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Pair Production: The Origin of Charge, Mass, and CP Symmetry

By
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Abstract

An elementary vector examination of pair-production for the undergraduate and below physics level has some interesting results. The goal was to find a way to explain pair-production with a geometrical vector approach. This would make a good introduction to the subject, and be useful in studying the symmetry of the process.

The Dirac equation has yet to reveal all its secrets. Each method used in examining pair production has its advantages and disadvantages. QED and Clifford algebra are two of the methods used on the Dirac that are looked at here as well. Before looking at pair-production, some basics are examined first to be properly incorporated into a geometric vector example.

Such topics as quantum spin and spinors must be represented in a vector model. The role of the magnetic moment, and how the vacuum and source fields fit into such a model. The model is a basic as possible and starts with few assumptions.

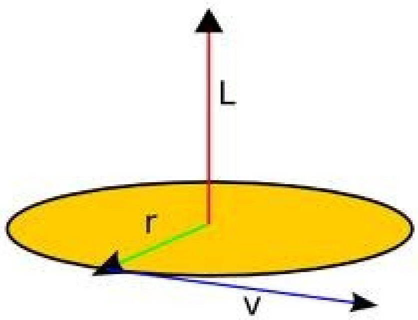
A representation of the vacuum is given by the model that can be easily understood and the "virtual" particles of the vacuum are clearly expressed. The process of the creation of charge and mass is examined. The symmetry behind charge parity, CP, is clearly seen as well, but time is not included, nor needed, for most of the paper. This suggests CP symmetry but not CPT symmetry in pair-production.

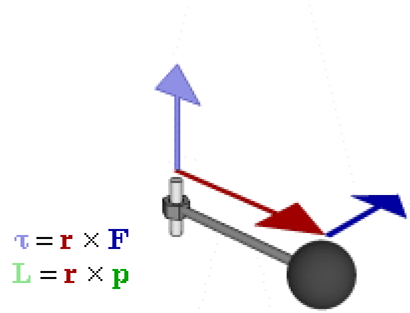
Quantum Spin

The Dirac equation lies at the heart of physics and describes pair-production. Despite its long history, the interpretation is not straight forward and beyond the grasp of many who would like to know more about physics.

The QED treatment of the Dirac equation in *Feynman Diagrams for Beginners* [1] is recommended reading as it simplifies the subject, and concepts in this paper can be used in Feynman Diagrams. One of the first problems Dirac had to overcome was the discovery of Quantum Spin by Wolfgang Pauli in 1924 and introduced what he called a "two-valued quantum degree of freedom".

At first no one knew how to interpret this discovery. In classical mechanics, the angular momentum of a particle can be described by **r** radius, the distance from the axis of rotation and a directional **F** force. For a 3-D spherical object, **r** is on the *y* plane and the the **F** force is in the +*z* or −*z* direction.





Quantum mechanical spin also contains information about direction, but in a more subtle form. Quantum mechanics states that QM spin is a component of angular momentum that can only take on certain values.

In the QED treatment of Dirac's equation, there are two solutions for σ, one with σ = 1 and another with σ = 2. These are the two spin states of 1/2 spin particles 2.3 [1]. These quantum states of the spin correspond to which direction, + or − of the z axis, that the vector for the **F** force is pointing in, these states are referred to as "spin up" and "spin down".

As a result, quantum mechanical spin is not described by vectors as in classical manner, but by spinors.

A spinor and a vector behave differently under coordinate rotations. If you rotate a 1/2 spin particle by only 360 degrees, it does not return to its starting position, but to the start with the opposite quantum phase. To return the particle to its exact original state, two full rotations, or 720 degrees is needed.

Spinors are a type of complex vector constructed in order to encompass more fully the geometry of orientation entanglement, or complex spin in a mathematically efficient way. There is a not so efficient method that can also be useful.

In a geometrical approach the spinors can be constructed from their vector components, and then examine how they behave under the action of the relevant Lie groups. This provides a concrete and elementary description of what a spinor is. However, such a description becomes unwieldy, still the basic concept can be expressed with vectors. In 3-D, this is how classical and quantum spin can be represented with vectors.

