The Physical Origin of Electron Spin
- *using quantum wave particle structure*

Contents

Abstract

It is shown how the spin of the electron and other charged particles arises out of the quantum wave structure of matter. Spin is a result of *spherical rotation* in quantum space of the inward (advanced) spherical quantum wave of an electron at the electron center in order to become the outward (retarded) wave. Wave rotation is required to maintain proper phase relations of the wave amplitudes. The spherical rotation, a unique property of 3-D space, can be described using SU(2) group theory algebra. In the SU(2) algebra, the inward and outward waves of the charged particle are the elements of a Dirac spinor wave function. Thus all charged particles satisfy the Dirac Equation.

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1. Introduction

A highly successful mathematical theory of spin has already been developed by P.A.M. Dirac and others (Eisele, 1960). It predicted the discovery of the positron (Anderson, 1922) and correctly gave the value of the spin, h/4pi angular momentum units. Prior to this paper, there has been no successful physical description of spin or any suggestion of its origin, although it was recognized to be a quantum phenomenon. The electron's structure, as well as its spin, had been a mystery. Providing a physical origin of spin for the first time is the purpose of this paper.

In Dirac's theoretical work the spin of a particle is measured in units of angular momentum, like rotating objects of human size. But particle spin is uniquely a quantum phenomenon, different than human scale angular momentum. Its value is fixed and independent of particle mass or angular velocity. However, spin properties are found to be related to other properties of the electron's quantum wave function; that is, mirror or parity inversion (**P**), time inversion (**T**), and charge inversion (**C**). For example, the quantum operation **CPT** on a particle is found to be invariant,**CPT**= {**C** harge inversion} x {**P**arity inversion} x {**T**ime inversion} = an invariant

This study returns to a proposal that was popular sixty years ago among the pioneers of quantum theory: namely that matter consisted of wave structures in space. Thus, it was proposed that matter substance, mass and charge, did not exist but were properties of the wave structure. Wyle, Schroedinger, Clifford, and Einstein were among those who believed that particles were a wave structure. Their belief was consistent with quantum theory, since the mathematics of quantum theory does not depend on the existence of particle substance or charge substance. In short, they proposed that quantum waves are real and mass/charge were mere appearances; 'Schaumkommen' in the words of Schroedinger. The reality of quantum waves, as suggested by Cramer (1986), supports the original concept of W. K. Clifford (1876) that all matter is simply "undulations in the fabric of space."

Wheeler and Feynman (1945) first modeled the electron as spherical inward and outward electromagnetic waves seeking the *response of the universe* (from other matter) to explain radiation, but encountered difficulties because there are no spherical solutions of the electromagnetic equations using vector fields. Cramer (1986) discusses the *response* for real quantum waves. Using a quantum wave equation (scalar fields) and spherical quantum waves, Wolff (1990, '91, '93, '95, '97) found and described a wave structure of matter which successfully predicted the Natural Laws as experimentally measured. It has predicted all of the properties of the electron except one - its spin. Now, this paper completes those predictions with a physical origin of spin that is in accord with quantum theory, the Dirac Equation, and the previous structure of the electron.

Briefly summarizing Wolff, the electron is comprised of two spherical scalar waves, one inward and one outward. These waves are superimposed at the origin with opposite amplitudes, as shown in Figure 1in the next section, to form a single *resonant standing wave* in space centered at the electron's location. A reversal of the inward wave occurs at the center where r = 0. Spin appears as a required rotation of the inward wave to become the outward wave. The outward wave induces a *response of the universe* when it encounters other matter in its universe and modulates their outward waves. The tiny Huygens components of those waves return to the center and become the inward wave. This simple structure, termed a *space resonance* (SR), produces all experimental properties of electrons.

This structure, the electron properties, and the laws of nature originate from *three basic principles* or assumptions. No other laws are required as these principles are the origin of the laws of nature. Briefly they are:

> **Principle I. A Wave Equation** . Determines the behavior of quantum waves.
>
> **Principle II. Wave Density Principle.** A quantitative generalization of Mach's principle, which determines the density of the quantum wave medium.
>
> **Principle III. Minimum Amplitude Principle (MAP).** The sum of wave amplitudes seeks a minimum at each point.

