Helical Solenoid Model of the Electron

Oliver Consa
Department of Physics and Nuclear Engineering, Universitat Politècnica de Catalunya
Campus Nord, C. Jordi Girona, 1-3, 08034 Barcelona, Spain
E-mail: oliver.consa@gmail.com

A new semiclassical model of the electron with helical solenoid geometry is presented. This new model is an extension of both the Parson Ring Model and the Hestenes Zitterbewegung Model. This model interprets the Zitterbewegung as a real motion that generates the electron's rotation (spin) and its magnetic moment. In this new model, the g-factor appears as a consequence of the electron's geometry while the quantum of magnetic flux and the quantum Hall resistance are obtained as model parameters. The Helical Solenoid Electron Model necessarily implies that the electron has a toroidal moment, a feature that is not predicted by Quantum Mechanics. The predicted toroidal moment can be tested experimentally to validate or discard this proposed model.

1 Introduction

Quantum mechanics (QM) is considered the most accurate physics theory available today. Since its conception, however, QM has generated controversy. This controversy lies not in the theory's results but in its physical interpretation.

One of the most controversial interpretations of QM was postulated by Bohr and Heisenberg. The "Copenhagen Interpretation" described QM as a system of probabilities that became definite upon the act of measurement. This interpretation was heavily criticized by many of the physicists who had participated in the development of QM, most notably Albert Einstein. Because of its probability features, Einstein believed that QM was only valid for analyzing the behavior of groups of particles and that the behavior of individual particles must be deterministic. In a famous quote from a 1926 letter to Max Born, Einstein stated, "He (God) does not play dice with the universe".

A major flaw in QM becomes apparent when the theory is applied to individual particles. This leads to logical contradictions and paradoxical situations (e.g., the paradox of Schrödinger's Cat). Einstein believed that QM was incomplete and that there must be a deeper theory based on hidden variables that would explain how subatomic particles behave individually. Einstein and his followers were not able to find a hidden variable theory that was compatible with QM, so the Copenhagen Interpretation was imposed as the interpretation of reference. If we assume that Einstein was correct, and that QM is only applicable to groups of particles, it is necessary to develop a new deterministic theory to explain the behavior of individual particles.

2 Spinning models of the electron

2.1 Ring Electron Model

In 1915, Parson [1] proposed a new model for the electron with a ring-shaped geometry where a unitary charge moves around the ring generating a magnetic field. The electron behaves not only as the unit of electric charge but also as the unit of magnetic charge or magneton. Several important physicists, including Webster, Gilbert, Grondahl and Page, conducted studies that supported Parson's Ring Electron Model. The most important of these studies was conducted by Compton [2], who wrote a series of papers showing that his newfound Compton Effect was better explained with Parson's Ring Electron Model than with the classical model that depicted the electron as a sphere. All these studies were compiled in 1918 by Allen [3] in "The Case for a Ring Electron" and discussed at a meeting of the Physical Society of London.

The Ring Electron Model was not widely accepted and was invalidated in 1923 by Schrödinger's wave equation of the electron. The Ring Electron Model has been unsuccessfully revisited several times by investigators like Iida, Carroll, Giese, Caesar, Bergman and Wesley [4], Lucas [5], Ginzburg or Kanarev [6]. Other researchers, such as Jennison [7], Gauthier [8], and Williamson and van der Mark [9], proposed similar models, with the additional assumption that the electron is a photon trapped in a vortex.

The Ring Electron Model proposes that the electron has an extremely thin, ring-shaped geometry that is about 2000 times larger than a proton. A unitary charge flows through the ring at the speed of light, generating an electric current and an associated magnetic field. This model allows us to combine experimental evidence that the electron has an extremely small size (corresponding to the thickness of the ring) as well as a relatively large size (corresponding to the circumference of the ring).

The Ring Electron Model postulates that the rotational velocity of the electric charge will match the speed of light and that the angular momentum will match the reduced Planck constant:

$$v_r = c, \tag{1}$$

$$L = mRv_r = \hbar. \tag{2}$$

As a consequence of (1) and (2), the radius of the ring will match the reduced Compton wavelength and the circum-

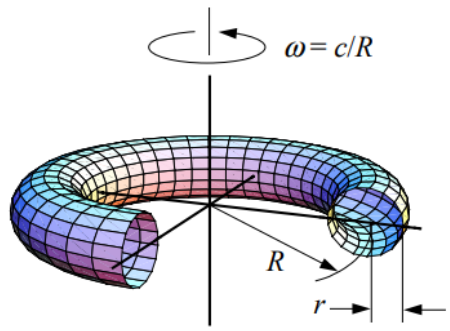

Fig. 1: Ring Electron Model.

ference will matches the Compton wavelength

$$R = \frac{\hbar}{m v_r} = \frac{\hbar}{mc} = \lambda_c \,, \tag{3}$$

$$2\pi R = \frac{h}{mc} = \lambda_c \,. \tag{4}$$

Meanwhile, the frequency, angular frequency and rotation time period of the ring electron are defined by:

$$f_e = \frac{v_r}{2\pi R} = \frac{mc^2}{h} \,, \tag{5}$$

$$w_e = 2\pi f_e = \frac{mc^2}{\hbar} \,, \tag{6}$$

$$T_e = \frac{1}{f_e} = \frac{h}{mc^2} \,. \tag{7}$$

The electron's ring acts as a circular antenna. In this type of antenna, the resonance frequency coincides with the length of the antenna's circumference. In the case of the electron ring, the resonance frequency coincides with the electron's Compton frequency.