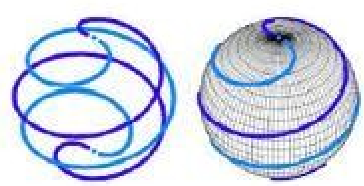
For a spherical object, one vector is on the *y* plane, equator, and the vector **F** is in the +*z* or −*z* direction. This is the classical spin, and as it is used as a reference, we will call primary spin. Quantum spin is represented by another vector with rotation in the *x* plane.

Blue = Primary classical spin
Green = Quantum 1/2 spin

Put a dot on the equator, *y* axis, at the tip of the arrow as the starting point. in one 360 degree revolution it will return to its starting point.
The spin on the *x* axis is moving at 1/2 the speed of the primary spin, so a dot at the North pole only makes it to the south pole in the same amount of time.
To return the particle to its exact original state, both dots in the same spot, two full rotations, or 720 degrees is needed.

However the dots we imagine on the surface do not travel a straight line due to the complex spin, but rather follow a curved or wavy path around the globe.

Here is an example with the quantum spin dot starting at the north pole to show the path of a spinor. The light and dark paths are the two separate paths during the two primary spins. There are a number of possible quantum spins, and spinors make this tracking of complex spin much more efficient.



Particles with any quantum spin can be mapped in this manner. Now you see why they call them "Spinors".

The point at the north can go one of two directions, the light or dark path first. This relates to the two quantum spin states.

So quantum spin can be represented in a geometrical vector manner that give an good visual representation, but is not efficient mathematically as matrices and spinors.

The paper *Spin, Charge and the Fine-Structure Constant* developed a QED like vector notation for the spin and charge of particles, here is the basics of that as it relates to spin [3].

A basic circle, O, represents a 3-D spherical particle with classical primary spin. Draw a circle and divide it in half top to bottom for 1/2 spin particles. An vector arrow at the top on the circle can be used to show the direction of the quantum spin and charge. To show the other possible quantum spin state, the notation can be moved to the bottom of the circle.

A← vector would be a negatively charged 1/2 spin particle.
A → vector would be a positively charged 1/2 spin particle.
A ↔ vector would be a neutral Spin 1 particle
A 0-spin particle does not need a quantum spin vector and is simply a circle, O.

This approach of treating quantum spin and charge as a vector has worked well in the "Golden FaTe" string theory being developed by the "String Theory Development group. In it a string can be given a twist with a single vector, or a complex twist. This has allowed the developing string theory to predict the observed leptons [4].

Understanding spin was one of the first problems faced by Dirac, but not the only problem he had to deal with. His equation also produced a negative energy solution. It was as if a second positive particle existed as well. This was latter confirmed as the positron, the anti-particle of the electron. This happened when the EM field was taken into account and is related to charge. When Clifford algebra was applied to the Dirac equation, a second axis of rotation appears in the matrix when the EM field is taken into account as well [2].

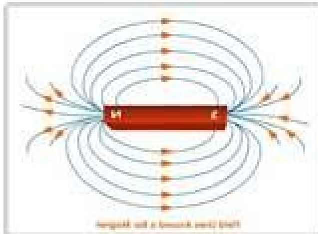
Now in Dirac's equation this negative-energy positively charged particle could be solved for by reversing time and making it negative. Because of this a positron has been called an electron going backwards in time.

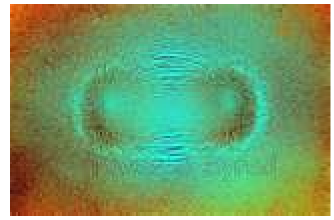
Spin and the Magnetic Moment

The magnetic moment can be defined by different methods. In older textbooks the example using a bar magnet.

