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Motion of particles at the fundamental level: NLHV theory predictions for a spiral gait locus

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Abstract

Context - The existing literature on particle motion at the fundamental level is sparse. Particles, whether classical or quantum, are assumed to move with a continuous (even if uncertain) velocity. **Purpose** - The work prospects for a descriptive theory of particle motion from a non-local hidden-variable (NLHV) perspective. This is worth attempting for the potential to better understand fundamental dynamics and kinematics. **Method -** The new physics provided by the cordus theory was used to infer the mathematical representation of the energisation behaviour of the inner structures, specifically the reactive ends. From this the motion function of the particle as a whole was determined. **Findings** - In three dimensional space the motion of each reactive end is an irregular spiral displacement locus. The motion comprises a movement phase and a brief immobile phase. This is called a 'gait' as it is reminiscent of biological locomotion. **Originality** - A novel theory of particle motion is offered. The theory predicts that motion comprises a complex spiral locus of the particle. This is unique among theories of physics. Further contributions are the provision of explanations for several physical phenomena: ponderomotive force, the nature of momentum, and bremsstrahlung radiation. Specifically, the theory explains why photon emission would be increasingly concentrated in the forward direction with increased electron energy. The theory provides a means to bridge quantum mechanics and special relativity, because it accommodates both particle uncertainty and field transmissions.

Keywords: fundamental physics; particle motion; new physics; NLHV theory; wave equation

1 Introduction

This paper addresses the ontological question of how particles move. The physical laws and mathematical descriptions for velocity and momentum are well-understood in physics and engineering, and not under debate here. However there is a lack of explanation of motion at the level of the fundamental particle. In classical mechanics the velocity of a particle corresponds to the rate at which its location moves along a spatial trajectory, and this motion is presumed to be continuous. The question of *how* the particle moves is therefore somewhat irrelevant when assuming a smooth space-time. It is simply taken for granted that motion exists and is smooth. The existing literature on particle motion at the fundamental level is sparse. There appears to have been a general assumption that particles, whether classical or quantum, move with a continuous (even if uncertain) velocity.

However, if space and time are discrete in some way, which is what quantum mechanics (QM) implies, then the question *does* become relevant. In quantum mechanics the location is intrinsically uncertain, being represented with a probability distribution. How that relates to motion along the locus is ambiguous. An explicit trajectory representation of this is provided by the de Broglie - Bohm pilot wave theory [1, 2], though that theory is not widely accepted and does not generalise to a broader theory of physics. The Dirac equation provides a wave equation with a relativistic component. It therefore includes both special relativity and quantum mechanics. The quantum Langevin equation provides a mathematical representation of the stochastic displacement and velocity behaviour of free Brownian particles in a thermal heat bath [3-5]. However neither provide an ontological explanation for motion. An additional complexity arises because particles also have a de Broglie frequency, and how this relates to motion is unclear. The fundamental physics literature is almost non-existent on the ontological question of how particles move.

Hence there is an unsolved problem in describing how particles move at a more fundamental level. While it is possible to mathematically represent the observed mechanics of *where* particles move, there is as yet no satisfactory explanation of *how* this behaviour arises. Examples of these foundational questions are: How does force cause velocity to change? Why is the product of velocity and mass (momentum) conserved? What are the deeper reasons for the laws concerning motion to have the forms they do?

The purpose of the current work was to prospect for a descriptive theory of particle motion, from a non-local hidden-variable perspective. This is worth attempting for the potential to better understand fundamental dynamics and kinematics. The approach uses the new physics provided by the cordus non-local hidden-variable (NLHV) theory [6]. The results predict that particle motion comprises a movement phase and a brief immobile phase. This is called a 'gait' as it is reminiscent of biological locomotion.

2 Method

2.1 Overall approach

A new approach was taken based on hidden variable theory, rather than using classical continuum mechanics, quantum mechanics, or string theory. Specifically, a theory-building approach was taken, starting with the existing cordus NLHV theory. As a hidden variable theory, this proposes that fundamental particles have physical substructures, and the observable properties of the particle arise from these substructures. The identity of these substructures has been inferred by consideration of known phenomena [7]. The theory-building approach used to construct the cordus theory generally was to apply abductive reasoning. This started with empirical established phenomena (the double-slit device was the original starting point), and then sought explanations that met three main principles: economical in the number of hidden variables proposed (parsimonious); sufficient to qualitatively explain the phenomenon; and consistent with other published parts of the theory. More description of the general method may be found in [8].

2.2 Context

The cordus theory proposes that particles are two-ended string-like structures, with substructures of reactive ends, fibril, and discrete forces. The numbers and types of discrete forces determine particle identity (electron, proton, etc.). The de Broglie frequency for the particle corresponds to the alternate energisation of the two reactive ends, and this is important in what follows.

The structure of the electron is shown in Figure 1 by way of an example. Further details about the structure and behaviour of particles under this theory are provided in the references below.

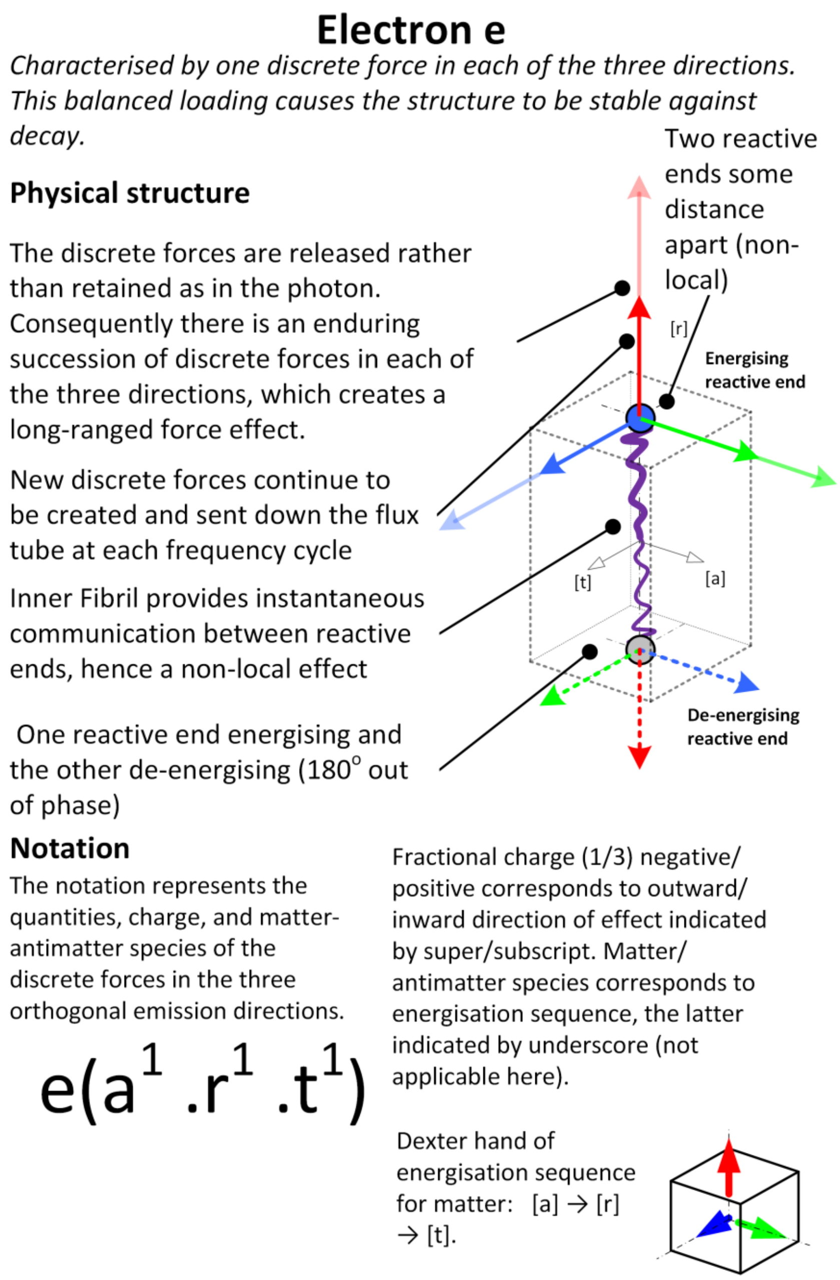


Figure 1: The representation of the electron's internal and external structures. It is proposed that the particle has three orthogonal discrete forces, energised in turn at each reactive end. Adapted from [9].

These are radical elements, and each of them has been elaborated and tested in other papers. The theory may seem unorthodox compared to QM, but has been shown to have wide applicability, see Table 1. It also explains several phenomena that otherwise have no explanation in conventional mechanics or quantum mechanics. The theory is compatible with quantum mechanics (which becomes a stochastic simplification of a deeper and more deterministic mechanics), general relativity (but introduces a new parameter called the fabric density of space), and string theory (both propose open string-like structures, and the number of parameters required to define a cordus particle is the same as some versions of string theory). However the theory does not trace its origin to any of those theories, but is instead an emergent designed solution, where the substructures were determined by logical consideration of what hidden structures a particle would need, for it to behave in the way that is observed (requisite variability).

Table 1: Applications of the cordus theory. Adapted from [10] and [11].