Substituting the electron's frequency (5) in the Planck equation ($E = hf$), we obtain the Einstein's energy equation

$$E = hf_e = h\,\frac{mc^2}{h} = mc^2. \tag{8}$$

The moving charge generates a constant electric current. This electric current produces a magnetic moment that is equal to the Bohr magneton:

$$I = ef_e = \frac{emc^2}{h} \,, \tag{9}$$

$$\mu_e = IS = \frac{emc^2}{h}\,\pi R^2 = \frac{e}{2m}\,\hbar = \mu_B \,. \tag{10}$$

The relationship between the magnetic moment and the angular momentum is called the "gyromagnetic ratio" and has the value "$e/2m$". This value is consistent with the magnetic moment generated by an electric current rotating on a circular surface of radius R. The gyromagnetic ratio of the electron can be observed experimentally by applying external magnetic fields (for example, as seen in the "Zeeman effect" or in the "Stern-Gerlach experiment"):

$$E = \frac{e}{2m}\,B. \tag{11}$$

The energy of the electron is very low, but the frequency of oscillation is extremely large, which results in a significant power of about 10 gigawatts:

$$P = \frac{E}{T} = \frac{m^2c^4}{h} = 1.01 \times 10^7 \text{ W}. \tag{12}$$

Using the same line of reasoning, the electric potential can be calculated as the electron energy per unit of electric charge, resulting in a value of approximately half a million volts:

$$V = \frac{E}{e} = \frac{mc^2}{e} = 5.11 \times 10^5 \text{ V}. \tag{13}$$

The electric current has already been calculated as 20 amps ($I = ef = 19.83$ A). Multiplying the voltage by the current, the power is, again, about 10 gigawatts ($P = VI$).

The Biot-Savart Law can be applied to calculate the magnetic field at the center of the ring, resulting in a magnetic field of 30 million Tesla, equivalent to the magnetic field of a neutron star:

$$B = \frac{\mu_0 I}{2R} = 3.23 \times 10^7 \text{ T}. \tag{14}$$

For comparison, the magnetic field of the Earth is 0.000005 T, and the largest artificial magnetic field created by man is only 90 T.

The electric field in the center of the electron's ring matches the value of the magnetic field multiplied by the speed of light:

$$E = \frac{e}{4\pi\epsilon_0 R^2} = cB = 9.61 \times 10^{12} \text{ V/m}. \tag{15}$$

The Ring Electron Model implies the existence of a centripetal force that compensates for the centrifugal force of the electron orbiting around its center of mass:

$$F = m\,\frac{v_r^2}{R} = \frac{m^2c^3}{\hbar} = 0.212 \text{ N}. \tag{16}$$

Electromagnetic fields with a Lorentz force greater than this centripetal force should cause instabilities in the electron's geometry. The limits of these electric and magnetic fields are:

$$F = eE + evB, \tag{17}$$

$$E = \frac{m^2c^3}{e\hbar} = 1.32 \times 10^{18} \text{ V/m}, \tag{18}$$

$$B = \frac{m^2c^2}{e\hbar} = 4.41 \times 10^9 \text{ T}. \tag{19}$$

In quantum electrodynamics (QED), these two values are known as the Schwinger Limits [10]. Above these values, electromagnetic fields are expected to behave in a nonlinear way. While electromagnetic fields of this strength have not yet been achieved experimentally, current research suggests that electromagnetic field values above the Schwinger Limits will cause unexpected behavior not explained by the Standard Model of Particle Physics.

2.2 Helical Electron Model

In 1930, while analyzing possible solutions to the Dirac equation, Schrödinger identified a term called the Zitterbewegung that represents an unexpected oscillation whose amplitude is equal to the Compton wavelength. In 1953, Huang [11] provided a classical interpretation of the Dirac equation in which the Zitterbewegung is the mechanism that causes the electron's angular momentum (spin). According to Huang, this angular momentum is the cause of the electron's magnetic moment. Bunge [12], Barut [13], Zhangi [14], Bhabha, Corben, Weyssenhoff, Pavsic, Vaz, Rodrigues, Salesi, Recami, Hestenes [15, 16] and Rivas [17] have published papers interpreting the Zitterbewegung as a measurement of the electron's oscillatory helical motion that is hidden in the Dirac equation. We refer to these electron theories as the Hestenes Zitterbewegung Model or the Helical Electron Model.

The Helical Electron Model assumes that the electron's charge is concentrated in a single infinitesimal point called the center of charge (CC) that rotates at the speed of light around a point in space called the center of mass (CM).

The Helical Electron Model shares many similarities with the Ring Electron Model, but in the case of the Helical Electron Model, the geometric static ring is replaced by a dynamic point-like electron. In this dynamic model, the electron's ring has no substance or physical properties. It need not physically exist. It is simply the path of the CC around the CM.