Bar Magnet and Field around it
Force between poles not visible

Force Between the Poles
Magnetic-field not clearly visible





The magnetic moment is equal to the force between the poles, but reversed as if this force was keeping the poles as is the real magnet was not there. So this force depends on two factors: one on the strength *p* of its poles, and on the vector **l** of the distance separating them. The moment is defined as

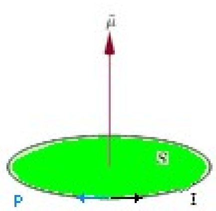
$$\boldsymbol{\mu} = p\,\mathbf{l}$$

It points from South to North pole, and obeys the right hand rule for the direction of the magnetic-field.

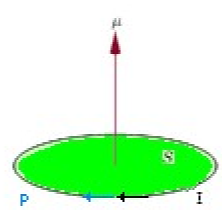
There is also the "Current Loop" definition for the magnetic moment.
Place a closed loop carrying an electric current **I** and a vector area **S**. Its magnetic moment **μ**, a vector, is defined as: $\boldsymbol{\mu} = \mathbf{I} \times \mathbf{S}$

Here is a graph is made of the electron and positron's magnetic moment, note the current will be reversed in the positron while other aspects of spin remain the same. **P** is the primary physical spin direction.

Electron Magnetic Moment
Right Hand Rule



Positron Magnetic Moment
Left Hand Rule



The change in the direction of current flow is due to the way we have defined current, which is that the flow of current is opposite that of the flow of electrons. So in the positron where there is a flow of positive rather than negative charges, we see current flowing in the same direction as the movement of charge. So the magnetic moment can be defined as a rotating charged particle as well.

It can also be defined where the mass of the particle is included. The intrinsic magnetic moment μ of an elementary particle with charge *q*, mass *m*, and spin angular momentum *S*, is

$$\mu = g\,\frac{q}{2m}\,S$$

The value of 2 arises from the Dirac equation, and a correction of 0.002319304... arises from the electron's interaction with the surrounding electromagnetic field, including its own field.

And g is the g-factor in the above equation and is related to the magnetic moment as well. The "electron spin g-factor", g_e, is defined by

$$\boldsymbol{\mu}_S = \frac{g_e \mu_\mathrm{B}}{\hbar} \boldsymbol{S}$$

Where $\boldsymbol{\mu}_S$ is the total magnetic moment resulting from the spin of an electron, $\boldsymbol{S}$ is the magnitude of its spin from angular momentum, and μ_B is the Bohr magneton, also related to the magnetic moment. I could go on, but many constants and concepts in physics are found in the process of pair-production.

Both the magnetic moment and magnetic field of a particle may be considered to be vectors having a magnitude and direction. The direction of the magnetic moment points from the south to north pole of a magnet. The magnetic field produced by a magnet is proportional to its magnetic moment as well.

The positron has the same spin as the electron, the only difference is charge. But how to explain the sudden appearance of the positron, which Dirac was not looking for, when an electron is created was a mystery.

Dirac tried to explain this with the concept know known as the "Dirac Sea". He pictured a 3-dimensional sea with neutral charge. When an electron was formed, this created an imbalance in this sea, and a positron is created in the sea to maintain the balance of electrical charge in the universe.

This is what is known as Charge Parity or CP for short.

Today, Dirac's view of a sea of invisible particles that can pop into our reality sounds a little silly and simplistic. Sometime it is ignored, bypassed or goes by another name.

In condensed matter physics the underlying concepts of Dirac Sea are still seen. The sea of conduction electrons in an electrical conductor is called the Fermi sea instead of the Dirac Sea and is functionally equivalent.

In Quantum Field Theory, QFT, the Bogoliubov transformation is used on the creation and annihilation operators. This in effect turns an occupied negative-energy electron state of the Dirac Sea into an unoccupied positive energy positron state of the Dirac sea, and the process is reversible. It is important to be aware of the relationship between mathematical methods like this and the underlying theories for them.

So as old fashioned as the Dirac Sea sounds, it is still a factor in physics today. Even the vacuum energy of quantum theory can be related to the Dirac Sea. Which means it is time to examine the vacuum energy and source fields of modern quantum theory if we are going to use vectors to model pair production in light of modern knowledge.