Phenomenon explained	**Key concept**	**Reference**
Wave-particle duality in the double slit device	One reactive end passes through each slit.	[7]
Derivation of optical laws from a particle perspective	Includes derivation of reflection and refraction laws, and Brewster's Angle from particle basis.	[7]
Prediction of particle structures	Electron, proton, neutron, neutrino species, photon	[9] [12] [13] [14] [15]
Explanation of the decay processes and prediction of a deeper decay model	Dependency identified on neutrino species loading	[13, 14]
Explanation for the selective spin characteristics of neutrinos whereby the direction of spin is correlated with the matter-antimatter species	Spin direction arises from reaction between incomplete discrete force emissions from the particle, and the background fabric.	[14]
Explanation for particle spin and derivation of the electron g factor g=2	Cordus particle structure naturally causes g=2	[10]
Explanation for the annihilation process	Description of the discrete force changes involved in remanufacture of these particle identities. Includes a conceptual explanation of the difference between otho- and para-positronium decay rates (ortho and para refer to spin combinations of the bound electron and anti-electron/positron).	[16]
Provision of a mechanics for pair production	Rearrangement of discrete forces changes the particle identity.	[17]
Explanation of process of photon emission	Excess energy in the electron changes its span, which is opposed by bonding constraints.	[18, 19]
Synchronous interaction	Synchronous interaction between discrete forces of different matter particles causes the strong nuclear force	[20]
Predicted structure of atomic nuclei and explanation of stability for nuclides H to Ne	Protons and neutrons are arranged in a nuclear polymer. The rules for this arrangement, and for the bridge neutrons, are inferred and are qualitatively consistent with observed stability/instability/non-existence of all nuclides in this range.	[21, 22]
Prediction of a mechanism for asymmetrical baryogenesis	Predicts a decay path for remanufacture of the antielectron to the proton. This also solves the asymmetrical leptogenesis problem.	[12]
Origin of entropy	Fabric increases the Irreversibility of geometric position of particle.	[23]

A theory for time as an emergent property of matter rather than a universal attribute	Time arises from the interaction between the frequency of a particle and the local density of the fabric.	[24]
Nature of the vacuum and the cosmological horizon	Vacuum comprises fabric of discrete forces from massy particles.	[25]
Origin of the finite speed of light	Determined by fabric density, hence variable with epoch of universe and local distribution of mass.	[26]
Quantitative derivation of the relativistic Doppler and the Lorentz factor	Derivation accomplished from a particle perspective. Identifies fabric density as a covert variable.	[6]
A mechanism for how a particle detects and moves in a field gradient	'The operation of force is proposed to occur from the interaction between the energisation sequence of the particle, with the field gradient, resulting in discrete displacement motions of the particle. Specifically the particle sub-structures sweep through a volume of space during their energisation cycle. This locus is warped by the incoming field, hence preferentially displacing the particle along the gradient.'	[11]
Unification of fundamental interactions	'All the interactions can be attributed to the discrete force emissions from the particle, more specifically from the different attributes thereof. Thus the electrostatic appears to arise from the direct linear effect of the discrete forces; magnetic from bending of the flux tube; gravitation from handed energisation sequence; strong from the synchronisation of emissions; and weak from rearrangement of discrete force emissions hence remanufacturing of particle identity.'	[8]

2.3 Approach to the motion problem

In the present work, the theory-building used the same logical considerations to infer a mechanism for how a particle would assuming the general assumptions of the cordus theory were valid. The literature is exceedingly sparse on how a particle might move at the deeper level, so no specific insights were gained from that direction. Rather, the conceptual initiator arose from [8, 11] which propose mechanisms for how force operates at a fundamental level. The connection between force and motion might not be an obvious one, but the useful starting point was the observation that theoretical prediction that force was an emergent effect for a deeper process of displacement of the reactive ends [8], i.e. that displacement was the primary effect. Acting on this theory, and extending it on logical grounds, lead to the theory presented here. Implications for motion were drawn from the force theory, and elaborated into lemmas (indicated §). Then these were applied to develop a theory for motion. Finally, the theory was tested for how it explains other phenomena.

In this context a lemma is a theorised principle, in the form of a proposition. They are not necessarily proven but rather are tentatively accepted as correct, and then used as subsidiary propositions for the further development of the theory. Lemmas are used throughout the construction of the cordus theory. There is an expectation that lemmas in one part of the theory will not contradict those in other parts. So far this has been preserved. Hence the lemmas provide the logical consistency across the theory. Confidence in the lemmas arises to the extent that the resulting theory gives satisfactory explanations of other known phenomena. Hence the application to other areas as shown in the latter part of the results.

3 Results

3.1 Mathematical representation of motion parameters

Consider a text particle, e.g. an electron. Per the cordus theory, it has two reactive ends, and these take alternate turns to energise. At energisation, the reactive end makes a discrete field emission. The following premises are used to develop a theory for motion under this NLHV architecture.

Lemma §1: Potential energy of discrete field emissions has a $\boldsymbol{sin^2(\theta/2)}$ function

In this theory fractional charge (which corresponds to colour charge in QM), is represented by an emission in one [i] of the three directions $[a, r, t,]$, see [8, 11]. Hence an electron with a total charge of 1 has fractional charge energisation in all three directions, and this is represented as $e[a^1, r^1, t^1]$. The discrete force, or more specifically its potential energy U, varies between 0 and 1 over a full cycle. The shape function for this is $sin^2\theta_i/2$ [8, 11]. For the individual axes, the shape functions are offset at thirds of the phase angle θ, and expressed as:

$$U_i = Q\ sin^2\frac{\theta_i}{2} \qquad (1)$$

For [a] component: $\theta_i = \theta\ S_p$ (2)

For [r] component: $\theta_i = \left(\frac{\theta}{2} + \frac{1\pi}{3}\right) S_p$

For [t] component: $\theta_i = \left(\frac{\theta}{2} + \frac{2\pi}{3}\right) S_p$

Where
Q is magnitude, assumed unity for simplicity
S_p is matter / antimatter species, represented as 1 or -1 respectively (sign convention).

Implications - Even during the sinusoidal null emissions in one axis, the other axes are populated. The flux tube represents the aggregation of the discrete forces. Consequently there are no breaks in the flux tube, which supports an assumption made in the relativistic Doppler part of the theory [6].

Lemma §2: Ability for reactive end to move is complementary to energisation
The mobility of reactive ends is assumed to be related to their degree of de-energisation. This is a key assumption in this part of the theory. A reactive end is assumed to be immobile at the phase of maximum energisation (which corresponds to maximal emission strength of discrete forces), and is maximally mobile when de-energised. The mobility of the reactive end to move is complementary to its emission state. Hence for potential energy $U_i = Q\ sin^2\frac{\theta_i}{2}$, the Mobility $M_i$is:

$$M_i = cos^2\frac{\theta_i}{2} \tag{3}$$

and takes values ranging from 0 to 1.

Lemma §3: The reactive end moves in a circular orbital motion around its mean position
The mobility is important for reasons relating to *mobility* and external *perturbation.* First, it leads to the conclusion that the reactive end of a stationary fundamental particle moves in a circular locus around its mean centre. This orbital motion arises because the vector sum of the mobility in the three directions [a,r,t], results in a circular orbit. We propose that this motion is causal to the emission of the discrete forces U_i. This has the consequence that the vector normal to the orbital plane is the same as the mathematical representation of the discrete force emission. Hence, for an electron with discrete forces $e[a^1, r^1, t^1]$ the normal to the orbital is [1,1,1] in the [a,r,t] directions. The corollary is that there is a correspondence between particle identity, which is represented by discrete force emission portfolio [12], and the orbital motion of the reactive end. This correspondence further implies that an emission in say the [a] direction corresponds to an orbit in the [r,t] plane.

The position of the reactive end in its orbit is given by:

$$RE_i = R_{RE} \cos(\theta_i)\ C_h \tag{4}$$

where

R_{RE} is the orbital radius, being a small unknown value,

θ_i is per Eqn 2.

C_h is sign of charge and takes the values 1 or -1 for negative or positive charge respectively (cordus sign convention).

The second outcome is that the mobility also represents the susceptibility of the reactive end to external perturbation. This occurs via incremental distortion of the orbit, under a field or acceleration [11]. This displacement is not constant through the energisation cycle, because of the phase dependency on the mobility. For the case of gravitation, this has been shown to eventuate as a distorted spiral locus, see [11]. A formulism for displacement follows later.

Lemma §4: Continuity of motion is stored as shear in the fibril

A body that is in motion will continue with that motion unless acted on by an external force (Newton's law). However at a fundamental level it is odd that a body, once it has been put in motion, should continue that motion indefinitely. What preserves velocity? This lemma represents the proposition that the continuity of motion is stored as shear in the fibril itself. The fibril is that substructure that connects the two reactive ends. It is proposed that once this internal shear is created, by an initial external interaction, it is preserved, and the particle continues with that velocity. At this point the physical nature of this shear is not elucidated – we merely propose its existence and show its implications for motion.

Specifically, the process is anticipated as follows.

(1) Initial acceleration of the particle arises by external discrete forces causing the reactive end to shift its energisation location in a translational displacement.

(2) This requires a change in energisation timing for the reactive end, hence a change in frequency of the fibril. This also changes the span of the fibril, since frequency and span are inversely proportional. It may be necessary for the particle to emit excess energy, hence bremsstrahlung (see below).

(3) The translational displacement of the reactive end, as set up by the external acceleration force, is stored in the fibril. We hypothesise it is stored as a type of shear force.

