

Fundamental Particle Spin: Derivation of the Energy-Frequency Relation, Schwarzschild Metric, and Fine Structure Constant

Xincal Luo
Newcosmos Institute, Bear, DE 19701, USA
Email: xincailuo@newcosmosinst.org

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Abstract

We present a novel theory of fundamental particle spin, deriving the energy-frequency relation of quantum theory, the Schwarzschild metric of general relativity, and the fine-structure constant from this single framework. Our theory posits that fundamental particles are composed of fundamental charges (FCs) and derives the energy-frequency relation and spin angular momenta of these particles from the circular motion of their constituent FCs, as described by Newtonian classical mechanics. The conservation of energy and angular momentum necessitates that each fundamental particle possesses wave-like properties, mathematically represented by corresponding wavefunctions in quantum mechanics. The phase angle of the wavefunction directly corresponds to the angle of this circular motion. The energy, which is proportional to the frequency of the FCs' circular motion, is expressed as the result of applying the operator $i\hbar \frac{\partial}{\partial t}$ to its wavefunction. Based on this wave arising from the circular motion of FCs, a particle's energy must propagate at the speed of light. This requirement extends beyond the constancy of the speed of light in all inertial frames proposed by special relativity. In the rest frame of a particle, precisely half of its energy moves forward and the other half moves backward at the speed of light, creating an apparent zero velocity. This constant energy propagation speed implies a constant energy flow rate, which then yields the Schwarzschild metric of general relativity. This work demonstrates that the principles of quantum mechanics and relativity are inherently linked to fundamental particle spins. Furthermore, the spin theory enables the derivation of electroweak coupling constants from first principles. The theoretical fine-structure constant derived from this spin model (without experimental input) exhibits strong agreement with experimental values (a discrepancy of only 0.14%), and the predicted electron charge (1.603×10^{-19} C) closely matches the experimentally determined value (1.602×10^{-19} C).

Keywords: particle spin, energy-frequency relationship, Schwarzschild metric, fine structure constant.

1. Introduction

Spin is a fundamental property of fundamental particles. The electron spin and magnetic moment are central to spintronics [1–3], a field holding significant potential for information storage and processing. The pairing of electrons with antiparallel spins plays a crucial role in the formation of covalent bonds in molecules [4]. In the Standard Model of particle physics, fundamental particles like photons and electrons are treated as point particles with no spatial extent. Experimental results consistently confirm that electrons are point-like, lacking substructure[5–9]. Similarly, a variety of particle interaction experiments indicate that leptons and quarks also behave as point particles without substructure[10–16]. These findings support the Standard Model's treatment of fundamental particles as point particles with localized charges. While electron spin has been known for a century [17,18], the mechanism by which a point-like electron generates its spin angular momentum and magnetic moment remains a subject of debate. Classical models of electron spin fail to accurately predict the g-factor [19]. In quantum theory, the spin angular momentum of a fundamental fermion is treated as an observable without a classical counterpart, arising from the application of Pauli matrices to abstract spinor wavefunctions [20]. The Dirac equation provides a correct prediction for the g-factor [21]. Classically generating angular momentum requires a non-zero spatial extent. The spin angular momentum and magnetic moment of an electron can be interpreted as the rotation of its wave [22–27].

Nature encompasses four fundamental forces. The Standard Model of particle physics studies fundamental particles based on quantum field theory, incorporating only electromagnetic, weak, and strong interactions [28–30]. In contrast, general relativity [31] describes gravity not as a force, but as the geometry of spacetime. This distinction means that gravity is currently not integrated with the other three forces within the Standard Model. Newtonian theory posits that the gravitational interaction between two particles is directly proportional to their masses [32]. Understanding the relationship between gravity and fundamental particle masses could yield profound insights into the origin of gravity and potentially unify it with the other three forces.