The CC moves constantly without any loss of energy so that the electron acts as a superconducting ring with a persistent current. Such flows have been experimentally detected in superconducting materials.

The CC has no mass, so it can have an infinitesimal size without collapsing into a black hole, and it can move at the speed of light without violating the theory of relativity. The electron's mass is not a single point. Instead, it is distributed throughout the electromagnetic field. The electron's mass corresponds to the sum of the electron's kinetic and potential energy. By symmetry, the CM corresponds to the center of the electron's ring.

We can demonstrate the principles of the Helical Electron Model with an analogy to the postulates of the Bohr Atomic Model:

- The CC always moves at the speed of light, tracing circular orbits around the CM without radiating energy.

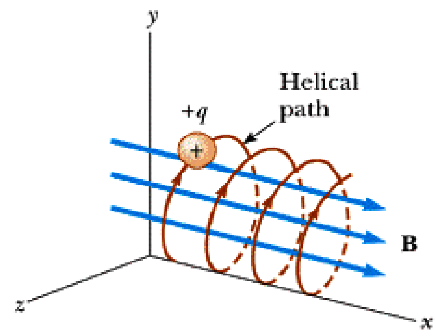

Fig. 2: Helical Electron Model.

- The electron's angular momentum equals the reduced Planck constant.
- The electron emits and absorbs electromagnetic energy that is quantized according to the formula $E = hf$.
- The emission or absorption of energy implies an acceleration of the CM.

The electron is considered to be at rest if the CM is at rest, since in that case the electric charge has only rotational movement without any translational movement. In contrast, if the CM moves with a constant velocity (v), then the CC moves in a helical motion around the CM.

The electron's helical motion is analogous to the observed motion of an electron in a homogeneous external magnetic field.

It can be parameterized as:

$$\begin{cases} x(t) = R\cos(wt)\,, \\ y(t) = R\sin(wt)\,, \\ z(t) = vt\,. \end{cases} \tag{20}$$

The electron's helical motion can be deconstructed into two orthogonal components: a rotational motion and a translational motion. The velocities of rotation and translation are not independent; they are constrained by the electron's tangential velocity that is constant and equal to the speed of light. As discussed above, when the electron is at rest, its rotational velocity is equal to the speed of light. As the translational velocity increases, the rotational velocity must decrease. At no time can the translational velocity exceed the speed of light. Using the Pythagorean Theorem, the relationship between these three velocities is:

$$c^2 = v_r^2 + v_t^2\,. \tag{21}$$

Then the rotational velocity of the moving electron is:

$$v_r = c\sqrt{1-(v/c)^2}\,, \tag{22}$$

$$v_r = c/\gamma\,. \tag{23}$$

Where gamma is the coefficient of the Lorentz transformation, the base of the Special Relativity Theory:

$$\gamma = \frac{1}{\sqrt{1-(v/c)^2}}\,. \tag{24}$$

Multiplying the three components by the same factor $(\gamma mc)^2$:

$$(\gamma mc)^2 c^2 = (\gamma mc)^2 v_r^2 + (\gamma mc)^2 v_t^2. \tag{25}$$

Substituting the value of the rotational velocity ($v_r = c/\gamma$) and linear momentum ($p = \gamma m v$), results in the relativistic energy equation:

$$E^2 = (\gamma mc^2)^2 = (mc^2)^2 + (pc)^2. \tag{26}$$

With this new value of the rotational velocity, the frequency, angular frequency and rotational time period of the helical electron are defined by:

$$f_e = \frac{v_r}{2\pi R} = \frac{mc^2}{\gamma h}\,, \tag{27}$$

$$w_e = 2\pi f_e = \frac{mc^2}{\gamma \hbar}\,, \tag{28}$$

$$T_e = \frac{1}{f_e} = \frac{\gamma h}{mc^2}\,. \tag{29}$$

The rotation time period of the electron acts as the electron's internal clock. As a result, although there is no absolute time in the universe, each electron is always set to its proper time. This proper time is relative to the electron's reference frame and its velocity with respect to other inertial reference frames.

The electron's angular momentum is always equal to the reduced Planck constant. This implies that the electron's mass has to increase γ times in order to compensate for the decrease in its rotational velocity:

$$L = mRv_r = (\gamma m)\, R\, (c/\gamma) = mRc = \hbar. \tag{30}$$

If the electron moves at a constant velocity, the particle's trajectory is a cylindrical helix. The geometry of the helix is defined by two constant parameters: the radius of the helix (R) and the helical pitch (H). The helical pitch is the space between two turns of the helix. The electron's helical motion can be interpreted as a wave motion with a wavelength equal to the helical pitch and a frequency equal to the electron's natural frequency. Multiplying the two factors results in the electron's translational velocity:

$$\lambda_e f_e = v\,, \tag{31}$$

$$\lambda_e = H = \frac{v}{f_e} = v\,\frac{\gamma h}{mc^2} = \gamma\beta\lambda_c\,. \tag{32}$$