(4) This shear is applied continuously to both reactive ends, which respond to it to the extent that they can, i.e. to the extent that they are *not* responding to external discrete forces (when they are de-energised). As the emissions of the two reactive ends are complementary, this means that there is no moment when the shear is ineffective in moving one or other of the reactive ends forward.

(5) The amount of internal shear can be added to or reduced by further external interactions at the reactive ends. Hence the store of velocity is accumulated or reduced as the particle experiences various episodes of acceleration.

(6) A shear component may also be created in the roll direction of motion (with respect to the fibril span), and this is proposed to correspond to circular polarisation.

Acceleration is the process of establishing this shear, by initially prescribing the translational displacement of the reactive ends. At each subsequent energisation cycle this shear is preserved, even after the accelerating force is removed. The shear is zero for stationary particles. A formulism for shear is given below.

Lemma §5: Displaced motion of reactive depends on mobility and shear

The orbital positional coordinates of the reactive end $[RE_a, RE_r, RE_t]$ have an added translational motion due to the velocity shear, and this is called the displacement. This is a deviation away from the circular orbit of the reactive end.

The displacement s_i of the reactive end in each of the three axes is determined from the integral of the mobility, with the product of the shear τ, hence:

$$s_i = \tau \int \cos^2 \frac{\theta_i}{2} d\theta = \tau(\frac{\theta_i}{2} + \frac{1}{2} sin\theta_i) \qquad (5)$$

The motion displacement for a nominal shear is shown for the three axes, in Figure 2.

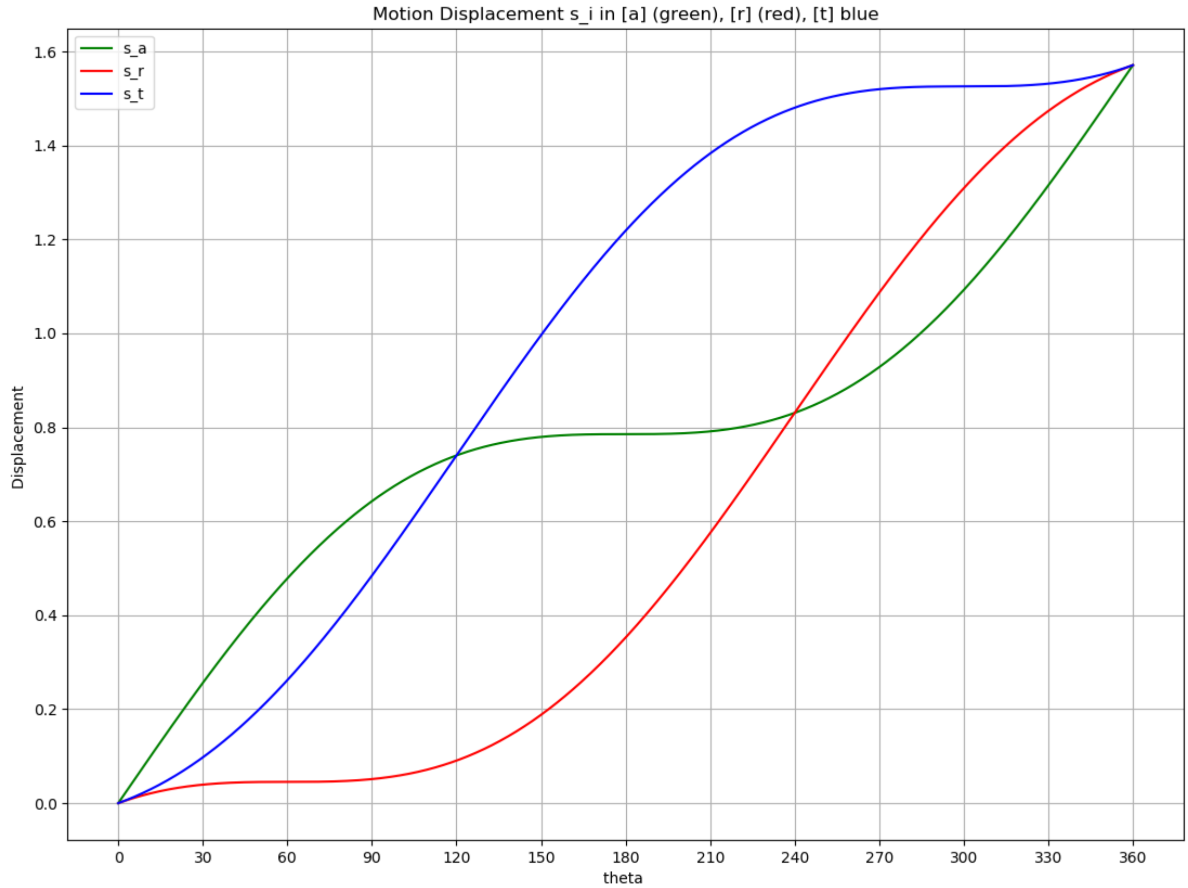


Figure 2: Motion displacement shear $\tau = 0.5$ for the three axes, for an electron. The total displacement per cycle is $P_a = \tau\pi$.

Consider linear motion in the [a] direction. The integral of s_a from Eqn 4, over one energisation cycle of 2π gives the total distance S_a moved by the particle in one cycle:

$$S_a = \tau\pi \tag{6}$$

This may also be expressed as

$$S_a = v/f \tag{7}$$

where v is the magnitude of the mean particle velocity, and f is its frequency. Hence

$$\tau = v/(\pi f) \tag{8}$$

Thus the fibril shear is proportional to the velocity and inversely proportional to the frequency (or energy).

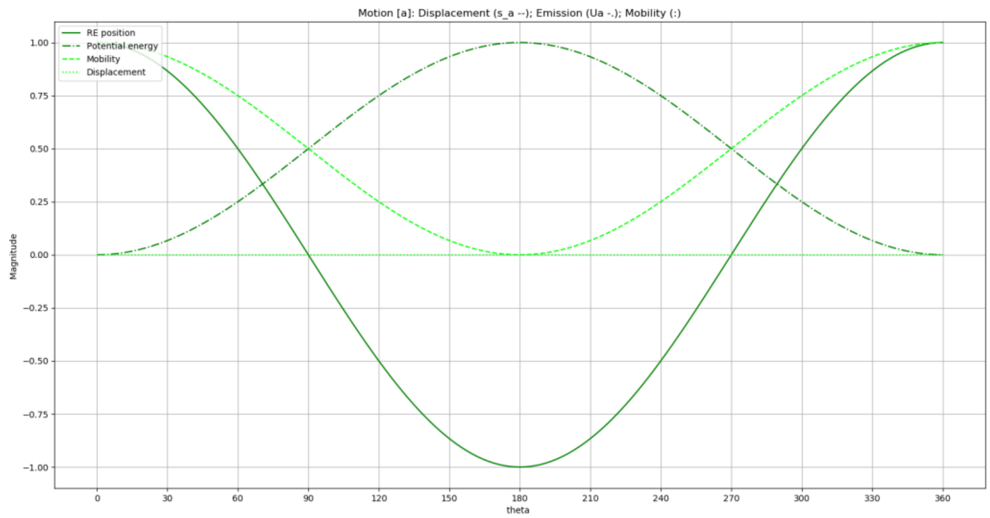
The frequency for the electron of 511 keV, per the relativistic formulation [27] is $\omega = 7.81E20\ s^{-1}$, hence the period is 8.04505E-21s, and the frequency is 1.24E+20 Hz. With a velocity 0.1 c, the shear per Eqn 8 is

$$\tau = \frac{v}{\pi f} = 7.68x10^{-14}\frac{m}{cycle} \tag{8b}$$

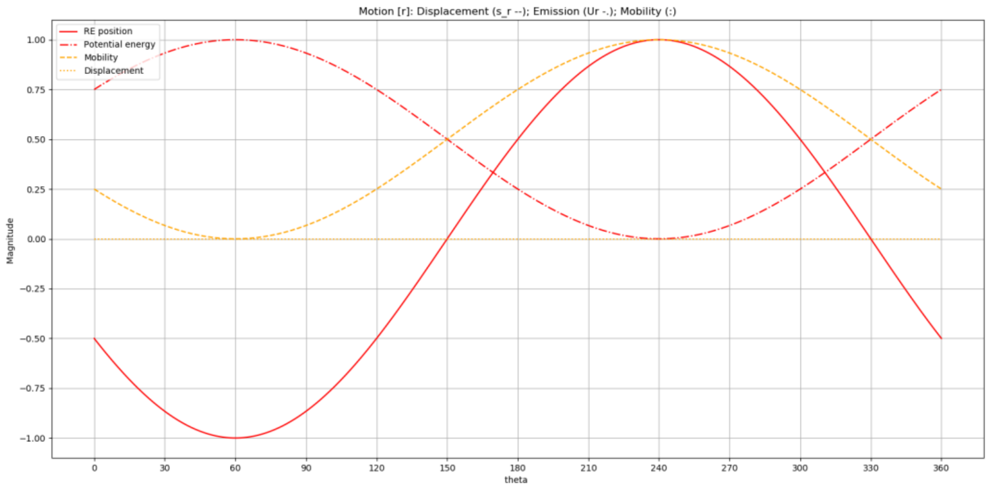
In what follows, much larger values are used, e.g. $\tau = 0.5$, for illustrative purposes.