The four fundamental forces of nature are each defined by a specific constant that determines their strength. Gravity is characterized by Newton's gravitational constant [31], electromagnetism by the fine-structure constant [28,33], the strong interaction by the strong coupling constant [30], and the weak interaction by the weak coupling constant [29,34]. Gravitational interactions between charged particles are typically negligible compared to electromagnetic interactions. Furthermore, the distance scales for strong and weak interactions are far smaller than those for chemical reactions. Consequently, processes in chemistry, biology, and materials science usually involve only electromagnetic interactions. The electron charge (or fine-structure constant) is an input parameter in all calculations involving electromagnetism, from quantum electrodynamics in particle physics to atomic and molecular property calculations in chemistry, biology, and materials science. Determining the electron charge solely from theoretical principles, without experimental input, is a key goal in theoretical physics. Success in this endeavor would provide profound

insights into the universe's fundamental nature and potentially address unresolved questions such as the hierarchy problem [35] and the nature of dark matter [36–39].

Fundamental particles exhibit both particle-like and wave-like behavior, described by wave functions. Spin, wave-particle duality, and the energy-frequency relationship are cornerstones of quantum theory [20]. While quantum theory provides a framework for describing these phenomena, it does not offer a deeper explanation of their underlying origins. A theory that connects these components with coupling constants could yield new insights and address unresolved problems in physics.

In [40], we presented a first-principles derivation of the electroweak coupling constants and Higgs boson mass based on a novel theory of fundamental particle spin. This paper explores the implications of this spin theory for quantum mechanics and relativity. The paper is structured as follows: Section 2 introduces the theory of fundamental particle spin and discusses its implications for quantum mechanics. Section 3 derives the Schwarzschild metric of general relativity from this framework. Section 4 presents a derived formula for calculating the electron charge without experimental input. The implications of these findings are discussed in Section 5, followed by concluding remarks in Section 6.

2. The energies and spins of fundamental particles

A fundamental charge (FC) is defined as a point charge with no spatial extent. For two fundamental charges, one positive and one negative, separated by a (very small) distance $2r$, the potential energy is given by the following equations:

$$U(r) = \frac{kr^2}{2}, \quad (1)$$

$$k = \frac{8c^4}{Gr_e}, \quad (2)$$

where G is the Newtonian gravitational constant, c is the speed of light, and r_e is the radius for the charge interaction. This potential energy includes the rest energy and the field-related energy, such as the electromagnetic field energy and gravitational potential energy, of the two FCs. The derivation of Eq. (1) is in a separate manuscript [41], which presents a gravitation theory grounded in the origin of fundamental particle masses.

Assume that each of the two FCs has mass $m_{FC}/2$ and orbits around the center of mass, which lies midway between them. The centripetal force required for the circular motion is provided by the potential energy from Eq. (1). The balance of forces is given by:

$$\frac{m_{FC}}{2} \frac{v^2}{r} = \frac{kr}{2}. \quad (3)$$

The factor 1/2 in Eq. (3) is due to that the two FCs share the mass and the potential energy equally such that each FC has a half of the mass and a half of the potential energy.

Solving Eq. (3) for velocity v , we obtain

$$v = \sqrt{\frac{k}{m_{FC}}} r . \quad (4)$$

The kinetic energy of the two FCs is therefore

$$E_k = \frac{m_{FC} v^2}{2} = \frac{kr^2}{2} = U . \quad (5)$$

Since the rest energy and all field-related energies are already incorporated into the potential energy, the total energy of the system is the sum of its kinetic energy and this potential energy:

$$E = E_k + U = m_{FC} v^2 = kr^2 . \quad (6)$$

Let a be the total angular momentum of the two FCs:

$$m_{FC} v r = a . \quad (7)$$

Their energy is

$$E = m_{FC} v^2 = \frac{m_{FC} v r v}{r} = 2\pi a \frac{v}{2\pi r} = 2\pi a f , \quad (8)$$

where f represents the frequency of the circular motion. Since the energy is proportional to the frequency, this energy-frequency relation is equivalent to the Planck's relation [20]. The relation implies that $2\pi a$ in Eq. (8) is equal to the Planck constant (h), meaning that a is the reduced Planck constant ($\hbar$). Consequently, the angular momentum of the two FCs is

$$m_{FC} v r = \hbar . \quad (9)$$

This result precisely matches the spin angular momentum of a photon. The angular momentum and energy-frequency relationship explain both the spin and the wave properties of the photon. These phenomena arise from the circular motion of two FCs that are closely coupled.