The rest of the parameters representative of a cylindrical helix can also be calculated, including the curvature (κ) and the torsion (τ), where $h = 2\pi H = \gamma\beta\bar{\lambda}_c$:

$$\begin{cases} \kappa = \dfrac{R}{R^2+h^2} = \dfrac{1}{\gamma^2 R}\,, \\[2ex] \tau = \dfrac{h}{R^2+h^2} = \dfrac{\beta}{\gamma R}\,. \end{cases} \tag{33}$$

According to Lancret's Theorem, the necessary and sufficient condition for a curve to be a helix is that the ratio of curvature to torsion must be constant. This ratio is equal to the tangent of the angle between the osculating plane with the axis of the helix:

$$\tan\alpha = \frac{\kappa}{\tau} = \frac{1}{\gamma\beta}\,. \tag{34}$$

2.3 Toroidal Solenoid Electron Model

In 1956, Bostick, a disciple of Compton, discovered the existence of plasmoids. A plasmoid is a coherent toroidal structure made up of plasma and magnetic fields. Plasmoids are so stable that they can behave as individual objects and interact with one another. From Parson's Ring Electron Model, Bostick [21] proposed a new electron structure, similar to that of the plasmoids. In his model, the electron takes the shape of a toroidal solenoid where the electric charge circulates at the speed of light. In the Toroidal Solenoid Electron Model, we assume that the electric charge is a point particle and that the toroidal solenoid represents the trajectory of that point electric charge.

In a toroidal solenoid, any magnetic flux is confined within the toroid. This feature is consistent with the idea that the mass of a particle matches the electromagnetic energy contained therein. Storage of electromagnetic energy in a toroidal solenoid superconductor without the loss of energy is called superconducting magnetic energy storage (SMES). According to the Toroidal Solenoid Electron model, an electron is a microscopic version of a SMES system.

Toroidal solenoid geometry is well known in the electronics field where it is used to design inductors and antennas. A toroidal solenoid provides two additional degrees of freedom compared to the ring geometry. In addition to the radius (R) of the torus, two new parameters appear: the thickness of the torus (r) and the number of turns around the torus (N) with N being an integer.

The toroidal solenoid can be parameterized as:

$$\begin{cases} x(t) = (R + r\cos Nwt)\cos wt\,, \\ y(t) = (R + r\cos Nwt)\sin wt\,, \\ z(t) = r\sin Nwt. \end{cases} \tag{35}$$

Where the tangential velocity is:

$$|r'(t)|^2 = (R + r\cos Nwt)^2 w^2 + (rNw)^2. \tag{36}$$

We postulate that the tangential velocity is always equal to the speed of light ($|r'(t)| = c$). For $R \gg rN$, the rotational

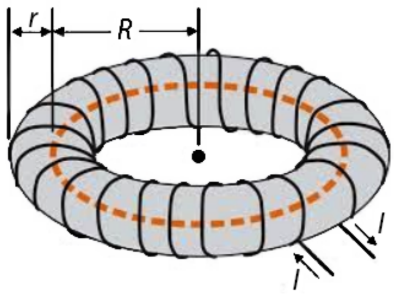

Fig. 3: Helical Toroidal Electron Model.

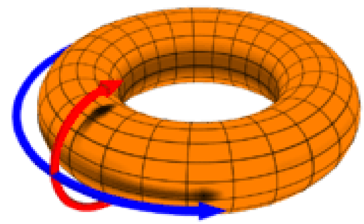

Fig. 4: Toroidal and Poloidal currents.

velocity can be obtained as:

$$c^2 = (Rw)^2 + (rNw)^2, \tag{37}$$

$$c/v_r = \sqrt{1 + \left(\frac{rN}{R}\right)^2}. \tag{38}$$

The second factor depends only on the geometry of electron. We call this value the helical g-factor. If $R \gg rN$, the helical g-factor is slightly greater than 1,

$$g = \sqrt{1 + \left(\frac{rN}{R}\right)^2}. \tag{39}$$

As a result, the rotational velocity is dependent on the helical g-factor and slightly lower than the speed of light:

$$v_r = c/g. \tag{40}$$

With this new value of the rotational velocity, the frequency, angular frequency and time period are defined by:

$$f_e = \frac{v_r}{2\pi R} = \frac{mc^2}{gh}, \tag{41}$$

$$w_e = 2\pi f_e = \frac{mc^2}{g\hbar}, \tag{42}$$

$$T_e = \frac{1}{f_e} = \frac{gh}{mc^2}. \tag{43}$$

The length of a turn of the toroidal solenoid is called the arc length. To calculate the arc length, we need to perform the integral of the toroidal solenoid over one turn:

$$\begin{aligned} l &= \int \sqrt{|r'(t)|^2} dt \\ &= \int \sqrt{(R + r\cos Nwt)^2 w^2 + (rNw)^2}\, dt. \end{aligned} \tag{44}$$

Approximating for $R \gg Nr$ and replacing the helical g-factor (39) results in:

$$\begin{aligned} l &= \int \sqrt{(Rw)^2 + (rNw)^2} dt \\ &= \int Rw\sqrt{1 + (rN/R)^2}\, dt = gR \int w dt = 2\pi g R. \end{aligned} \tag{45}$$

This means that the arc length of a toroidal solenoid is equivalent to the length of the circumference of a ring of radius $R' = gR$:

$$l = 2\pi g R = 2\pi R'. \tag{46}$$

In calculating the electron's angular momentum, we must take into consideration the helical g-factor. The value of the rotational velocity is reduced in proportion to the equivalent radius, so that the angular momentum remains constant:

$$L = mR'v_r = m\,(gR)\left(\frac{c}{g}\right) = \hbar. \tag{47}$$

The electric current flowing through a toroidal solenoid has two components, a toroidal component (red) and a poloidal component (blue).