The following wave equation is the *First Principle.*

2. Wave Structure of the Electron

The structure of the electron consists of solutions of a general wave equation (Wolff, 1990). This equation governs the behavior of all particle waves in space, and is:

$$\mathbf{(grad)^2(AMP) - (1/c^2)\, d^2 (AMP)/ dt^2 = 0} \qquad [1]$$

where AMP is a scalar amplitude, c is the velocity of light, and t is the time. These waves are scalar quantum waves, not electromagnetic waves. This wave equation has two spherical solutions for the amplitude of the electron: one of them is an inward wave converging to the center; the other is a diverging outward wave. The two solutions are:

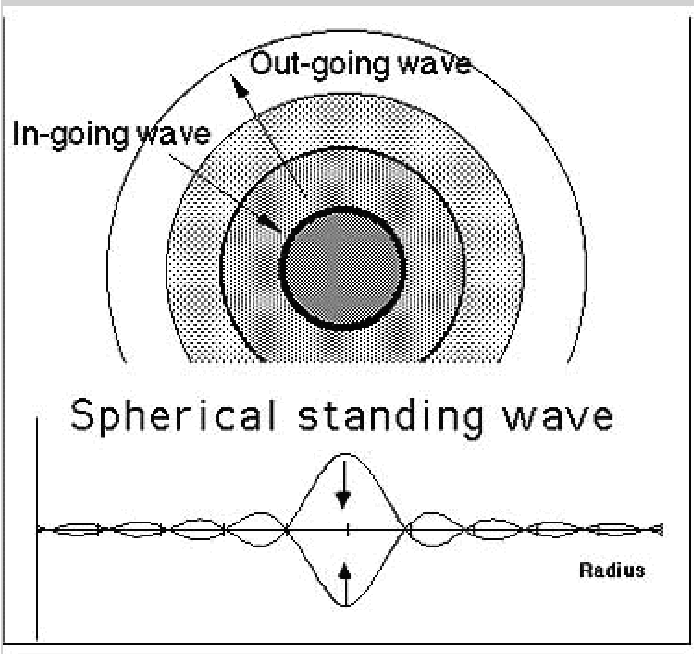
$$\{\text{IN-amplitude}\} = (1/r)\,\{\text{AMP-max}\}\,\exp(iwt + ikr)$$
$$\{\text{OUT-amplitude}\} = (1/r)\,\{\text{AMP-max}\}\,\exp(iwt - ikr) \qquad [2]$$

where:

$w = 2pi\ mc^2/h$ = the angular frequency

$k = 2pi/\{\text{wave length}\}$ = the wave number.

The inward wave converges to its center and rotates to become a diverging outward wave. The superposition of the continuous inward and outward waves forms the electron, Figure 1, and is termed a *space resonance.* To transform the inward wave to an outward wave and obtain constructive interference with proper phase relation requires a rotation and phase shift at the center. This rotation produces a spin value h/4pi, the same for all charged particles because all particles propagate in the same universal wave medium.



igure 1. Electron Structure. *The upper iagram shows a cross-section of the pherical wave structure, something like ie layers of an onion. It is comprised of n inward moving wave and an outward ioving wave. The two waves combine to orm a single dynamic standing wave tructure with its center as the nominal ocation of the electron. Note that the mplitude of a quantum wave is a scalar umber, not an electromagnetic vector. hus these waves are part of quantum ieory, not electric theory. At the center ie quantum wave amplitude (and the lectric potential) is finite, not infinite, in greement with the observed electron Wolff, 1995). The lower diagram shows ie same quantum wave amplitude plotted along a radius outwards from the electron center. The lower diagram is a 'slice' from the upper diagram.*

3. Spherical Rotation

Rotation of the inward quantum wave at the center to become an outward wave is an absolute requirement to form a particle structure. Rotation in space has conditions. Any mechanism that rotates (to creates the quantum "spin") must not destroy the continuity of the space. The curvilinear coordinates of the space near the particle must participate in the motion of the particle. Fortunately, nature has provided a way - known as *spherical rotation* - a unique property of 3-D space. In mathematical terms this mechanism, according to the group theory of 3-D space, is described by stating that the allowed motions must be represented by the SU(2) group algebra which concerns simply-connected geometries.

Spherical rotation is an astonishing property of 3-D space. It permits an object structured of space to rotate about any axis without rupturing the coordinates of space. After two turns, space regains its original configuration. This property allows the electron to retain spherical symmetry while imparting a quantized "spin" along an arbitrary axis as the inward waves converge to the center, rotate with a phase shift to become the outward wave, and continually repeat the cycle.

The required phase shift is a 180^{o} rotation that changes inward wave amplitudes to become those of the outward wave. There are only two possible directions of rotation, CW or CCW. One choice is an electron with spin of +h/4pi, and the other is the positron with spin of -h/4pi.