For an electron, the system consists of a stationary positive FC at the center, and two negative FCs orbiting around it. This arrangement is equivalent to a negative FC combined with a photon. During one complete spatial revolution of the orbiting FCs (a rotation of 2π radians), the central positive FC effectively forms a photon with one of the negative FCs. In the subsequent complete spatial revolution, the central positive FC then forms a photon with the other negative FC.

Therefore, it takes two complete spatial revolutions (a total rotation of 4π radians) for the system to return to its initial spatial position and physical state. The energy of the electron is:

$$m_{FC}v^2 = E = hf = h\frac{v}{4\pi r} = \hbar\frac{v}{2r}. \quad (10)$$

Multiplying both sides of Eq. (10) by r/v , we obtain the following angular momentum of the electron:

$$m_{FC}vr = \frac{\hbar}{2}. \quad (11)$$

Therefore, the spin of the electron is $1/2$, providing a theoretical explanation for its intrinsic angular momentum. This derivation eliminates the need for *ad hoc* hypotheses. Furthermore, the circular motion naturally accounts for the electron's g-factor, which is approximately 2, in its magnetic moment. For the spin of the electron, two negative FCs are moving in the circular orbit while the positive FC is at the center, resulting in twice the magnetic moment generated by one negative FC.

In a system of four FCs—two positive and two negative—arranged in a circle, the system returns to its initial state after traversing half a circle (an angle of π radians) due to symmetry considerations. The resulting energy and angular momentum for this system are:

$$m_{FC}v^2 = E = hf = h\frac{v}{\pi r} = 2\hbar\frac{v}{r}, \quad (12)$$

$$m_{FC}vr = 2\hbar. \quad (13)$$

The spin of the system with four FCs is 2.

In summary, a fundamental charge (FC) is defined as a point charge. A photon, consisting of one positive and one negative FC, is electrically neutral. The circular motion of these two FCs generates the photon's spin angular momentum ($\hbar$) and its energy-frequency relationship. Similarly, an electron comprises two negative FCs and one positive FC, resulting in a net negative charge. The circular motion of the two negative FCs around the positive FC produces the electron's spin angular momentum ($\hbar/2$) and its corresponding energy-frequency relationship. The g-factor for the magnetic moment, observed to be 2 experimentally, arises from this circular motion of two negative FCs.

These FCs are not particles. Their circular motions, governed by Newton's laws, generates fundamental particles with intrinsic spin and energy. The frequency of a fundamental particle corresponds to the frequency of the FC's circular motion, with energy directly proportional to that frequency. Given the substantial mass of each FC, a sufficiently small radius is required for their circular motion to produce the angular momentum. The principles of quantum theory emerge from these fundamental circular motions.

The circular motion of FCs naturally explains the wave-particle duality observed in fundamental particles. In a photon, the two original FCs are extremely massive and closely spaced, contributing to its particle-like nature. For example, based on Eq. (1), a photon with an energy of

2 eV contains two heavy FCs—one positive and one negative—separated by a distance of 1.37×10^{-39} meters. The mutual gravitational and electric fields between these FCs reduce their energy. This reduced energy is directly proportional to the frequency of their circular motion. In an isolated system, both energy and angular momentum are conserved. For the two heavy FCs in the photon with an energy of 2 eV, a circular motion of a small radius (6.85×10^{-40} meters) is sufficient to generate the spin angular momentum ($\hbar$). The particle nature of the photon stems from the spatial extent of the original energy of these FCs (1.37×10^{-39} meters for a 2 eV photon). Since their energy is reduced by mutual fields, the actual energy of the photon becomes 2 eV. The radius required to generate angular momentum $\hbar$ from this reduced energy is $\hbar c/E$. Consequently, the reduced energy must spread out spatially to produce this angular momentum, giving rise to the wave-like properties of the photon. The particle nature arises from the original FC spatial extent (1.37×10^{-39} meters), while its wave-like characteristics are related to the spatial extent of the reduced energy of 2 eV. This provides a physical foundation for the observed wave-particle duality in fundamental particles.