The Dirac Sea and its relation to the Vacuum and Source Field

The vacuum energy is hard to describe, and due to that there are a lot of misconceptions about it. Half of the energy for electron/positrons comes from the vacuum energy, and the other half from the waves of the source field. So these basic concepts of quantum theory are at the heart of pair production.

Now the vacuum has been described as being filled with "Virtual" particles that don't have mass in Quantum Field theory. The vacuum ground state is a seething mass of these virtual particles and fields of probabilities.

The Dirac Sea has mass-less invisible particles, the Vacuum has mass-less virtual particles. But this simple vies of a sea full of not quite real particles is not sufficient to describe the vacuum and these "virtual" particles are only used when it is mathematically convenient to do so.

Another way to model the vacuum energy that is responsible for the mass of the electron is to treat it as an ideal gas. Density Functional Theory takes this approach and has its origin in the Thomas-Fermi model and the two Hohenberg-Kohn theorems (H-K).

DFT demonstrates that the ground state properties of many-electron system are determined by the electron density based on only **3 spatial coordinates**. There are versions as well; Kohn-Sham DFT or just KS DFT, Orbital Free Density Functional Theory OFDFT, and Time Dependent Density Functional Theory TDDFT.

The model has also been expanded to include EM effects in Current Density Functional Theory CDFT and Magnetic Field Functional Theory (BDFT). Even the Golden FaTe string theory has the equivalent concept, Mark Aaron Simpson *"Our model describes space as a vast continuous opportunity of singularities (particles)."*

In this paper the vacuum will be modeled in a similar fashion, as an ideal gas or liquid depending on density, without discrete, real, particles having mass. The density of the vacuum energy must be addressed as well in free space in addition to its contribution to mass in particles.

This paper will set the energy density of the vacuum equal to the cosmological constant.

The cosmological constant Λ appears in Einstein's modified field equation.

$$R_{\mu\nu} - \frac{1}{2}R\,g_{\mu\nu} + \Lambda\,g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

When **Λ** is zero, this becomes the original field equation of general relativity. When ***T*** is zero, the field equation describes empty space, the vacuum. The cosmological constant has the same effect as an intrinsic energy density of the vacuum. In General Relativity, the cosmological constant is proportional to the energy density of empty space, and can be measured by the curvature of space.

Setting the vacuum energy equal to the cosmological constant was used with good results in an earlier work by the author [5], and has work well in the Golden FaTe string theory as well [4], when applied to pair production,though the value varies locally of course due to relativity and other factors. This helped keep both models in line with relativity.

The vacuum may best be described as Latent Background Energy. It is not Potential energy, as it has no lower state to fall to, nor Kinetic energy of motion, like a wave.

The waves of the source field by comparison are quite simple to explain compared to the vacuum energy. That one electron receives a Broglie wave from another electron is at the heart of QM. Any particle, because it is a standing wave, is an oscillator that produces these waves for other particles.

Now Dirac started with a complete electron equation. In section 3.2 **Plane wave solutions** of *Complex four-vectors and the Dirac equation* it shows that a plane wave solution would work, as a small section of any spherical wave can be considered a plane wave at distance from its origin [2].

This approach will greatly simplify the use of vectors in pair-production. The intensity of a wave is the energy density times the wave speed, which is the speed of light.