It is an awesome thought that if 3-D space did not have this geometric property of spherical rotation, particles and matter as we know them could not exist.

4. Dirac Theory of Electron Spin

The newly discovered quantum mechanics of the 1920s began to be applied to the physics of particles, seeking to further understand particles. Nobel Laureate P A.M. Dirac sought to find a relation between quantum theory and the conservation of energy in special relativity given by

$E^2 = p^2c^2 + mo^2c^4$ [3]

He speculated that this energy equation might be converted to a quantum equation in the usual way, in which energy E and momentum p are replaced by differential calculus operators:

E = (h/i) {d AMP/dt} and
p = h{d AMP/dx} + .. etc. [4]

He hoped to find the quantum differential wave equation of the particle. Unfortunately, Eqn [3] uses squared terms and Eqn [4] cannot. The road was blocked!

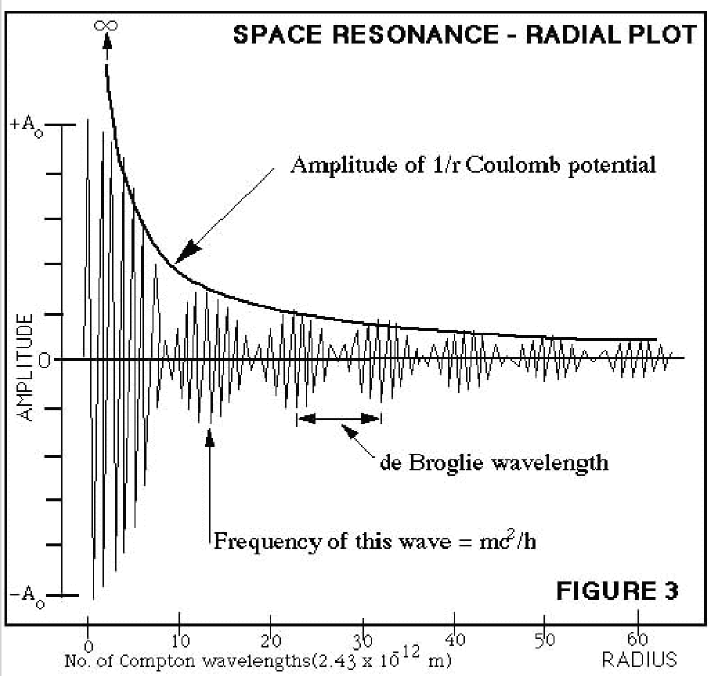


Figure 2. Radial Plot of the Electron Structure. *When the IN and OUT quantum waves combine they form a standing wave. This detailed plot, the same as the approximate lower plot of Fig. 1 above, corresponds exactly to the equations below. The envelope of the wave amplitude matches the Coulomb potential everywhere except at the center, where it is not infinite in agreement with the observations of Lamb and Retherford. If the electron were moving and observed by another detector atom with relative velocity v, the deBroglie wavelength appears as a Doppler effect on* <u>both</u> *waves. The frequency mc^2/h of the waves was first proposed by Schroedinger and deBroglie, proportional to the mass of the electron. This frequency is the mass so that mass measurements are actually frequency measurements. There is no mass 'substance' in nature.*

Dirac had a crazy idea, "Let's try to find the factors of Eqn [3] without squares, by writing a matrix equation"

[Identity]E = [alpha]pc + [beta]m_oc^2 [5]

where: [Identity] is the identity matrix.
[alpha] and [beta] are new matrix operators of a vector algebra.

Dirac was lucky! He found that if [alpha] and [beta] were 4-vector matrices then Eqn [5] works okay. It is the famous Dirac Equation. Eqns [4] and [5] can now be combined to get [Identity] (ih) d[AMP]/dt = (ch/i) {[alpha-x] d[AMP]/dx + [alpha-y] d[AMP]/dy + [alpha-z] d[AMP]/dz + [beta]m_oc^2[AMP]}

In general, [AMP] is a 4-vector: [AMP] = [AMP1, AMP2, AMP3, AMP4].

For the electron, this reduces to: [AMP] = [0, 1, AMP3(E,p) , AMP4(E,p)]

Dirac realized that for an electron only two wave functions, AMP3 and AMP4, were needed. These predicted an electron and a positron of energy E with spin

$$E = \pm mc^2 \quad \text{and} \quad \text{spin} = \pm h/4pi$$

The positron was discovered five years later by Anderson (1931).