Each fundamental particle is composed of multiple point charges (FCs), but due to their proximity, the particle effectively behaves as a single point particle. For instance, the maximum separation between FCs in a free electron at rest is 6.9×10^{-37} meters—a distance far smaller than the scale currently accessible to experimental physics. An FC cannot exist in isolation; it must combine with others to form fundamental particles. Separating the two FCs in a photon by 2 meters requires an energy of 6.87×10^{59} joules, comparable to the total energy contained within the Milky Way Galaxy.

The circular motion of the FCs within a fundamental particle is described by Newtonian mechanics, from which both its angular momentum and energy-frequency relationship derive. The resulting wave—a consequence of this circular motion and the conservation of energy and angular momentum—is mathematically represented by corresponding wavefunctions in quantum mechanics. The phase angle of the wavefunction directly corresponds to the angle of this circular motion. As the energy of a fundamental particle is proportional to the frequency of its FCs' circular motion, it can be expressed as the result of applying the operator $i\hbar \frac{\partial}{\partial t}$ to its wavefunction. Consequently, the operators for momentum components (p_x , p_y , p_z) are expected to be $-i\hbar \frac{\partial}{\partial x}$, $-i\hbar \frac{\partial}{\partial y}$, and $-i\hbar \frac{\partial}{\partial z}$ respectively, consistent with the relativistic treatment of $(E/c, p_x, p_y, p_z)$ as a vector. This correspondence between physical observables and quantum mechanical operators demonstrates that fundamental principles of quantum mechanics arise from the Newtonian classical mechanics of FCs. The Dirac and Schrödinger equations are direct consequences of these correspondences.

The spin angular momentum of a fundamental particle is the classical orbital angular momentum of its constituent FCs. This circular motion generates the particle's intrinsic spin. Within the resulting wavefunction, the spin angular momentum manifests as rotation of the wave itself, a phenomenon observed and discussed by numerous authors [22–27].

3. Spacetime metric

As described in Section 2, a photon is composed of two FCs, one with a positive charge and the other with a negative charge. The intrinsic spin angular momentum of the photon arises from the circular motion of these two FCs, and its energy is directly proportional to the frequency of this motion. For a photon with an energy of 2 eV, each FC has a mass of 3.72×10^{28} kg and they are separated by a distance of 1.37×10^{-39} meters. The Schwarzschild radius for a mass of 3.72×10^{28} kg is 55.3 meters. The radial distance of 1.37×10^{-39} meters is 40 orders of magnitude smaller than the Schwarzschild radius. Consequently, the FC mass of 3.72×10^{28} kg within such a small radial distance effectively creates a black hole. This implies that one FC is located at 1.37×10^{-39} meters from the center of this black hole, formed by the other FC with a mass of 3.72×10^{28} kg. According to general relativity, spacetime near such a massive object must be extremely curved, and the motion of the FC must be described by general relativity. However, the motion of the FC within this strong gravitational field is governed by Newtonian mechanics. Therefore, the local curvature of space near a massive object is an effect of the wave generated by the circular motion of these FCs (the spin of the fundamental particle).

Relativity arises from the fundamental particle spins. Specifically, during each period of rotation, one FC advances while the other recedes. In the rest frame of a fundamental particle, its velocity is zero; however, its energy still moves at the speed of light due to spin. When momentum (and therefore velocity) is zero, precisely half of the energy moves forward and the other half moves backward, creating an apparent zero velocity. When momentum is non-zero, more than half of the energy moves forward, while less than half moves backward, resulting in a net momentum (velocity). As illustrated in Eq. (6), the energy of a particle is:

$$E = E_k + U = \frac{1}{2} m_{FC} v^2 + U = \frac{1}{2} m c^2 + U = m c^2, \quad (14)$$