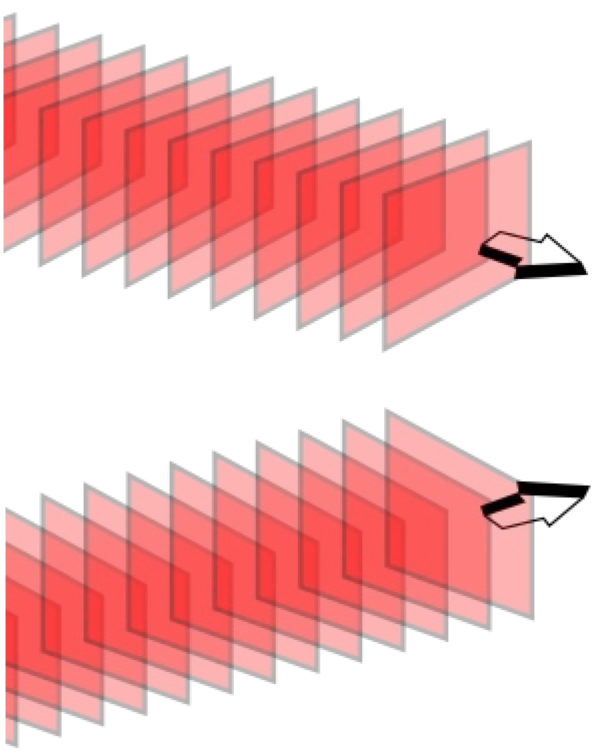
"Virtual" Pair-production with Vectors

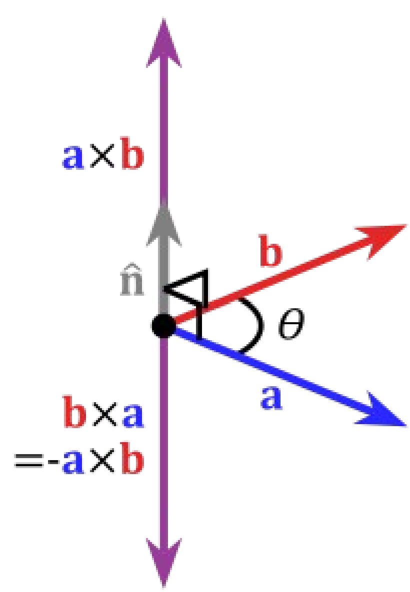
The intersection of two plane waves moving at the speed of light, with the vectors denoting direction opposed 90 degrees, is examined.

Plane wave **A** is on the (x,z) plane and moving in the vector **a** direction.
Plane wave **B** is on the (x,y) plane and moving in the vector **b** direction.
Both also have a given intensity based on the Density of the vacuum energy.

The vector diagram is known as a Vector Cross Product.

This form of vector multiplication is only valid in 3-dimensions, and 7 dimensions for multidimensional theories.





The cross product, denoted **a** x **b**, is a vector perpendicular to both **a** and **b** and is defined as

$$\mathbf{a} \times \mathbf{b} = \|\mathbf{a}\| \, \|\mathbf{b}\| \sin(\Theta) \, \mathbf{n}$$

Where $\boldsymbol{\Theta}$ is the measure of the angle between **a** and **b**, and **n** is a unit vector perpendicular to both **a** and **b**, which obeys the right-hand rule.

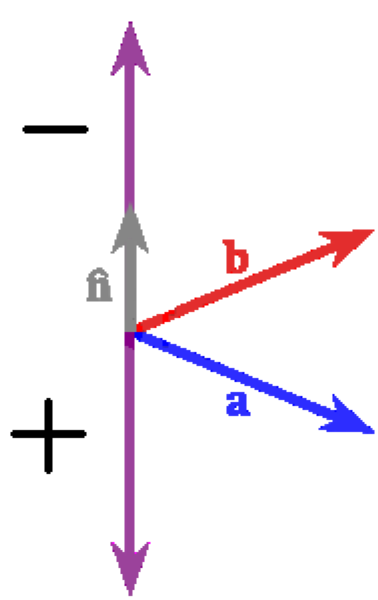
There is also a solution for - **n** which obeys the left-hand rule. The two solutions for **n** are known a Pseudo-vectors. Examples of pseudo-vectors include torque, and the magnetic field. So the force exerted by pseudo-vectors is clearly evident as a real force.

