frac{1}{2}\hbar/mc$ as mentioned earlier. Combining this rms position result with the calculated rms value $mc/\sqrt{2}$ for the circulating momentum *mc* gives:

$$\Delta x \Delta p_x = (\frac{1}{2}\hbar/mc)(\frac{1}{\sqrt{2}}\cdot mc) = .707\cdot\frac{1}{2}\hbar = .707\frac{h}{4\pi}\ , \tag{3}$$

$$\Delta y \Delta p_y = (\frac{1}{2}\hbar/mc)(\frac{1}{\sqrt{2}}\cdot mc) = .707\cdot\frac{1}{2}\hbar = .707\frac{h}{4\pi}\ . \tag{4}$$

Comparing this result with the Heisenberg uncertainty relations:

$$\Delta x \Delta p_x \geq \frac{h}{4\pi} \text{ and } \Delta y \Delta p_y \geq \frac{h}{4\pi} \tag{5}$$

we see that the relations in (3) and (4) for the TEQ electron model contain a value .707 times that in the Heisenberg uncertainty relation. These position/momentum relations for the electron model would therefore not be directly experimentally detectable in principle, according to the Heisenberg uncertainty relation.

TESTING THE TEQ ELECTRON MODEL

Recently Catillon et al (2008) provided experimental evidence supporting the existence of the zitterbewegung frequency in electrons. Any electron model containing the zitterbewegung frequency $2mc^2/h$ can therefore now be tested to determine how well it can predict the observed experimental results. The experiment observed electron channeling through a thin silicon crystal at incoming electron energies around 80 Mev. This energy range was chosen so that if the electron has an internal clock going at a particular frequency, then that frequency (either the de Broglie frequency mc^2/h or the zitterbewegung frequency $2mc^2/h$ could be synchronous with the rate that these relativistic electrons pass silicon atoms lined up due to the chosen crystal orientation. The experiment did find evidence for a resonance effect (a dip in the rate of electrons passing through the silicon crystal) near the electron incoming energy corresponding to the zitterbewegung frequency of the electron. Hestenes (2008) has shown that zitterbewegung models of the electron can be tested based on the amount of resonance scattering observed in such an experiment.

CONCLUSION

The electron is modeled as helically circulating point-like transluminal energy quantum (TEQ) having both particle-like (E and $\vec{P}$) and wave-like (ω and λ) characteristics. The number of quantitative and qualitative similarities between the Dirac electron with *zitterbewegung* and the proposed TEQ model of the electron is remarkable, given the TEQ's relatively simple mathematical form. This suggests that the TEQ concept for the electron may provide a useful physical model for the electron and perhaps for other elementary particles as well.

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