where m_{FC} is the mass of the original FCs and m represents the final reduced mass generated from the original mass by gravitational and electric fields. Half of this energy manifests as kinetic energy, while the other half appears as potential energy. The kinetic energy corresponds the kinetic energy of a mass m at the speed of light, as described by the Newtonian mechanics. The velocity (and therefore momentum) of a particle is determine by the fraction of its energy that move forward. The increase in the speed of a particle is proportional to the increase in the fraction of its energy propagating forward. For light, 100% of its energy move forward, resulting in a velocity equal to the speed of light. In contrast, for massive particles, the velocity is below the speed of light because less than 100% of their energy propagates forward. The speed of light at which energy must propagate remains invariant across all inertial systems. This demonstrates that the special relativity, which is based on the assumption that the speed of light is constant in all inertial frames, arises from particle spins.

For a fundamental particle with mass m_0 and momentum p , the amount of energy moving forward is

$$E_f = \frac{E + pc}{2} \quad (15)$$

and the amount of energy moving backward is

$$E_b = \frac{E - pc}{2} . \quad (16)$$

The total energy is the sum of the energy moving forward and that moving backward, while the net energy moving forward is the difference between the two:

$$E = E_f + E_b , \quad (17)$$

$$pc = E_f - E_b . \quad (18)$$

The energy is increased from the rest energy m_0c^2 to

$$E = \frac{m_0c^2}{\sqrt{1 - \frac{v^2}{c^2}}} \quad (19)$$

by a factor of $(1-v^2/c^2)^{-1/2}$.

The motion of the FCs in a fundamental particle is governed by Newtonian mechanics, which establishes an inherent spacetime defined by absolute distances between any two locations. These absolute distances remain constant regardless of inertial frames or local gravitational influences. In contrast, general relativity describes the dynamics of particles within a gravitational field using a gravity-dependent metric derived from energy-momentum and curvature tensors. Therefore, Newtonian mechanics employs a fixed metric of absolute space and time, while general relativity utilizes a dynamic metric that reflects the curvature of spacetime. Both metrics exist within the same space; they provide different descriptions applicable to different physical scenarios. The motion of the FCs in a fundamental particle is governed by Newtonian mechanics in the absolute space and time while the motion of the particle in a gravitational field is described by general relativity.

In the absence of gravity and in a rest frame, a fundamental particle does not experience length contraction or time dilation. There is also no local curvature due to gravity. In this scenario, the wavelength of the particle corresponds to absolute distances within Newtonian space, and the period of its wave corresponds to absolute time in Newtonian time. The energy carried by a fundamental particle always travels at the speed of light. The relationship between energy (E) and wavelength (λ) for generating spin angular momentum is described by the following equations:

$$\frac{E}{c} \frac{\lambda}{2\pi} = \hbar , \quad (20)$$

$$E\lambda = 2\pi\hbar c = hc . \quad (21)$$

The product of energy and wavelength must remain constant across all inertial frames and locations in the universe. When the energy increases by a factor of $(1-v^2/c^2)^{-1/2}$ in an inertial frame, the wavelength must decrease by the same factor, resulting in length contraction. Given that the energy of a fundamental particle always propagates at the speed of light, this relationship can be interpreted as a constant energy flow rate for the particle. In a rest frame of a fundamental particle and in the absence of gravity, the energy flow rate is:

$$\frac{E_0 \lambda_0}{T_0} = E_0 c, \quad (22)$$

where E_0 ($m_0 c^2$) represents the rest energy of the particle, λ_0 is its wavelength, T_0 is the period of the circulation motion of the FCs within the particle, and c is the speed of light that the energy in the particle must move. This constant energy flow rate implies that an increase in energy within an inertial frame reduces the distance the particle can traverse within a given time period, leading to length contraction. Conversely, it increases the time required for the energy to travel a given distance, resulting in time dilation.