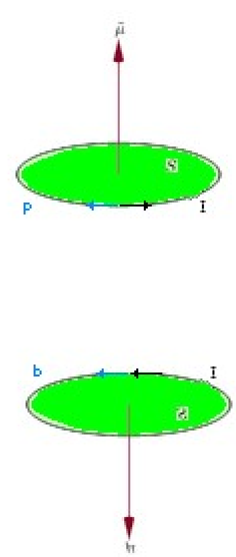
The distinction between vectors and pseudo-vectors is often ignored, but it becomes important in studying symmetry, which is needed in examination in the pair-production process.

This relationship where vectors **a** x **b** = **n** is the same relationship we see in the magnetic moment of the electron where vectors **I** x **S** = **μ** with both using the right-hand rule, and a negative solution for the positron using the left-hand rule.

Premise: That a force obeying the right and left hand rule the same as the magnetic moment in particles could induce a polarization of the vacuum energy and a magnetic moment.

Researchers have induced a magnetic moment in neutral atoms using lasers to induce a spin [6]. The concept of polarization by a vector field that gives the density of a permanent or induced electric dipole moment is a critical part of the work by Maxwell on electromagnetism. So this premise is a reasonable one.





I placed the graphics of the electron and positron magnetic moments next to the vector diagram, with the positron upside down so the vectors for the magnetic moment are aligned in the same direction.

The pseudo-vectors in effect create a pseudo-magnet. Notice that the flow of current for both magnetic moments are flowing in the same counter-clockwise direction. The pseudo-magnet created by the pseudo-vectors sets up the electromagnetic field for the flow of current.

Due to the magnetic field and the current trying to flow in the plane waves themselves, they become entangled with the EM field trying to form a complete circuit.. When the current begins to flow, it causes the polarized vacuum energy to acquire a physical spin based on the charge contained.

Now the energy density of the vacuum would need to be very high to create a particle, the density of the vacuum is barely above zero, and it takes a lot of energy to meet the requirements of

$$E = mc^2$$

While the two waves at the speed of light is part of the equation, the rest of the energy must come from somewhere, be it a strong EM field, the energy of a decaying particle, or a high energy density environment like in high energy particle collisions or the early universe.

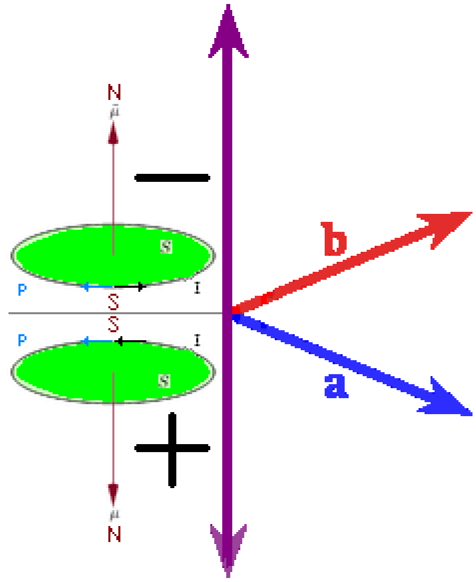
Without the required energy, real 1/2 spin particles can not form. Until then they are just pseudo-particles. They have everything in place except the last ingredient, mass. As the vacuum is filled with intersecting waves, there is a virtual sea of these pseudo-particles.

By starting with the vacuum being defined by relativity, it is shown to be equivalent with the vacuum ground state of QFT, the vacuum and source fields of QED, some string theories and the authors semi-classical educational model.

All these various fields of physics are saying basically the same thing, each from their own viewpoint and terminology, which is one of the biggest hurdles in learning physics, yet every method has its strong points and weaknesses.

Real Pair-production

If there is sufficient energy, real particles can arise from these pseudo-particles. When this happens each of the two particles will develop real physical spin, and generate their own real magnetic moment, which brings an added force to the picture.



I placed the magnetic moments to the side of the vector for clarity. When they develop their own electric magnetic moment separate from the pseudo-magnet magnetic moment of the vector force, due to the symmetry of formation, the South poles of both are nearly touching.

This provides the final force needed to separate them and why when particle pairs first appear, they are spiraling away from each other, despite their opposite charges.