3.2 Motion parameters

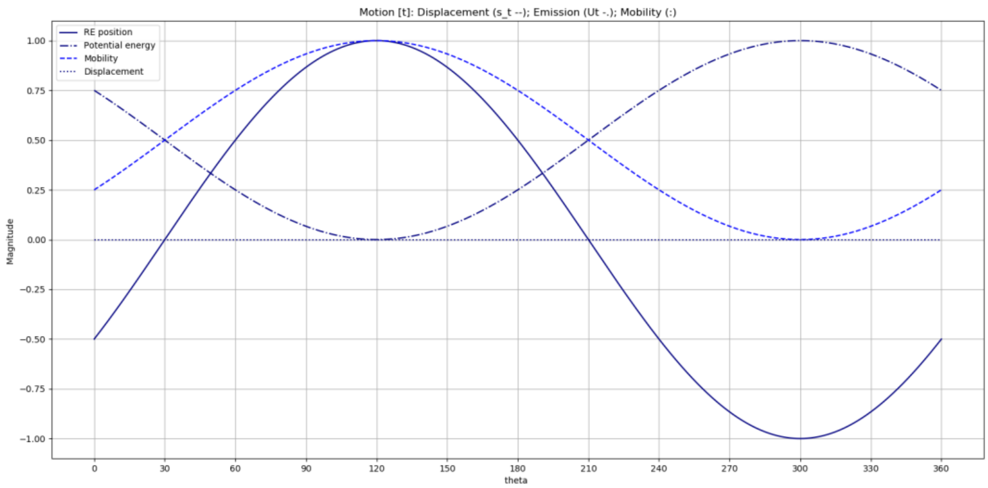
Hence for each of the directional axes [a], [r], and [t] there are a set of parameters that define the motion state: potential energy of the emissions in that direction U_i; mobility; position of the reactive end in its orbit (for a stationary particle); and motion displacement during the cycle s_i which is in response to the velocity shear τ. These parameters are shown in Figure 3, for $\tau = 0.5$.



(a) Motion parameters of the reactive end in the [a] direction.



(b) Motion parameters of the reactive end in the [r] direction.



(c) Motion parameters of the reactive end in the [t] direction.

Figure 3(a-c): Motion parameters of the reactive end in the [a], [r], and [t] directions, as a function of energisation, for an electron with $\tau = 0.5$.

The displacement parameter s_i is of the greatest interest since it describes the deviated locus of the reactive end, and hence the motion of the particle over multiple cycles. Note that it is an incremental motion, characterised by having a stationary or dwell period.

3.3 Motion in one direction

An interesting effect is observed when examining the emissions in one axis, say [a], as a function of location. There are several aspects to this, as follow.

3.3.1 Compressed pulse of emissions – the discrete force

Both the strength of the emissions U_a and the displaced position of the reactive end s_a depend on the phase angle, but differently. Consequently if emissions are plotted against the displacement, then a localised effect is apparent, see Figure 4. The emissions strengthen rapidly while the displacement stalls, creating a peak.

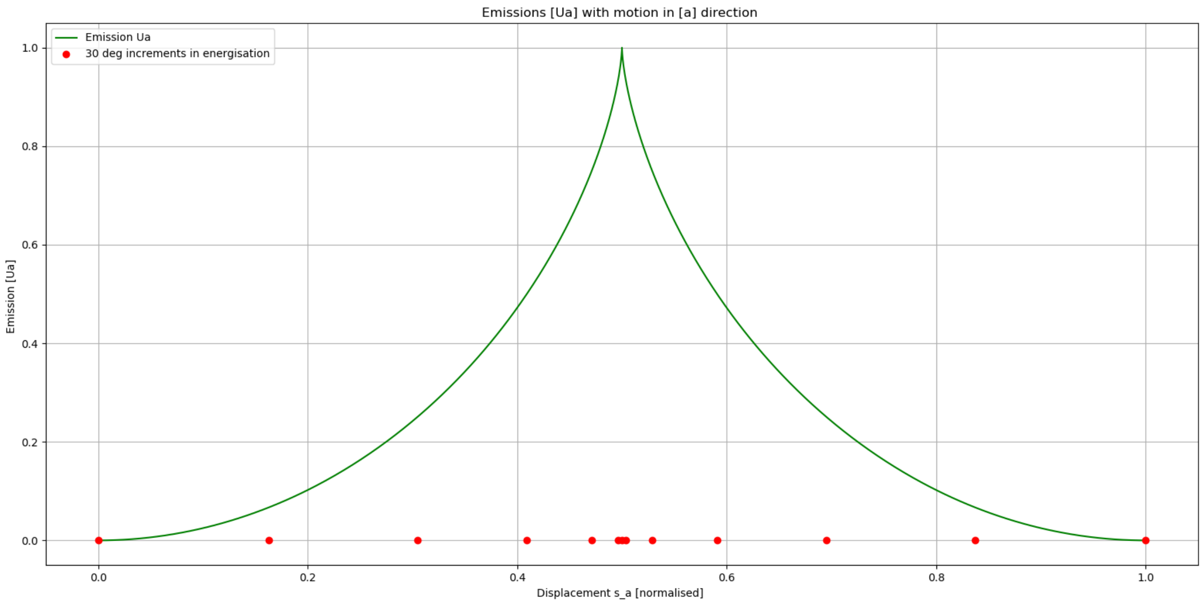


Figure 4: Emissions in [a] as a function of displacement in the same direction. Displacement has been normalised by dividing by $P_a = \tau\pi$. Red dots indicate sample locations of the reactive end, and show how it initially moves quickly, slows to a momentary stop, and then quickens its displacement again.

The result is the emissions are compressed into a pulse during motion, at least when one axis is considered. This confirms and expands on the idea in the early works of the theory, where the emissions were premised to comprise a 'discrete force' travelling in a flux tube [6]. Depending on which functionality one wishes to emphasise, the emissions can be thought of as either smooth or discrete. Parts of the theory that use the smooth emission concept are the theory for the relativistic Doppler [6], whereas the discrete concept is apparent in the explanation for asymmetrical baryogenesis [12] and the remanufacture of particle identity more generally (decay) [14, 28]. Either perspective is suitable for the synchronous (strong) interaction [20] and the explanation of nuclear structure [21, 22]. Note that the pulse effect depends on the energisation phase θ, and also the velocity, though this is not apparent in the figure as the data have been normalised.

3.3.2 Gait locomotion of two reactive ends

Up to here all the analysis has been on one reactive end only. An interesting observation is obtained when examining both reactive ends, see Figure 5. This shows that the one reactive end quickly advances while the other is tending towards being stationary. As the fibril connects the reactive ends, it means that the fibril itself takes oblique angles during the motion. As the energisation alternates, so each reactive end in turn has an opportunity to move forward. An equivalent explanation is that the particle moves by partially tunnelling its de-energised reactive end forward at each energisation cycle. This is consistent with another part of the theory that explained the operation of interferometer partial mirrors [29]. As the reactive end moves, it drags the fibril with it, hence causing yaw on the fibril, and a zig-zag motion of the particle.

Thus velocity, in this interpretation, is discrete translational displacement per frequency cycle. In contrast classic physics tends to see velocity as a continuous motion, and quantum theory sees it as an intrinsic (or mathematical) property of the particle, and also implies it is continuous (albeit uncertain).

We refer to this motion as *gait,* as it is similar to the bipedal gait of human locomotion, where one foot is fixed to the ground while the other does the toe off, swing-through, and heel strike. Conceptually there need be no issue with the idea that a gait locomotion can result in an overall velocity that is approximately continuous.

Note that the emissions of the two reactive ends (A and B) are complementary. The potential energy in the emissions of A are of the form $UA_r = \sin^2(\theta/2)$ while those at the B reactive end are $UB_r = \cos^2(\theta/2)$ and this sums to unity.

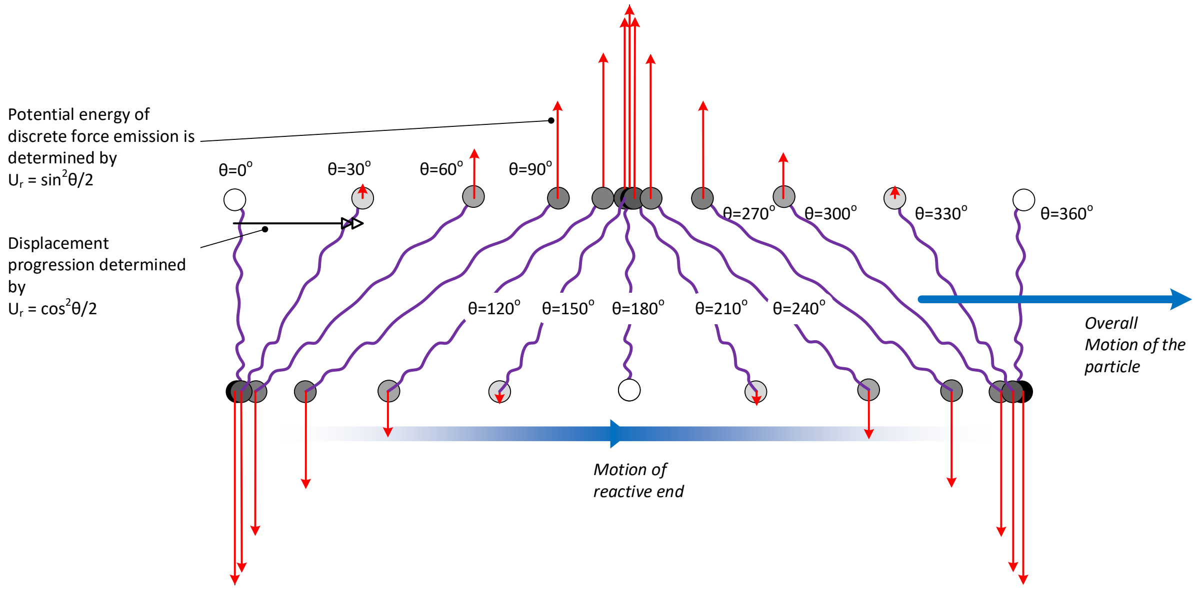


Figure 5: Energisation phase determines the potential energy of a reactive end and also its displacement progression, resulting in a pulse of emissions.