In our particle spin theory, not only is the speed of light constant across all inertial frames as proposed by special relativity, but also all energy in the universe must move at that speed. While a particle can be at rest due to an equal distribution of forward and backward moving energy, its constituent energy must propagate at the speed of light. The requirement of a constant energy flow rate for a fundamental particle binds independent time and space – concepts inherent in Newtonian mechanics – into the four-dimensional spacetime described by relativity.

For a particle with mass m located at a distance r from the center of an astronomical object with mass M , its rest energy is reduced by the gravitational potential energy. When $GM/c^2 r \ll 1$, this reduction is equivalent to the kinetic energy of the particle with velocity v as follows:

$$\frac{1}{2} m v^2 = \frac{GMm}{r}. \quad (23)$$

Multiplying both sides of Eq. (20) by $2/mc^2$, we obtain:

$$\frac{v^2}{c^2} = \frac{2GM}{c^2 r}. \quad (24)$$

Because the energy flow rate is constant, a decrease in energy will result in an increase in the distance over which the energy can propagate within a given time period and a decrease in the time required to travel a given distance. The resulting metric in this weak-field limit is

$$\begin{aligned} ds^2 &= c^2 \left(1 - \frac{v^2}{c^2} \right) dt^2 - \left(1 - \frac{v^2}{c^2} \right)^{-1} dr^2 - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2 \\ &= c^2 \left(1 - \frac{2GM}{c^2 r} \right) dt^2 - \left(1 - \frac{2GM}{c^2 r} \right)^{-1} dr^2 - r^2 d\theta^2 - r^2 \sin^2 \theta d\phi^2. \end{aligned} \quad (25)$$

This spacetime metric is consistent with the predictions of general relativity [31,43] and is known as the Schwarzschild metric. It quantifies the differential distances and time intervals within the gravitational field generated by a mass M . The factor $(1-v^2/c^2)^{-1/2}$ and $(1-2GM/c^2r)^{-1/2}$ describe how distances and time intervals deviate from their absolute values. These deviations are assessed by considering the distance traveled by energy and the time it takes for that energy to propagate. Absolute distances and time intervals represent those in the absence of gravity. The gravity reduces the energy that consequently increases the distance and reduces the time interval.

In summary, the spin angular momentum and energy-frequency relationship of a fundamental particle originate from the circular motion of its FCs. The phase angle of the wavefunction corresponds to the angle of this circular motion. Consequently, the energy always propagates at the speed of light in all inertial frames. In a rest frame, half of the energy moves forward and half backward at the speed of light, resulting in a zero effective particle velocity. Due to this constant energy flow rate, increasing energy in an inertial frame leads to time dilation (increased time for energy to move) and length contraction (decreased distance the energy can traverse). Conversely, a decrease in energy within a gravitational field results in decreased time for the energy to propagate and increased distance that the energy can move. This constant energy flow rate generates a spacetime metric that aligns with general relativity.

4. The electron charge

As detailed in Section 2, the conservation of energy and angular momentum arising from the circular motion of the FCs necessitates that each fundamental particle exhibit wave-like properties. This wave nature allows the energy to propagate and generate spin angular momentum arising from the circular motion of its FCs. As detailed in [40], this model yields equations for electroweak coupling constants, enabling their derivation without experimental input.

The electromagnetic interaction governs particle interactions across diverse fields including biology, chemistry, and materials science. Its strength is characterized by the fine-structure constant. Using the electroweak coupling constants derived from the spin model [40], we obtain the fine structure constant at energy scale of $m_\tau c^2$ as follows:

$$\alpha(m_\tau c^2) = \frac{(\pi - 2)^2 - 1}{\pi^3(\pi - 2)^2}. \quad (23)$$

The theoretical fine structure constant at the rest energy of the tau lepton, obtained from Eq. (23), is 0.007504, which closely matches the reported value of 0.007493 [44], exhibiting an error of 0.14%. The electron charge is related to the fine-structure constant as follows:

$$e^2 = 4\pi\epsilon_0\hbar c\alpha(m_e c^2) = 4\pi\epsilon_0\hbar c \frac{\alpha(m_\tau c^2)}{1.027}$$

$$= \frac{4\pi\epsilon_0\hbar c (\pi - 2)^2 - 1}{1.027 \pi^3 (\pi - 2)^2}, \quad (24)$$

$$e = \left(\frac{4\pi\epsilon_0\hbar c (\pi - 2)^2 - 1}{1.027 \pi^3 (\pi - 2)^2} \right)^{\frac{1}{2}}. \quad (25)$$