By symmetry, the magnetic moment due to the poloidal components (red) is canceled, while the toroidal component (blue) remains fixed. No matter how large the number of turns in the toroidal solenoid, a toroidal component generates a corresponding axial magnetic moment [22]. This effect is well known in the design of toroidal antennas and can be canceled with various techniques. The exact value of the axial magnetic moment is:

$$m = I\pi R^2 \left[1 + \frac{1}{2}\left(\frac{r}{R}\right)^2\right]. \tag{48}$$

A comparison of the Toroidal Solenoid Electron Model ($v = 0, r > 0$) with the Ring Electron Model ($v = 0, r = 0$) reveals that the radius still coincides with the reduced Compton wavelength. The electric current is slightly lower, since the electron's rotational velocity is also slightly lower:

$$I\pi R^2 = ef\pi R^2 = \frac{ev_r R}{2} = \frac{ec\hbar}{2gmc} = \frac{e\hbar}{2mg} = \frac{\mu_B}{g}, \tag{49}$$

$$m = \frac{\mu_B}{g}\left[1 + \frac{1}{2}\left(\frac{r}{R}\right)^2\right], \tag{50}$$

$$m \simeq g\mu_B. \tag{51}$$

In calculating the angular momentum, the rotational velocity decreases in the same proportion as the equivalent radius increase, compensating for the helical g-factor. However, in the calculation of magnetic moment, the rotational velocity decreases by a factor of g, while the equivalent radius increases by a factor approximately equal to g squared. This is the cause of the electron's anomalous magnetic moment.

2.4 Helical Solenoid Model

The geometries of both the Ring Electron Model and the Toroidal Solenoid Electron Model represent a static electron ($v = 0$). For a moving electron with a constant velocity ($v > 0$), the ring geometry becomes a circular helix, while the toroidal solenoid geometry becomes a helical solenoid. On the other hand, if the thickness of the toroid is negated ($r = 0$), the toroidal solenoid is reduced to a ring, and the helical solenoid is reduced to a helix.

Experimentally, the electron's magnetic moment is slightly larger than the Bohr magneton. In the Ring Electron Model, it was impossible to explain the electron's anomalous magnetic moment. This leads us to assume that the electron has a substructure. The Toroidal Solenoid Electron Model allows us to obtain the electron's anomalous moment as a direct consequence of its geometry.

Geometry	$v = 0$	$v > 0$
$r = 0$	Ring	Helix
$r > 0$	Toroidal Solenoid	Helical Solenoid

The universe generally behaves in a fractal way, so the most natural solution assumes that the electron's substructure is similar to the main structure, that is, a helix in a helix.

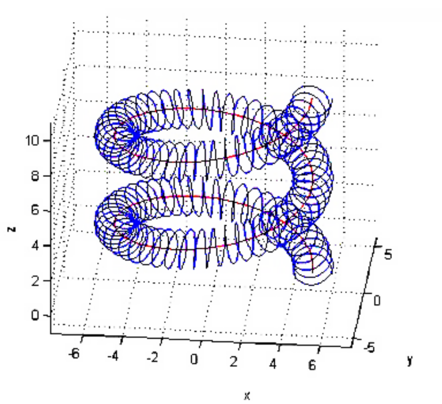

Fig. 5: Helical Solenoid Electron Model.

The trajectory of the electron can be parameterized with the equation of the helical solenoid:

$$\begin{cases} x(t) = (R + r\cos Nwt)\cos wt\,, \\ y(t) = (R + r\cos Nwt)\sin wt\,, \\ z(t) = r\sin Nwt + vt\,. \end{cases} \tag{52}$$

Like the other electron models discussed above, the Helical Solenoid Electron Model postulates that the tangential velocity of the electric charge matches the speed of light and that the electron's angular momentum matches the reduced Planck constant.

$$|r'(t)|^2 = c^2 = (Rw)^2 + (rNw)^2 + v^2 \\ + rw(2Rw + rw\cos Nwt + 2vN)\cos Nwt\,. \tag{53}$$