Everything revolves around the pseudo-magnet magnetic moment, which creates real electric magnetic moments equal to it in magnitude. As mentioned before, many constants and concepts in physics are related to the magnetic moment. It would be interesting to see how many could be derived from this model.

Conclusions

Time

Time has not been mentioned for several reasons. Philosophically time for a particle does not begin for it till the particle is created, just as time did not exist for the universe till it was created in the Big Bang. A vector cross product is a 3-dimensional phenomenon, also 7-dimensional in multidimensional theories, so it did not seem necessary to include it at the start, but when needed at particle formation when an electron equation can be derived with time included as it can only have a frequency once created, and frequency can be considered the internal clock of the particle.

Mark Aaron Simpson felt the same about many string theories being developed, *"I think too many string theories place the wave function as a predetermined function too early in the models synthesis of space, either for a lack of intuition, or because they can not model dimensions without time as a component."*

Prior work by the author [3] and the Golden FaTe string theory [4] showed a vector approach would work with good or better results.

While time does not exist for the particle till it is created, it does exist for an independent observer observing the process of pair-production.

The orientation of the plane waves were chosen to reduce the effects of time as much as possible. The point of intersection of the two waves would travel in a vector **a** + **b** with the waves, creating a stable system over time to examine.

If the two waves meet head on at 180 degrees, the effects of time would be maximized and the pseudo-particle will exist only briefly. The intensity of a wave does not hit all at once. It goes from a value of 0 to maximum intensity and back to 0. Due to the rapid expansion and contraction of the EM field, simulating the movement of a standing wave, this type of wave interaction may be more conducive to pair-production.

Even if time is considered, the positron is not an electron going backwards in time by this vector model of pair production, The positron and electron are a result of 3-dimensional space and the basic mathematical rules of vectors. The only difference is charge and the effects stemming from charge.

Charge and Mass

Charge itself is an effect of 3-dimensional space and the basic mathematical rules of vectors. Charge is created by the polarization of the neutral vacuum energy by the force of a vector cross product from the intersection of two waves.

Just as the creation of charge is clearly seen, the creation of mass is a clear example of

$$E = mc^2$$

The energy density of the vacuum is multiplied by the speed of the waves, the speed of light, to give the intensity for each wave, which is then multiplied by the vector cross product when the two waves intersect.

This creates a process whereby pseudo-magnetic and electromagnetic fields use the plane wave to create standing wave containing the vacuum energy which created it. Once confined to the particle, we detect it as mass.

So the energy density at the time of pair-production will give us the mass of the particles that will be created. That does not mean the particle will be stable when created, and may decay or even produce another particle as it moves towards a stable state or its death as a particle.

Dirac Equation or Electron Model of Choice

Even the Clifford algebra approach started with the complex quantum spin as part of the plane wave, but this paper did not set such complex starting conditions. It is best to start with as few assumptions as possible in any model, and complex spin could arise as part of the pair-production process.

As a result the pseudo-particles does not have quantum spin. But that could arise at several points in the formation of real particles. The flow of current in the plane wave may induce the quantum spin as the sphere is formed from the plane wave. Or the spin may be induced at the time when the two south poles of the electric magnetic moment kicks them apart. The force is inducing rotation from the pole, the right vector direction for quantum spin.

At this point one can pick the electron model of their choosing and try to see how it could form from this process of twisting a plane wave into a particle. The Dirac equation which assumes complex spin vectors on the plane wave as in the Clifford algebra approach to the Dirac equation [2] could be used to get the Dirac electron.

Ring, torus, and other electron models could be used. For example the author [7] and the Golden FaTe [4] string theory both used a standing wave for particles that had a "double solution" one for the finite point particle and one for the extended wave.

In this case the two plane waves could form tubes, one inside the other. The outside one would be caught by the extended EM field, the second and much smaller tube is caught in the vector cross product at the center. When the mass forms a real particle and the electromagnetic moment kicks the two apart, the tubes break apart forming spheres as 1/2 quantum spin is introduced.

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