$\alpha(m_\tau c^2)$ in Eq. (23) is from our particle spin theory. The electron charge corresponds to the fine structure constant at energy scale of $m_e c^2$. Erler [44] determined the ratio (1.027) of the fine-structure constant at $m_\tau c^2$ to that at $m_e c^2$ using standard high-order quantum field calculations. The electron's charge obtained from Eq. (25) is 1.603×10^{-19} C, which is in close agreement with the experimentally determined value of 1.602×10^{-19} C [45]. This result demonstrates that our theory accurately determines the electron charge without relying on experimental input.

5. Discussion

Fundamental particles arise from the circular motion of FCs. While each individual FC is very heavy, the mutual gravitational and electromagnetic fields within a fundamental particle reduce the energy to a potential energy proportional to the square of the distance between them. The circular motion, driven by this potential energy, generates the fundamental particle with energy proportional to its frequency and an intrinsic angular momentum. For the original heavy FC mass, even a small radius can generate the required angular momentum; for the reduced mass to generate the angular momentum, the energy must spread out as wave. The wave is described by wavefunction with the phase angle equivalent to that of the circular motion. The energy, which is proportional to the frequency, can be obtained by applying the operator $i\hbar\partial/\partial t$ to the wavefunction. This demonstrates that the principles of quantum theory emerge from these fundamental circular motions.

Based on the wave arising from the circular motion of FCs, a particle's energy—and therefore its mass—must maintain a constant velocity: the speed of light. This requirement extends beyond the constancy of the speed of light in all inertial frames proposed by special relativity. While traditional physics assumes particles and their associated energy do not move within their rest frame, our particle spin theory demonstrates that energy propagates at the speed of light even in the particle's rest frame. This propagation generates a kinetic energy of $mc^2/2$. Since the potential energy arising from the FCs within a fundamental particle equals this kinetic energy, the particle's total energy is mc^2 . The velocity of a particle in a given direction is determined by the proportion of its energy directed forward. When 50% of a particle's energy contributes to forward motion, its velocity is zero. In contrast, light travels at the speed of light because 100% of its energy is directed forward. Massive particles, however, have less than 100% of their energy contributing to forward motion, resulting in velocities below the speed of light.

For generating the spin angular momentum, the product of the particle's energy (E) and wavelength (λ) must be constant (hc) across all inertial frames and throughout the universe, leading to a constant energy flow rate for the particle. In any inertial frame, variations in energy lead to changes in the distance over which that energy can propagate within a fixed time interval,

effectively causing length contraction. Conversely, the time required for an energy to traverse a specific distance increases, resulting in time dilation. Similarly, due to the constant energy flow rate, a decrease in energy due to gravity results in a decrease in the time needed for energy to travel a given distance and an increase in the distance it can propagate within a fixed time interval. The spacetime metric derived from this constant energy flow rate agrees with that of general relativity in regions where general relativity has been rigorously tested. This demonstrates that the principles of relativity emerge from fundamental particle spins.

The effective kinetic energy term ($mv^2/2$) in Eq. (23) is valid only when the velocity (v) is significantly less than the speed of light (c), a condition analogous to that in special relativity. This approximation breaks down as the velocity approaches the speed of light. Consequently, the Schwarzschild metric of general relativity is expected to be applicable only in weak gravitational fields. In [41], we presented a metric suitable for strong gravitational fields (where $GM/r \gg c^2$).