This equation can be obtained directly from the helical solenoid geometry without any approximation. This equation shows a component that oscillates at a very high frequency with an average value of zero. Consequently, the Helical Solenoid Electron Model implies that the electron's g-factor is oscillating, not fixed. Since the value oscillates, there is a maximum level of precision with which the g-factor can be measured. This prediction is completely new to this model and is directly opposite to previous QED predictions. For $R \gg rN$, this oscillating component can be negated, and the equation reduces to

$$c^2 = (Rw)^2 + (rNw)^2 + v^2. \tag{54}$$

The rotational velocity can be obtained as a function of the speed of light, the Lorentz factor, and the helical g-factor:

$$c^2 = (Rw)^2(1 + (rN/R)^2) + v^2, \tag{55}$$

$$c^2 = (v_r)^2 g^2 + v^2, \tag{56}$$

$$gv_r = c\sqrt{1 - v^2/c^2}\,, \tag{57}$$

$$v_r = c/g\gamma. \tag{58}$$

With this new value of the rotational velocity, the frequency, angular frequency, rotation time period and the wavelength (o pitch) of the helical solenoid electron are defined by:

$$f_e = \frac{v_r}{2\pi R} = \frac{mc^2}{g\gamma h}\,, \tag{59}$$

$$w_e = 2\pi f_e = \frac{mc^2}{g\gamma\hbar}\,, \tag{60}$$

$$T_e = \frac{1}{f_e} = \frac{g\gamma h}{mc^2}\,, \tag{61}$$

$$\lambda_e = H = \frac{v}{f_e} = g\gamma\beta\lambda_c\,. \tag{62}$$

In 2005, Michel Gouanère [18] identified this wavelength in a channeling experiment using a beam of ~80 MeV electrons aligned along the < 110 > direction of a thick silicon crystal ($d = 3.84 \times 10^{-10}$ m). While this experiment has not had much impact on QM, both Hestenes [19] and Rivas [20] have indicated that the experiment provides important experimental evidence consistent with the Hestenes Zitterbewegung Model:

$$d = g\gamma\beta\lambda_c = (\gamma mv)\frac{gh}{(mc)^2} = p\,\frac{gh}{(mc)^2}\,, \tag{63}$$

$$p = d\,\frac{(mc)^2}{gh} = 80.874 \text{ MeV/c}. \tag{64}$$

In the Helical Solenoid Electron Model, the rotational velocity is reduced by both the helical g-factor and the Lorentz factor. In contrast, the equivalent radius compensates for the helical g-factor while the increasing mass compensates for the Lorentz factor. The angular momentum remains equal to the reduced Planck constant:

$$L = m'R'v_r = (\gamma m)(gR)(c/\gamma g) = mRc = \hbar. \tag{65}$$

3 Consequences of the Helical Solenoid Electron Model

3.1 Chirality and helicity

In 1956, an experiment based on the beta decay of a Cobalt-60 nucleus demonstrated a clear violation of parity conservation. In the early 1960s the parity symmetry breaking was used by Glashow, Salam and Weinberg to develop the Electroweak Model, unifying the weak nuclear force with the electromagnetic force. The empirical observation that electroweak interactions act differently on right-handed fermions and left-handed fermions is one of the basic characteristics of this theory.

In the Electroweak Model, chirality and helicity are essential properties of subatomic particles, but these abstract concepts are difficult to visualize. In contrast, in the Helical Solenoid Electron Model, these concepts are evident and a direct consequence of the model's geometry:

- Helicity is given by the helical translation motion ($v > 0$), which can be left-handed or right-handed. Helicity is not an absolute value; it is relative to the speed of the observer.
- Chirality is given by the secondary helical rotational motion, which can also be left-handed or right-handed. Chirality is absolute since the tangential velocity is always equal to the speed of light; it is independent of the velocity of the observer.

3.2 Quantum Hall resistance and magnetic flux

The movement of the electric charge causes an electrical current ($I = ef_e$) and a electric voltage ($V = E/e = hf_e/e$). Applying Ohm's law, we obtain a fixed value for the impedance of the electron equal to the value of the quantum Hall resistance. This value is quite surprising, since it is observable at the macroscopic level and was not discovered experimentally until 1980:

$$R = \frac{V_e}{I_e} = \frac{hf_e/e}{ef_e} = \frac{h}{e^2}\,. \tag{66}$$

According to Faraday's Law, voltage is the variation of the magnetic flux per unit of time. So, in a period of rotation, we obtain a magnetic flux value which coincides with the quantum of magnetic flux, another macroscopically observable value. This value was expected since, in this model, the electron behaves as a superconducting ring, and it is experimentally known that the magnetic flux in a superconducting ring is quantized:

$$V = \phi_e/T_e\,, \tag{67}$$

$$\phi_e = V_e T_e = \frac{hf_e}{e}\frac{1}{f_e} = \frac{h}{e}\,. \tag{68}$$

3.3 Quantum LC circuit

Both the electrical current and the voltage of the electron are frequency dependent. This means that the electron behaves as a quantum LC circuit, with a Capacitance (C) and a Self Inductance (L). We can calculate these coefficients for a electron at rest, obtaining values $L = 2.08 \times 10^{-16}$ H and $C = 3.13 \times 10^{-25}$ F:

$$L_e = \frac{\phi_e}{I_e} = \frac{h}{e^2 f_e} = \frac{g\gamma h^2}{mc^2 e^2}\,, \tag{69}$$

$$C_e = \frac{e}{V_e} = \frac{e^2}{hf_e} = \frac{g\gamma e^2}{mc^2}\,. \tag{70}$$

Applying the formulas of the LC circuit, we can obtain the values of impedance and resonance frequency, which coincide with the previously calculated values of impedance and natural frequency of the electron:

$$Z_e = \sqrt{\frac{L_e}{C_e}} = \frac{h}{e^2}\,, \tag{71}$$

$$f_e = \frac{1}{\sqrt{L_e C_e}} = \frac{mc^2}{g\gamma h} = f_e\,. \tag{72}$$

As the energy of the particle oscillates between electric and magnetic energy, the average energy value is

$$E = \frac{LI^2}{2} + \frac{CV^2}{2} = \frac{hf}{2} + \frac{hf}{2} = hf\,. \tag{73}$$

The above calculations are valid for any elementary particle with a unit electric charge, a natural frequency of vibration and an energy which match the Planck equation ($E = hf$).