3.3.3 Regression of the flux tube

As the particle moves forward the discrete force emissions propagate out into space at the local speed of light, over a spherical front. Over one gait cycle the particle itself moves forward a distance S_a. Meanwhile the discrete forces have moved radially outward to a distance of c/f where c is the speed of light. Consequently the locus of the flux tube trails (regresses) behind the particle. This is similar to the light cone concept in relativity. On average this angle is given by

$$\beta = \tan^{-1} v/c \qquad (9)$$

where β is measured from the normal to the velocity. Hence for a stationary particle $\beta = 0^o$ and for one travelling at the speed of light $\beta = 90^o$. However since the motion of the particle is non-uniform, the location from which the emission occurs needs to be taken into account. The result is a bent locus of the emitted field, see Figure 6 (dashed line).

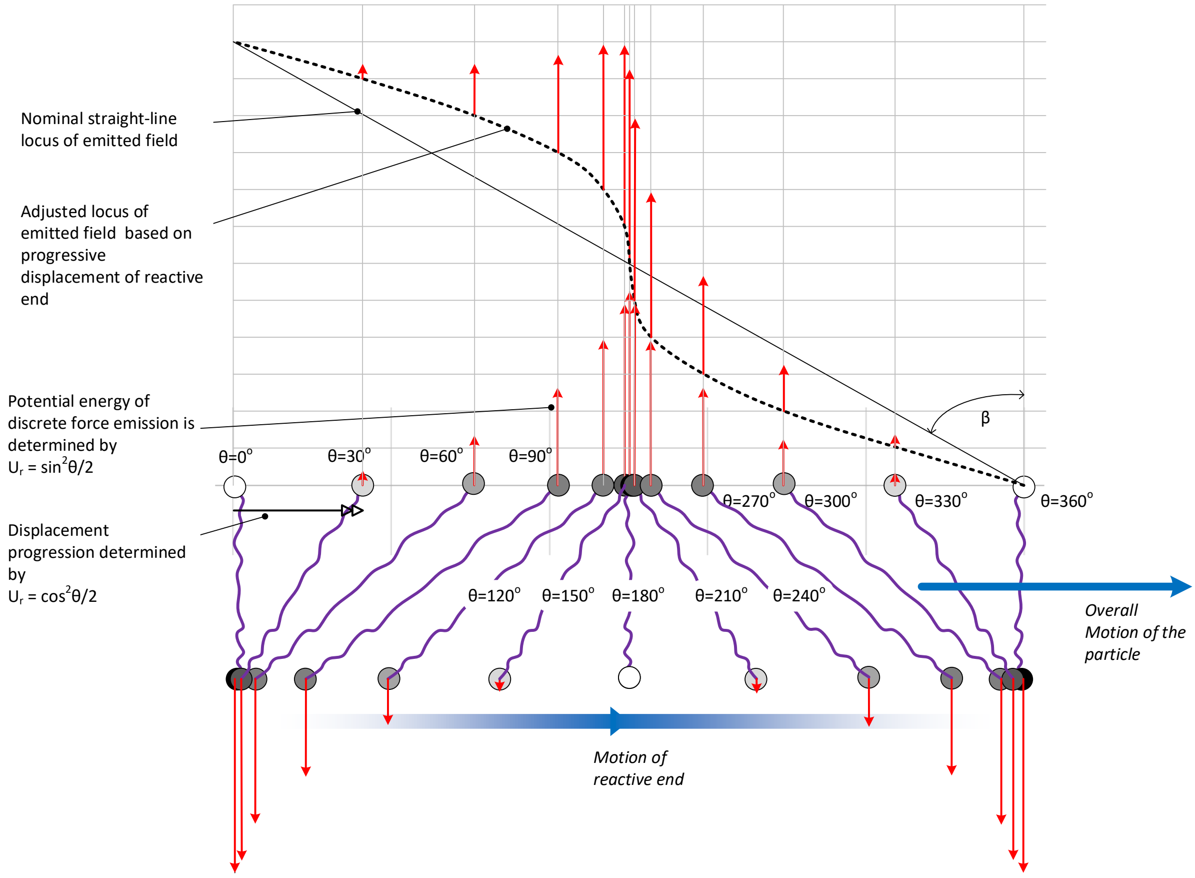


Figure 6: Locus of emitted discrete field in the radial (r) direction.

Thus the flux tube for a moving particle trails the motion with an average orientation angle determined by its velocity and the local speed of light (which in turn is affected by the fabric density Ø, but with many small jogs corresponding to the phase where the energised reactive end stalls in its forward motion. This is consistent with the magnetism part of the theory, where the interaction is proposed to be communicated to remote moving particles by this distortion of the flux tube, see [11]. This variability of potential energy U_a is propagated out into space with the flux tube. Thus a remote particle will receive a compressed pulse of electrostatic field, with the jogs in the flux tube conveying information about the motion of the basal particle (magnetism). The three phases of the emissions $[U_a, U_r, U_t]$ convey the gravitational information [8].

3.4 Orbit motion of reactive end during translational motion

For each of the directional axes [a], [r], and [t] there are a set of parameters that define the motion state: potential energy of the emissions in that direction U_i; mobility; position of the reactive end in its orbit (for a stationary particle); and motion displacement during the cycle s_i which is in response to the velocity shear τ.

At the end of the energisation cycles the motion displacement s_i does not undo the effect (as occurs with the orbital), but instead accumulates. Thus over multiple cycles the displacement accumulates, see Figure 7.

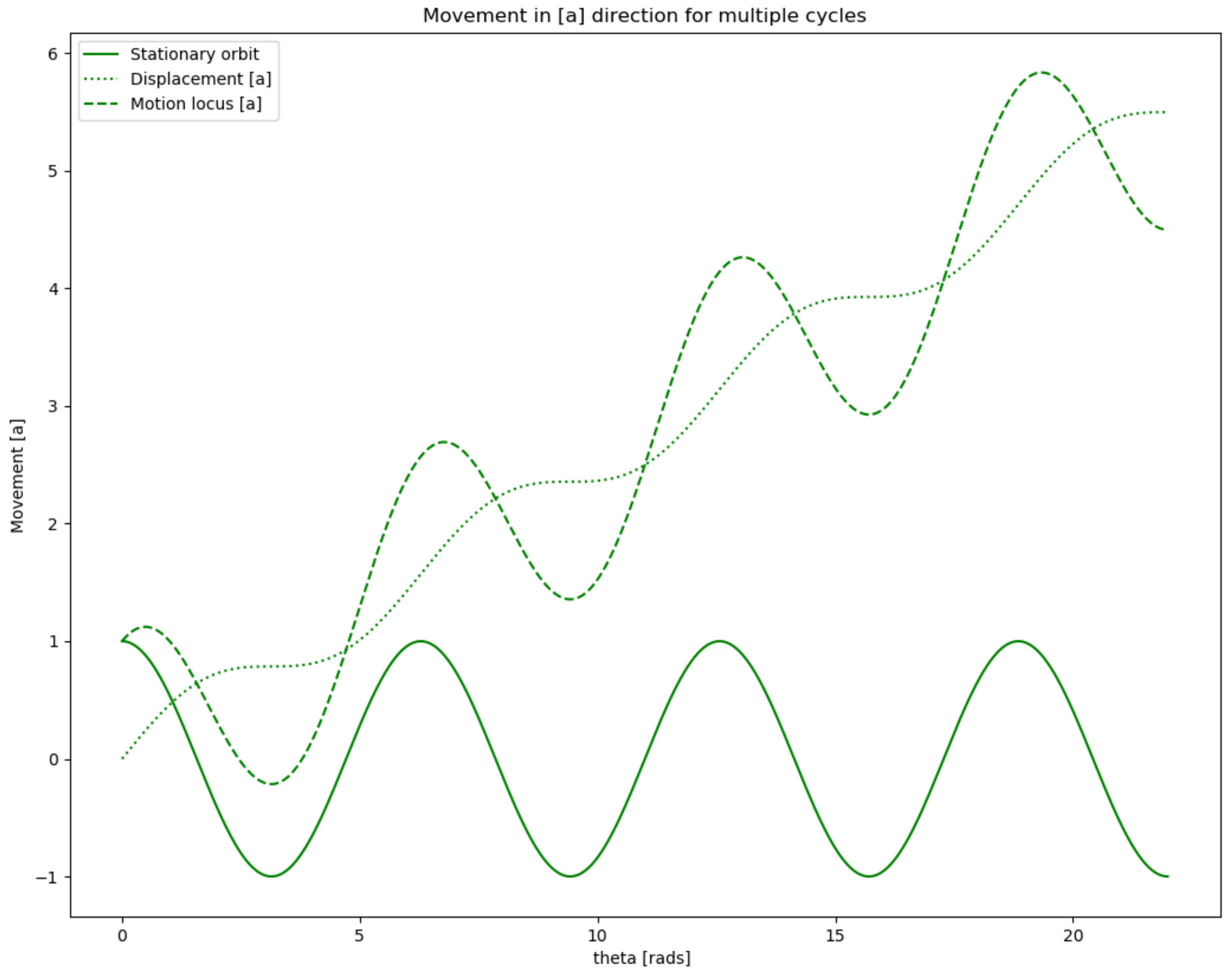


Figure 7: Cumulative displacement in the [a] direction over multiple energisation cycles, for an electron with $\tau = 0.5$ *and* $R_{RE} = 1$.