Nature encompasses four fundamental forces. Electromagnetic, weak, and strong interactions are described by quantum field theory within the Standard Model – a framework based on energy. Gravity, however, is described by general relativity, which is metric-based. This fundamental difference makes unifying gravity with the other three forces, which are inherently energy-based, exceedingly challenging. We have demonstrated that relativity arises from particle spin. Energy within the fundamental particles must propagate at the speed of light in all inertial frames, resulting in a constant energy flow rate from which the spacetime metric can be derived. In this framework, all four forces exist within the same space where energy is defined. As described in Section 3, the spacetime metric is a property determined by the energy flow within this space. This framework provides first-principles derivation of all Standard Model parameters—including the masses of all fundamental particles [46,47], electroweak coupling constants [40], strong coupling constant [48], neutrino mixing angle and CP-violating phase within Pontecorvo-Maki-Nakagawa-Sakata (PMNS) matrix, quark mixing angles and CP-violating phase within the Cabibbo-Kobayashi-Maskawa (CKM) matrix—without experimental input. The gravitational constant is intrinsically linked to the relative magnitudes of fundamental particle masses across different generations or types. Conversely, the relative magnitudes of these particle masses are partially determined by the gravitational constant. For example, the mixing angle ($\sin\theta_{23}$) between second and third generation quarks within the CKM matrix is related to the gravitational constant as follows:

$$G = \frac{\alpha^4 (\sin\theta_{23})^{16}}{2^{14} \pi^{20}} \frac{\hbar c}{m_e^2}, \quad (26)$$

where m_e is the electron mass, α is the fine structure constant, and θ_{23} is the mixing angle. For $\sin\theta_{23}=0.041857$, Eq. (26) yields a theoretical gravitational constant of $6.67 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$.

As detailed in two separate manuscripts [49,50], this framework enables a unified mechanism for particle acceleration across a wide range of energies—from solar energetic particles [51] to ultra-high-energy cosmic rays [52].

6. Conclusions

We have demonstrated that the energy-frequency relation and spin angular momenta of fundamental particles can be derived from the circular motions of FCs as described by Newtonian classical mechanics. The wave associated with the circular motion in a fundamental particle is mathematically represented by corresponding wavefunctions in quantum mechanics. The phase angle of the wavefunction directly corresponds to the angle of this circular motion, with energy proportional to the frequency of rotation. The spin angular momentum of a fundamental particle is equivalent to the classical orbital angular momentum of its constituent FCs. The energy, which is proportional to the frequency of the FCs' circular motion, is expressed as the result of applying the operator $i\hbar \frac{\partial}{\partial t}$ to its wavefunction. This relationship between energy and frequency, along with the correspondence between physical observables and quantum mechanical operators, demonstrates that fundamental principles of quantum mechanics emerge from Newtonian classical mechanics applied to FCs. This model yields equations for electroweak coupling constants, enabling their derivation without experimental input. The resulting theoretical fine-structure constant exhibits strong agreement with experimental values (discrepancy of only 0.14%), and the predicted electron charge (1.603×10^{-19} C) closely matches the experimentally determined value (1.602×10^{-19} C).

Within the wave arising from the circular motion of FCs, a particle's energy must propagate at a constant speed—the speed of light. This requirement extends beyond the constancy of the speed of light in all inertial frames proposed by special relativity. In the particle's rest frame, an equal distribution of energy propagates both forward and backward at the speed of light, resulting in zero net velocity. The propagation at the speed of light generates a kinetic energy of $mc^2/2$. Since the potential energy associated with the FCs within a fundamental particle equals this kinetic energy, the total energy of the particle is mc^2 . The constant speed of energy propagation implies a constant energy flow rate. Consequently, changes in energy within an inertial frame cause variations in the distance over which that energy can propagate within a fixed time interval, effectively leading to length contraction. Conversely, the time required for an energy to traverse a specific distance increases, resulting in time dilation. Similarly, due to the constant energy flow rate, a decrease in energy caused by gravity results in a decrease in the time needed for energy to traverse a given distance and an increase in the distance the energy can propagate within a given time interval. The spacetime metric derived from this constant energy flow rate agrees with that of general relativity in regions where it has been experimentally verified. This demonstrates that the principles of relativity are inherent to fundamental particle spins.

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Data availability statement

No data were created or analyzed in this study.

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