Dirac simplified the matrix algebra by introducing 2-vectors (number pairs) which he termed 'spinors.' Spin matrices, which operate on the vectors, were defined as follows:

{spi n-x} =	{spin -y} =	{spi n-z} =	{iden tity} =

0
1

Thus Dirac had created a two-number algebra to describe particles instead of our common single number algebra. This 'spinor' algebra, while eminently successful, was entirely theoretical and gave no hint of the physical structure of the electron. Now, in this paper, it is seen that the inward-outward quantum waves are the physical structure which corresponds to the Dirac spinor. The two waves form a Dirac spinor, as was shown by Battey-Pratt et al (1986). The two physical spinor elements of the electron, or any charged particle, are as follows:

$$[\text{electron amplitude}] = \begin{matrix}\{\text{IN-AMP}\} \\ \{\text{OUT-AMP}\}\end{matrix} = (1/r)\ \{\text{AMP-max}\} \begin{matrix} e^{(iwt + ikr)} \\ e^{(iwt - ikr)} \end{matrix} \qquad [6]$$

An easily read description of the algebra of the Dirac Equation is given in Eisele (1960).

5. Geometric Requirements of Electron Spin

Structuring particles out of space (the continuum) presents a problem if the particles are considered free to spin. If part of the continuum is part of the particle then another part of space would slide past the spinning particle. As a result, the coordinate lines used to map out the whole space would become twisted up and stretched without limit. The structure of space would be torn or ripped so that one part of the continuum would slide past another along a surface of discontinuity.

If you accept the philosophical position that "ripping of space" is unacceptable, then you have to postulate that the mathematical groups of the particle motion are simply *connected* and *compact.* In this case the motion in the continuum will be cyclic and the configuration of space can repeatedly return to an earlier initial phase. Does this occur in nature? Yes, nature accommodates this requirement. Mathematicians have long known of the *spherical rotation* property of 3D space in which a portion of space can rotate and return identically to an earlier state after two turns. This unusual motion was described in Scientific American (Rebbi, 1979) and in the book *Gravitation* (Misner et al., 1973). It is the basis of spin in this article.

What are the geometric requirements on the motion of a particle which does not destroy the continuity of the space? The curvilinear coordinates of the space near the particle must participate in the motion of the particle. This requirement according to the group theory of 3D space is satisfied by stating that the allowed motions must be represented by a compact simply-connected group. The most elementary such group for the motion of a particle with spherical symmetry is named SU(2). This group provides all the necessary and known properties of spin for charged particles, such as the electron.

4. Understanding Spherical Rotation

This seldom studied motion can be modeled by a ball held by threads attached to a frame. The threads represent the coordinates of the space and the rotating ball represents a property of the space at the center of a charged particle composed of converging and diverging quantum waves. The ball can be turned about any given axis starting from any initial position. If the ball is rotated indefinitely it will be found that after every two rotations the system returns to its original configuration.

In the traditional analysis of rotating objects, it is usual to assume that the process of inverting the axis of spin is identical to reversing the spin. However, if the object is an electron which is continuously connected to its environment as part of the space around it, this ceases to be true. A careful distinction must be made between the *inversion* and the *reversal* of particle spin. This distinction provides insight to one of the most fundamental properties of particles.

To reverse the spin axis, one can reverse time (t --> -t) or reverse the angular velocity (w --> -w). Either are equivalent to exchanging the outgoing spherical wave of an electron with the incoming wave. Then the spinor becomes,

$$\{\text{amplitude}\} = \begin{matrix} e^{iwt} \\ 0 \end{matrix} \quad \text{-->} \quad \begin{matrix} e^{-iwt} \\ 0 \end{matrix}$$

To invert the spin axis of the structure of the particle, it is necessary to turn the structure about one of the axes perpendicular to the z spin axis, for example the y axis. Then the inverted spin state is given by the inversion matrix operation,

$$\{\text{amplitude}\} = \begin{matrix} 0 & -1 \\ 1 & 0 \end{matrix} \; \begin{matrix} e^{iwt} \\ 0 \end{matrix} \quad \text{-->} \quad \begin{matrix} 0 \\ e^{iwt} \end{matrix}$$

Thus, inversion and reversal are *not* the same. The difference between these operations is characteristic of the quantum nature of the electron. They are distinct from our human-sized view of rotating objects and are important to understand particle structure.