Motion in the [a] direction corresponds to no change in the orbital positions in the [r] and [t] directions, and the overall effect is a spiral motion of the reactive end, see Figure 8. This is not a smooth helix, because of the aforementioned dwell part way through.

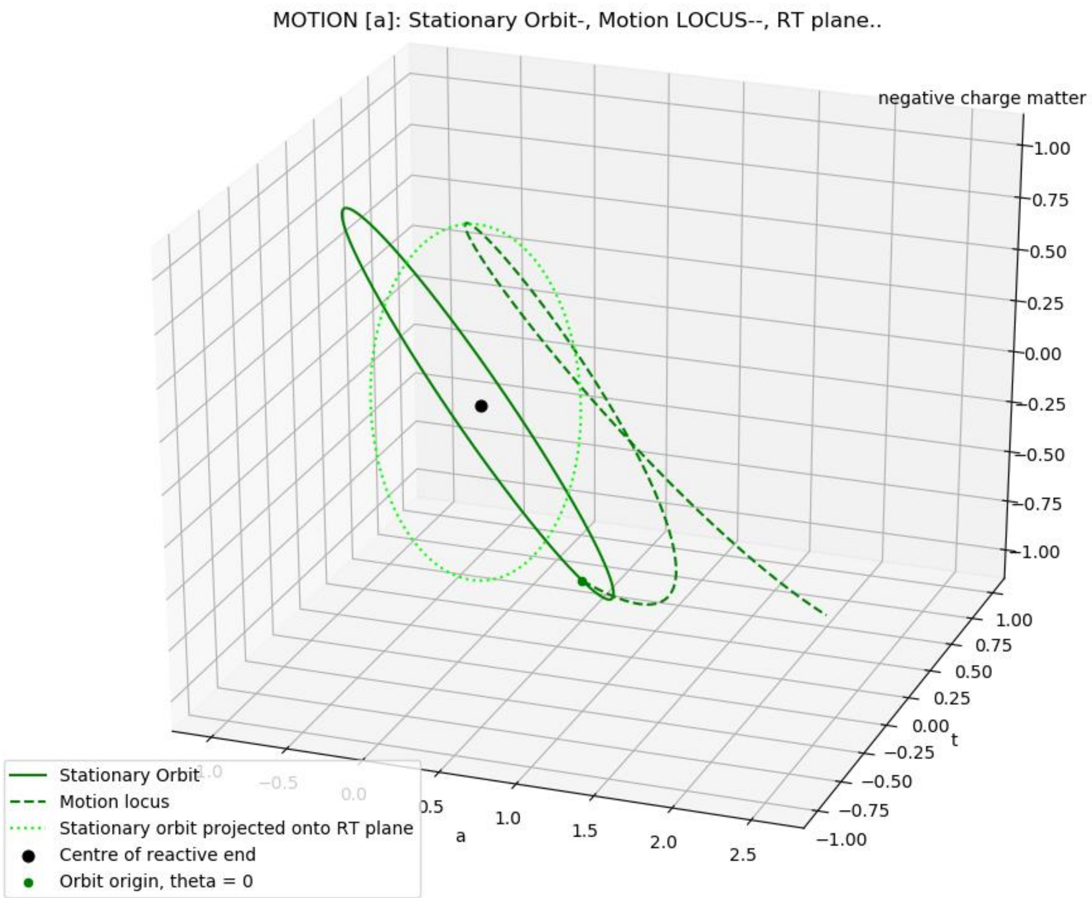


Figure 8: Motion of the reactive end over one energisation cycle, showing the spiral nature of the movement, for an electron with $\tau = 0.5$ and $R_{RE} = 1$. Vertical axis is [r]. Note that the helix angle is not constant, but rather is a periodic variable.

The idea of the reactive end moving in a circular orbit goes some way to providing a physical explanation for particle frequency. A key principle in QM is that of particles having a relationship between frequency & energy ($E = hf$), and wavelength & momentum ($p = h/\lambda$), hence wave particle duality. Within QM there are two different formalisms for frequency, based on relativistic and Schrödinger nonrelativistic considerations. The relativistic one is believed to be more accurate [27]. The frequency of the electron for the relativistic version is $\omega = 7.81E20\ s^{-1}$, hence the duration of one cycle is 8.04505E-21s. However there is no physical description for frequency within QM, which is understandable since QM assumes 0D point particles. The present theory provides an explicit representation for frequency as the periodic energisation of the reactive ends, and the concurrent circular motion of the reactive end.

3.5 A note on time

The analysis has been with energisation as the variable, rather than time. Degree of energisation θ is the proxy for time. The reasons for this are somewhat complex because the theory integrates both the relativistic and quantum concepts of time, as follows.

In this theory time at the macroscopic scale is an emergent property of matter [24]. Specifically time arises from the energisation sequence of particles. It is emergent because particles emit discrete fields as part of their energisation, and hence an observer will experience a fabric of discrete forces from the surrounding spatial distribution of matter. In turn this fabric affects the macroscopic passage of time, by obstructing the emissions of the particles in the observer's own timepiece whether that be a mechanical, biological, atomic, or any other type of clock. Thus time dilation occurs in regions of higher fabric density Ø, or higher gravitational field [24] [6].

This raises a deeper question: What determines the frequency of the particle? As one critic of this theory observed, 'time cannot be defined as oscillation frequency of a particule, because frequency itself requires time' [30]. However we believe the answer is that the frequency is intrinsic to the type of particle, and is traced back to leptogenesis [12]. Hence an electron with discrete force structure of $e[a^1, r^1, t^1]$ will always have the same rest mass and frequency when measured in the situation of Earth, irrespective of what locus through space and other fabric densities that electron took to get here. In non-Earth situations where the fabric density is different, the frequency of the electron is expected to change [6]. However this will not be detectable from within the same situation, because all the particles in that situation will be likewise affected.

Hence at the particle level it is useful to ignore the effect of fabric density and instead consider the energisation sequence as the origin of time. The theory does not extend to describe the mechanism that regulates the energisation. At the macroscopic level of general relativity, the precise energisation details are less important than the malleability of particle frequency when subject to different fabric density, hence time dilation. At this level the single direction of time becomes apparent, due to entropic interactions between particles [23]. Also, at this level time can be approximated as a continuous phenomenon, as opposed to a discrete one. While the behaviour within a particle is coherent, at a macroscopic scale time is more obviously represented by the relatively slow non-coherent molecular interactions such as mechanical and physiological processes. There is no conceptual difficulty accommodating personal cognitive time and the simultaneity of interactions with other people in this model.

3.6 Application of the theory to other motion phenomena

3.6.1 Ponderomotive force

The ponderomotive force moves a charged particle –of either sign- towards the weak field area when exposed to an inhomogeneous oscillating electromagnetic field. The mathematical derivation is well-established. The physical explanation per the current theory is that the orbital motion of the reactive end always has a component in the direction of the gradient of the external field, i.e. the reactive end moves up-gradient and down at each orbit. In this way the reactive end is able to sample the gradient of the external field [11]. The oscillating external field is neutral in its effect but its existence causes the reactive end to have more difficulty expressing its own discrete forces. This difficulty is greater at that part of the orbit experiencing the stronger field, e.g. closer to the source. Hence the reactive end favours that part of the orbit where it experiences less external harassment, and moves in the direction of weaker field. Thus the particle moves towards the weak field region.

The bending of light in a gravitational field could be considered an inverse ponderomotive force. The explanation is as above, except the photon has the oscillating field [15] and it experiences more resistance to motion in regions of higher external field gradient (or higher fabric density).

3.6.2 Linear momentum

As shown above, this theory offers an explanation for a body continuing with velocity until acted on by an external force (Newton's law). However it is not immediately obvious –from an ontological perspective- why momentum should be the product of velocity and mass, and why this should be conserved. Derivation of the classical momentum equation from Newton's 3rd law for a collision is based on the two bodies experiencing the same impulse, i.e. the product of reaction force and time duration. The theory provides a physical explanation of this at the particle level.

Consider two cordus particles in a collision. Call the moving one the protagonist, and the stationary one the antagonist. We propose that momentum may be understood as the force response that an antagonist particle must make if it is to arrest the motion of the protagonist particle. The protagonist particle has a pulse of force emissions (see above) over a period of time (one frequency cycle). The antagonist particle is subject to all of this (namely $\int Udt$), and must deal with it. The faster the protagonist moves the shorter the available interaction time and hence the antagonist has to mount a proportionally greater force response. Also, the emissions of the protagonist are increased by having more discrete forces, which relates to mass. In this theory, particle identity, and therefore also rest mass, is determined by the portfolio of discrete forces emitted by a particle [12, 31]. The more numerous these emissions the greater the mass. Hence both velocity and mass are included in the momentum formulation.