From this result, we infer that the electron is formed by two indivisible elements: a quantum of electric charge and a quantum of magnetic flux, the product of which is equal to Planck's constant. The electron's magnetic flux is simultaneously the cause and the consequence of the circular motion of the electric charge:

$$e\phi = h. \tag{74}$$

3.4 Quantitative calculation of the helical G-factor

The g-factor depends on three parameters (R, r and N) but we do not know the value of two of them. We can try to figure out the value of the helical g-factor using this approximation [28]:

Using this expansion series:

$$\sqrt{1 + (a)^2} = 1 + 1/2(a)^2 + \ldots \tag{75}$$

The helical g-factor can be expressed as:

$$\sqrt{1+\left(\frac{rN}{R}\right)^2} = 1 + \frac{1}{2}\left(\frac{rN}{R}\right)^2 + \ldots \qquad (76)$$

QED also calculates the g-factor by an expansion series where the first term is 1 and the second term is the Schwinger factor:

$$g.factor(QED) = 1 + \frac{\alpha}{2\pi} + \ldots \qquad (77)$$

The results of the two series are very similar. Equaling the second term of the helical g-factor series to the Schwinger factor, we obtain the relationship between the radius of the torus and the thickness of the torus:

$$\frac{1}{2}\left(\frac{rN}{R}\right)^2 = \frac{\alpha}{2\pi}, \qquad (78)$$

$$\frac{rN}{R} = \sqrt{\frac{\alpha}{\pi}}. \qquad (79)$$

What gives a value of helical g-factor of

$$g = \sqrt{1+\alpha/\pi}. \qquad (80)$$

This gives us a value of the helical g-factor = 1.0011607. This result is consistent with the Schwinger factor, and it offers a value much closer to the experimental value.

3.5 Toroidal moment

In 1957, Zel'dovich [23] discussed the parity violation of elementary particles and postulated that spin-1/2 Dirac particles must have an anapole. In the late 1960s and early 1970s, Dubovik [24, 25] connected the quantum description of the anapole to classical electrodynamics by introducing the polar toroidal multipole moments. The term toroidal derives from current distributions in the shape of a circular coil that were first shown to have a toroidal moment. Toroidal moments were not acknowledged outside the Soviet Union as being an important part of the multipole expansion until the 1990s. Toroidal moments became known in western countries in the late 1990s. Finally, in 1997, toroidal moment was experimentally measured in the nuclei of Cesium-133 and Ytterbium-174 [26].

In 2013, Ho and Scherrer [27] hypothesized that Dark Matter is formed by neutral subatomic particles. These particles of cold dark matter interact with ordinary matter only through an anapole electromagnetic moment, similar to the toroidal magnetic moment described above. These particles are called Majorana fermions, and they cannot have any other electromagnetic moment apart from the toroid moment. The model for these subatomic particles of dark matter is compatible with the Helical Solenoid Electron Model.

In an electrostatic field, all charge distributions and currents may be represented by a multipolar expansion using only electric and magnetic multipoles. Instead, in a multipolar expansion of an electrodynamic field new terms appear. These new terms correspond to a third family of multipoles: the toroid moments. The toroidal lower order term is the toroidal dipole moment. The toroidal moment can understood as the momentum generated by a distribution of magnetic moments. The simplest case is the toroidal moment generated by an electric current in a toroidal solenoid.

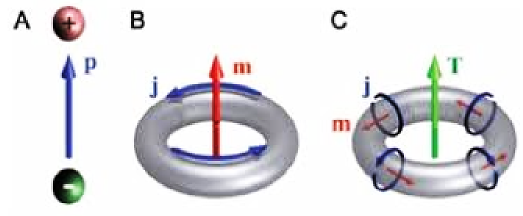

Fig. 6: Electric, Magnetic and Toroidal dipole moments.

The toroidal moment is calculated with the following equation [24]:

$$T = \frac{1}{10}\int \left[(\mathbf{j}\cdot\mathbf{r})\,\mathbf{r} - 2r^2\mathbf{j}\right] dV. \qquad (81)$$

In the case of the toroidal solenoid, the toroidal moment can be calculated more directly as the B field inside the toroid by both the surface of the torus and the surface of the ring [25]:

$$\mu T = BsS = B\left(\pi r^2\right)\left(\pi R^2\right), \qquad (82)$$

$$B = \frac{\mu N I}{2\pi R}. \qquad (83)$$

Using B, the toroidal moment is obtained as [22]:

$$T = \frac{NI}{2\pi R}\left(\pi r^2\right)\left(\pi R^2\right) = \frac{NI\left(\pi r^2\right)R}{2}. \qquad (84)$$

Rearranging and using the relation (79):

$$T = \mu_B \frac{R}{g2N}\left(\frac{rN}{R}\right)^2 = \mu_B \frac{\lambda_c}{gN}\left(\frac{\alpha}{2\pi}\right). \qquad (85)$$

According the Helical Solenoid Electron Model, the electron's theoretical toroidal moment is about $T \simeq 10^{-40}$ Am^3. The theoretical toroidal moment value for the neutron and the proton should be one million times smaller. The existence of a toroidal moment for the electron (and for any other subatomic particle) is a direct consequence of this model, and it may be validated experimentally. Notably, QM does not predict the existence of any toroidal moments.