5. The Group Mathematics of Spherical Rotation

Each configuration of the spherically rotating ball (or the electron center) can be represented by a point on a Euclidean 4-D hypersphere which is also the space of the SU(2) mathematics group. A rotation in the spherical mode can be represented by any operator that will transform one vector into another position. It is usual to assign the hypersphere a unit radius. Then the rotations of the ball can be described by the mathematics of the SU(2) group. It is also convenient to place the center of the unit hypersphere at the origin and let the vector (1,0,0,0) represent an initial configuration of the ball or electron. Any other configuration is often chosen with the symbols (*a,b,c,d*). Then $a^2 + b^2 + c^2 + d^2 = 1$.

A common representation for the hypersphere vectors is the *quaternion* notation

$$\{\text{amplitude}\} = a + \mathbf{i}b + \mathbf{j}c + \mathbf{k}d$$

It can be shown (Battey-Pratt and Racey, 1986) that the 4x4 quaternion operator is equivalent to a 2x2 operator as follows:

$\{\text{amplitude}\} =$ $a + \mathbf{i}d$ $c - ib$

where the matrix elements (often just 1, i, or 0) are now complex numbers. You can see that the determinant of this is also $a^2 + b^2 + c^2 + d^2 = 1$, as above. The spinor (operand) form of (amplitude) is:

This is the notation of the Spinors invented by Dirac to represent the electron configuration, as shown in TABLE I. They also represent rotations in the spherical mode which are members of the closed uni-modular SU(2) group.

TABLE I: Properties of Spherical Rotation for

an electron in the SU(2) Representation

(spin-y)				

For example, the spherical quantum waves in space can be rotated 180^o about the z axis by the operator (spin-z). If there is continuous rotation of the quantum wave in space with angular velocity w the spinor is represented by

$$\{amplitude\} = \begin{matrix} e^{iwt} \\ 0 \end{matrix}$$

6. How Spin Arises from the Wave Structure of the Electron

The wave structure of the electron is composed of a spherical inward quantum wave and an outward wave traveling at light speed c (Wolff, 1990, 1993, 1995). Figures 1 and 2 show the wave structure of an electron termed a *space resonance.* The outward (OUT) wave of an electron travels to and communicates with other matter in its universe. When these waves arrive at other matter, a signature is modulated into their outward waves. These outward-wave signatures are the *response* (Wheeler & Feynman, 1945; Cramer, 1986, Ryazanov, 1991) from the other matter. The total of response waves from other matter in the universe, as a Fourier combination, becomes the inward (IN) wave of the initial electron. The returned inward waves converge to the initial wave center and reflect with a *phase shift* rotating them to become the outward wave and repeating the cycle again.

The central phase shift is similar to the phase shift of light when it reflects at a mirror. The required phase shift is a 180o rotation of the wave, *either* CW or CCW. There are only two possible combinations of the rotating inward and outward waves. One choice of rotation becomes an electron, the other becomes a positron. The angular momentum change upon rotation is either +h/4 or -h/4 . This is the origin of spin. One wave set is the mirror image of the other set producing the CPT invariance rule.

7. Conclusions

7.1. A COMPLETE SET OF ELECTRON PROPERTIES

The origin of spin completes the properties of the electron. All properties can now be derived from the space-resonance structure and match all experimental observations of the electron. There is now little doubt that matter is composed of spherical quantum wave structures that obey the *three principles* of *wave structure* of matter. But note that spin, and other properties, are attributes of the underlying quantum space rather than of the individual particle. This is why spin, like charge, has only one value for all particles. The properties depend on the structure of space.

7.2. A UNIVERSE OF QUANTUM WAVES AND SPACE

Although the origin of spin has been a fascinating problem of physics for sixty years, spin itself is not the important result. Instead, the most extraordinary conclusion of the wave electron structure is that the laws of physics and the structure of matter ultimately depend upon the waves from the total of matter in a universe. Every particle communicates its wave state with all other matter so that the particle structure, energy exchange, and the laws of physics are properties of the entire ensemble. This is the origin of Mach's Principle. The universal properties of the quantum space waves are also found to underlie the universal clock and the constants of nature.

This structure settles a century old paradox of whether particles are waves or point-like bits of matter. They are wave structures in space. There is nothing but space. As Clifford speculated 100 years ago, matter is simply, "undulations in the fabric of space".

7.3 THE SIMPLE ELECTRON

The elegance of the electron structure is its basic simplicity. It is only two spherical waves gracefully undulating around a center, each transforming into the other. Its spherical wave structure combines with the waves of other charged particles to create myriads of standing wave structures. These structures become the crystalline matter of the solid state. If you could see its wave structure, a crystal might appear like many shimmering bubbles neatly joined in geometric arrays. The arrays are held together with immense rigidity - a property of space.

The next frontier science of the future is to understand the meaning and structure of *space.*

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