The explanation for why momentum is the product, rather than some other function of velocity and mass, is that the velocity of a particle arises from the fibril shear and its mass by the number of discrete forces, and there is no co-dependency between these variables. Both contribute in linear proportion to the momentum.

3.6.3 Mass and momentum of the photon

What about the momentum of the photon? The question relates to how a particle without mass also has momentum. This phenomenon may be explained in the cordus theory by noting that the photon emits discrete forces differently to massy particles: it emits only one discrete force (not a set of three), it emits and then withdraws its discrete force (rather than let it propagate further out into space), and while one reactive end emits the other withdraws (oscillatory reactive end behaviour) [29]. The absence of a mass property therefore arises because the photon's discrete force lacks the (a,r,t) energisation sequence, hence lacks the handed torsional effect that is necessary for mass and gravitation [11].

The apparent mass effect arises because when a photon strikes and is absorbed by a massy particle [18] such as an electron, the energy in the photon goes into the energisation of the recipient electron: specifically the frequency increases [19]. That corresponds to more rapid energisation of the electron. Since particle mass is determined by the number of discrete force emissions *and* the frequency thereof, the overall effect is to increase the mass of the recipient particle.

3.6.4 Bremsstrahlung radiation under deceleration

When moving under deceleration the gait of the particle has to be shortened. This is because the decelerating force acts at the reactive ends and causes them to be dislocated (retarded) in their progression. To shorten the gait involves the energisation cycle of the reactive end being truncated, so that some discrete force emissions cannot be completed. This abandonment of energisation requires the corresponding discrete forces to be expunged from the particle. They are instead released as independent discrete forces, which is a photon. The mechanism for this emission at the sub-particle level is shown in Figure 9. Several of these principles were adopted from [18, 19], with one important difference: in the bremsstrahlung case it appears that the photon reactive ends may detach sequentially, rather than simultaneously as in [18, 19].

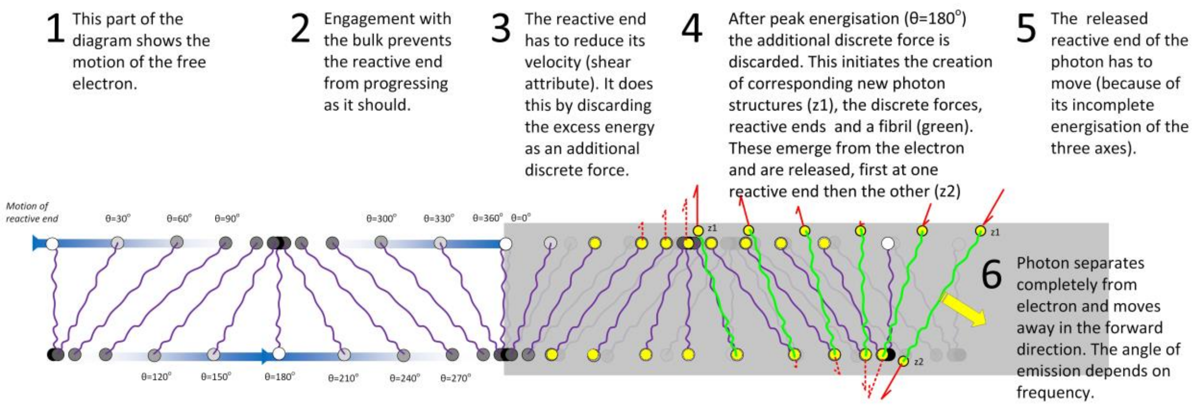


Figure 9: Proposed process whereby a photon is emitted from the electron in bremsstrahlung. The shortening of the electron gait results in photon emission.

The span of the photon is parallel to that of the electron. The gait theory of motion, with its inclined fibril, naturally concludes that the photon would be emitted in the forward arc. Furthermore, the higher the energy of the electron, the greater its frequency and the less inclined its fibril ($\beta \rightarrow 0^o$ in Eqn 9), so the photons ought to be emitted in a narrower forward cone. This is indeed what is observed in practice, with photon emission direction being increasing concentrated in the forward direction as electron energy increases [32].

The cordus theory suggests that if the bremsstrahlung electrons were all controlled for the orientation angles of the fibril [10], then the photon emissions ought to be directionally anisotropic in a bi-lobed distribution.

A neutral particle does not emit bremsstrahlung. The tentative explanation in the cordus theory is that the neutral particle only exists because it comprises two or more fundamental particles of opposite charge, with their reactive ends co-located and synchronised in emissions. For an example of this applied to the neutron see [14, 20]. In this theory, charge sign is represented by medially vs. distally directed emissions for positive and negative charge respectively. Hence, the bremsstrahlung emission is proposed to be internally short-circuited: that of the negative discrete force is opposite in effect to that of the positive, so the whole emission is self-contained within the particle. The member particles accommodate the deceleration distress experienced by the other.

4 Discussion

4.1 Findings

The main finding is that, under this theory, the motion of a particle involves each reactive end taking a spiral-like locus, with the reactive ends being in opposite states of energisation. When viewed in one axis only, the motion appears as a gait, with each reactive end moving forward in turn. During motion, the emissions are compressed into a pulse or discrete force, at least when one axis is considered. These findings substantiate other parts of the cordus theory which assumed the existence of discrete forces (e.g. in the synchronous interaction binding the atomic nucleus [20, 22]) and of the flux tube (e.g. the relativistic considerations [6]).

We propose that the verification of the theory is provided by two mechanisms. First, the paper shows how the theory is consistent with observable motion phenomena (ponderomotive force, linear momentum, mass and momentum of the photon, bremsstrahlung radiation). This part of the work provides a descriptive treatment of the phenomena, which contributes to a potentially improved understanding of the underlying effects. The second mechanism of justification is provided by the wider theory, which provides multiple points of comparison with existing empirical observable phenomena. It also provides explanations for phenomena that are poorly understood by existing theories, e.g. asymmetrical baryogenesis [12], and nuclide stability [21]. Moreover, these explanations are coherent across all parts of the theory. Furthermore, it provides a single framework that covers aspects of particle, wave, and gravitational phenomena [8]. No claim is made that these justifications are at the level of proof, nonetheless they do provide a degree of confidence that the theory has sufficient merit to be considered as a candidate new theory of physics.

4.2 Contrast to existing theories

The philosophical basis of the cordus theory is that of physical realism – that physically observed attributes arise from physical substructures to the particle. This is different to the premise of quantum mechanics, where the fundamental particle is a zero dimensional (0-D) structure and its observables are attributed to intrinsic variables. As shown here, the idea of a particle having two ends leads to the idea that particle motion involves the reactive ends moving non-continuously. This is somewhat unexpected. Nonetheless the idea has several plausible aspects.

First, for any one reactive end, the position and velocity are conjugate variables, being derivatives of action. This is consistent with the Heisenberg uncertainty principle, hence the results are conceptually consistent with quantum mechanics. This is further reinforced by observing that the cordus theory predicts a potential energy of the reactive ends of the form $sin^2\theta_i/2$ (Eqn 1), with the other reactive end taking $cos^2\theta_i/2$. This is significant as the total energy in the particle is unity. This type of relationship is broadly consistent with QM.

Second, the idea of the reactive end moving with an orbital motion provides a physical explanation for frequency that is consistent with QM (which lacks a physical explanation for frequency). This orbital motion is related to the energisation cycle of the fibril and hence to the frequency of the particle itself. Third, the flux tube with its three energisation components is consistent with prior cordus work that derived the relativistic Doppler from flux tube considerations [6]. Hence the theory accommodates both those great theories of physics, gravitation and quantum mechanics [8].

Fourth, the theory is qualitatively consistent with the observed behaviour of emissions in bremsstrahlung, specifically the forward direction of emission, and the narrower cone of emission with higher frequency.

Finally, , the concept has some similarity with de Broglie's idea of the pilot wave [1, 2], in that one might consider the cordus theory as approximately equivalent to linear locus with a superimposed wave component.

Thus the gait locus of particle motion, while it seems strange at first, is compatible with other theories of physics, and with other developments in the cordus theory.

4.3 Critique and future work

While the motion of the particle is evident in the gait of the reactive ends, at a still deeper level the velocity of the particle is proposed to be a property of the shear in the fibril. The fibril is the structure that carries this property and causes the other structures (reactive ends and their emissions) to behave accordingly. At this time the theory does not anticipate how the internal shear interaction is physically based. It seems to imply a still deeper structure. In the case of quantum mechanics there is reason to believe that no deeper structure is permissible within that theory [33], though it can be argued that constraint merely arises because QM assumes from the outset that particles are 0-D points. In the case of the cordus theory there appears to be at least one level deeper, and potentially more.

The mathematical representation of the energisation and position of the reactive ends is a welcome development, since a common critique of previous reviewers of the theory has been the lack of a mathematical formulism. However, more remains to be done since there are other variables that need inclusion, see [10]. The number of such variables is similar to that of string theory. Hence the cordus theory may be compatible with string theory, but if so the correspondence of variables between them is not easy to establish. To fully describe a cordus particle it seems necessary to use a combination of continuous and discrete parameters, and it is not clear how this may be achieved.

5 Conclusions

The findings are that, under the assumptions of this theory, the motion of a particle occurs by each reactive end making an irregular spiral displacement in three dimensional space. The motion comprises a movement phase and a brief immobile phase.