3.6 Nucleon model

By analogy to the theory underlying the Helical Solenoid Electron Model, we assume that all subatomic particles have the same structure as the electron, differing mainly by their charge and mass. Protons are thought to be composed of other fundamental particles called quarks, but their internal organization is beyond the scope of this work.

The radius of a nucleon is equal to its reduced Compton wavelength. The Compton wavelength is inversely proportional to an object's mass, so for subatomic particles, as mass increases, size decreases. Both the proton and the neutron have a radius that is about 2000 times smaller than the electron. Historically, the proton radius was measured using two independent methods that converged to a value of about 0.8768 fm. This value was challenged by a 2010 experiment utilizing a third method, which produced a radius of about 0.8408 fm. This discrepancy remains unresolved and is the topic of ongoing research referred to as the Proton Radius Puzzle. The proton's reduced Compton wavelength is 0.2103 fm. If we multiple this radius by 4, we obtain the value of 0.8412 fm. This value corresponds nicely with the most recent experimental radius of the proton. This data supports our theory that the proton's radius is related to its reduced Compton radius and that our Helical Solenoid Electron Model is also a valid model for the proton.

The current of a nucleon is about 2000 times the current of an electron, and the radius is about 2000 times lower. This results in a magnetic field at the center of the nucleon's ring that is about four million times bigger than that of the electron or thousands of times bigger than a neutron star. This magnetic field is inversely dependent with the cube of the distance. This implies that while the magnetic field inside the neutron's ring is huge, outside the ring, the magnetic field decays much faster than the electric field. The asymmetrical behavior of the neutron's magnetic field over short and long distances leads us to suggest that the previously identified strong and weak nuclear forces are actually manifestations of this huge magnetic field at very short distances.

3.7 Spin quantum number

In 1913, Bohr introduced the Principal Quantum Number to explain the Rydberg Formula for the spectral emission lines of atomic hydrogen. Sommerfeld extended the Bohr theory with the Azimuthal Quantum Number to explain the fine structure of the hydrogen, and he introduced a third Magnetic Quantum Number to explain the Zeeman effect. Finally, in 1921, Landé put forth a formula (named the Landé g-factor) that allowed him to explain the anomalous Zeeman effect and to obtain the whole spectrum of all atoms.

$$\begin{aligned} g_J = g_L &\frac{J(J+1) - S(S+1) + L(L+1)}{2J(J+1)} \\ + g_S &\frac{J(J+1) + S(S+1) - L(L+1)}{2J(J+1)}. \end{aligned} \quad (86)$$

In this formula, Landé introduced a fourth Quantum Number with a half-integer number value (S = 1/2). This Landé g-factor was an empirical formula where the physical meaning of the four quantum numbers and their relationship with the motion of the electrons around the nucleus was unknown. Heisenberg, Pauli, Sommerfeld, and Landé tried unsuccessfully to devise a new atomic model (named the Ersatz Model) to explain this empirical formula. Landé proposed that his g-factor was produced by the combination of the orbital momentum of the outer electrons with the orbital momentum of the inner electrons. A different solution was suggested by Kronig, who proposed that the half-integer number was generated by a self-rotation motion of the electron (spin), but Pauli rejected this theory.

In 1925, Uhlenbeck and Goudsmit published a paper proposing the same idea, namely that the spin quantum number was produced by the electron's self-rotation. The half-integer spin implies an anomalous magnetic moment of 2. In 1926, Thomas identified a relativistic correction of the model with a value of 2 (named the Thomas Precession) that compensated for the anomalous magnetic moment of the spin. Despite his initial objections, Pauli formalized the theory of spin in 1927 using the modern theory of QM as set out by Schrödinger and Heisenberg. Pauli proposed that spin, angular moment, and magnetic moment are intrinsic properties of the electron and that these properties are not related to any actual spinning motion. The Pauli Exclusion Principle states that two electrons in an atom or a molecule cannot have the same four quantum numbers. Pauli's ideas brought about a radical change in QM. The Bohr-Sommerfeld Model's explicit electron orbitals were abandoned and with them any physical model of the electron or the atom.

We propose to return to the old quantum theory of Bohr-Sommerfeld to search for a new Ersatz Model of the atom where the four quantum numbers are related to electron orbitals. We propose that this new atomic model will be compatible with our Helical Solenoid Electron Model. We also propose that the half-integer spin quantum number is not an intrinsic property of the electron but a result of the magnetic fields generated by orbiting inner electrons.

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