This work make several original conceptual contributions. The first is the conceptual contribution of offering a novel theory of particle motion. The existing literature on particle motion at the fundamental level is sparse. There has been a general assumption that particles, whether classical or quantum, move with a continuous (even if uncertain) velocity. The present gait theory suggests that at the deeper level this apparent continuity is made up of a more complex spiral locus of the particle. Another contribution is the derivation of a formulism for the energisation and mobility of the reactive ends, based on a set of plausible lemmas. This leads to an explicit relationship for the orbital motion of reactive end during translational motion, and hence the prediction of an irregular spiral motion of the particle. Further contributions are the provision of explanations for several physical phenomena: ponderomotive force, the nature of momentum, and bremsstrahlung radiation. Specifically, the theory explains why photon emission would be increasing concentrated in the forward direction with increased electron energy. Another novel contribution of a broad kind is that this theory provides a means to bridge quantum mechanics and special relativity, because it accommodates both particle uncertainty and field transmissions.

Declarations

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References

1. de Broglie, L., *The wave nature of the electron*, in *Nobel Lecture*. 1929, Nobel Prize in Physics.

2. Bohm, D. and J. Bub, *A proposed solution of measurement problem in quantum mechanics by a hidden variable theory.* Reviews of Modern Physics, 1966. **38**(3): p. 453-469,DOI: http://dx.doi.org/10.1103/RevModPhys.38.453

3. Das, A., et al., *Quantum Brownian motion: Drude and Ohmic baths as continuum limits of the Rubin model.* Physical Review E, 2020. **102**(6),DOI: 10.1103/PhysRevE.102.062130.

4. Shen, H.Z., et al., *Non-Markovian quantum Brownian motion in one dimension in electric fields.* Physical Review A, 2018. **97**(4),DOI: 10.1103/PhysRevA.97.042121.

5. Wojnar, R., *The Brownian motion in a thermal field.* Acta Physica Polonica, Series B., 2001. **32**(2): p. 333-349.

6. Pons, D.J., A.D. Pons, and A.J. Pons, *Effect of matter distribution on relativistic time dilation.* Journal of Modern Physics, 2018. **9**(3): p. 500-523,DOI: https://doi.org/10.4236/jmp.2018.93035 http://vixra.org/abs/1611.0128.

7. Pons, D.J., et al., *Wave-particle duality: A conceptual solution from the cordus conjecture.* Physics Essays, 2012. **25**(1): p. 132-140,DOI: http://dx.doi.org/10.4006/0836-1398-25.1.132.

8. Pons, D.J., *Towards unification of fundamental interactions using non-local hidden-variable theory.* Journal of Modern Physics, 2020. **11**(10): p. 1598-1619,DOI: https://doi.org/10.4236/jmp.2020.1110100

9. Pons, D.J., *Internal structure of the electron (Image licence Creative Commons Attribution 4.0).* Wikimedia Commons, 2015(Creative Commons Attribution 4.0 International license),DOI: https://commons.wikimedia.org/wiki/File:Internal_structure_of_the_electron.jpg.

10. Pons, D.J., A.D. Pons, and A.J. Pons, *A physical explanation for particle spin* Journal of Modern Physics, 2019. **10**(7): p. 835-860,DOI: https://doi.org/10.4236/jmp.2019.107056

11. Pons, D.J., *A mechanism for how a particle detects and moves in a field gradient* Journal of Modern Physics, 2020. **11**: p. 1560-1575,DOI: http://dx.doi.org/10.4236/jmp.2020.1110097

12. Pons, D.J., A.D. Pons, and A.J. Pons, *Asymmetrical genesis by remanufacture of antielectrons.* Journal of Modern Physics, 2014. **5**(17): p. 1980-1994,DOI: http://dx.doi.org/10.4236/jmp.2014.517193

13. Pons, D.J., A.D. Pons, and A.J. Pons, *Weak interaction and the mechanisms for neutron stability and decay* Applied Physics Research, 2015. **7**(1): p. 1-11,DOI: http://dx.doi.org/10.5539/apr.v7n1p1

14. Pons, D.J., A.D. Pons, and A.J. Pons, *Beta decays and the inner structures of the neutrino in a NLHV design.* Applied Physics Research, 2014. **6**(3): p. 50-63,DOI: http://dx.doi.org/10.5539/apr.v6n3p50

15. Pons, D.J., *Internal structure of the photon (Image licence Creative Commons Attribution 4.0).* Wikimedia Commons, 2015(Creative Commons Attribution 4.0 International license),DOI: https://commons.wikimedia.org/wiki/File:Internal_structure_of_the_photon.jpg.

16. Pons, D.J., A.D. Pons, and A.J. Pons, *Annihilation mechanisms.* Applied Physics Research 2014. **6**(2): p. 28-46,DOI: http://dx.doi.org/10.5539/apr.v6n2p28

17. Pons, D.J., A.D. Pons, and A.J. Pons, *Pair Production Explained in a Hidden Variable Theory* Journal of Nuclear and Particle Physics 2015. **5**(3): p. 58-69,DOI: http://dx.doi.org/10.5923/j.jnpp.20150503.03.

18. Pons, D.J., *Inner process of Photon emission and absorption.* Applied Physics Research, 2015. **7**(4): p. 14-26,DOI: http://dx.doi.org/10.5539/apr.v7n4p24

19. Pons, D.J., A.D. Pons, and A.J. Pons, *Energy conversion mechanics for photon emission per non-local hidden-variable theory.* Journal of Modern Physics, 2016. **7**(10): p. 1049-1067,DOI: http://dx.doi.org/10.4236/jmp.2016.710094

20. Pons, D.J., A.D. Pons, and A.J. Pons, *Synchronous interlocking of discrete forces: Strong force reconceptualised in a NLHV solution* Applied Physics Research, 2013. **5**(5): p. 107-126,DOI: http://dx.doi.org/10.5539/apr.v5n5107

21. Pons, D.J., A.D. Pons, and A.J. Pons, *Nuclear polymer explains the stability, instability, and non-existence of nuclides.* Physics Research International 2015. **2015**(Article ID 651361): p. 1-19,DOI: http://dx.doi.org/10.1155/2015/651361

22. Pons, D.J., A.D. Pons, and A.J. Pons, *Explanation of the Table of Nuclides: Qualitative nuclear mechanics from a NLHV design.* Applied Physics Research 2013. **5**(6): p. 145-174,DOI: http://dx.doi.org/10.5539/apr.v5n6p145

23. Pons, D.J., A.D. Pons, and A.J. Pons, *Entropy at the level of individual particles: Analysis of Maxwell's Agent with a hidden-variable theory.* Journal of Modern Physics, 2016. **7**(10): p. 1277-1295,DOI: http://dx.doi.org/10.4236/jmp.2016.710113

24. Pons, D.J., A.D. Pons, and A.J. Pons, *Time: An emergent property of matter.* Applied Physics Research, 2013. **5**(6): p. 23-47,DOI: http://dx.doi.org/10.5539/apr.v5n6p23

25. Pons, D.J. and A.D. Pons, *Outer boundary of the expanding cosmos: Discrete fields and implications for the holographic principle* The Open Astronomy Journal, 2013. **6**: p. 77-89,DOI: http://dx.doi.org/10.2174/1874381101306010077.

26. Pons, D.J., A.D. Pons, and A.J. Pons, *Speed of light as an emergent property of the fabric.* Applied Physics Research, 2016. **8**(3): p. 111-121,DOI: http://dx.doi.org/10.5539/apr.v8n3p111.

27. Zürcher, U., *What is the frequency of an electron wave?* European Journal of Physics, 2016. **37**(4): p. 045401,DOI: 10.1088/0143-0807/37/4/045401.

28. Pons, D.J., A.D. Pons, and A.J. Pons, *Asymmetrical neutrino induced decay of nucleons* Applied Physics Research, 2015. **7**(2): p. 1-13,DOI: http://dx.doi.org/10.5539/apr.v7n2p1 or http://vixra.org/abs/1412.0279.

29. Pons, D.J., *Explanation of Photon Navigation in the Mach-Zehnder Interferometer.* Optics, 2020. **1**: p. 243-254,DOI: https://doi.org/10.3390/opt1030018 http://viXra.org/abs/2009.0004

30. Lacina, K., *It Is Not What It Looks Like—A Response to D. J. Pons, A. D. Pons, and A. J. Pons Theory of Time.* Applied Physics Research, 2014. **1**(1): p. 26-34,DOI: http://dx.doi.org/10.5539/apr.v6n1p26.

31. Pons, D.J., A.D. Pons, and A.J. Pons, *Differentiation of Matter and Antimatter by Hand: Internal and External Structures of the Electron and Antielectron.* Physics Essays, 2014. **27**: p. 26-35,DOI: http://dx.doi.org/10.4006/0836-1398-27.1.26.

32. Faw, R.E. and J.K. Shultis, *Radiation Sources*, in *Encyclopedia of Physical Science and Technology (Third Edition)*, R.A. Meyers, Editor. 2003, Academic Press: New York. p. 613-631.DOI: https://doi.org/10.1016/B0-12-227410-5/00636-0.

33. Colbeck, R. and R. Renner, *No extension of quantum theory can have improved predictive power.* Nature Communications, 2011. **2**: p. 5,DOI: http://dx.doi.org/10.1038/ncomms1416.