The Isolated Magnetic Monopoles as Free Quantized Magnetic Charges

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ABSTRACT

By obtaining pin, like a tiny string, as a further intrinsic quantum property with the general nature of an intrinsic linear momentum of an observable quantum state besides spin as an intrinsic quantum property with the general nature of an intrinsic angular momentum of an observable quantum state, we would find the subatomic particles contain spin, pin, magnetic moment and electric moment, the four intrinsic quantum properties of their own. As such, considering the four intrinsic quantum properties of subatomic particles and remembering the Maxwell's realization that the laws governing electricity and magnetism are identical, we would be able to obtain theoretically the isolated electric monopoles as free quantized electric charges carried by some particles, as well as, the isolated magnetic monopoles as free quantized magnetic charges carried by some specific particles in quantum mechanics and particle physics.

As such, we would obtain the Gauss's law and the Coulomb's law in magnetostatics analogous to the same laws in electrostatics, and also magnetic charge density and magnetic current density counterpart of electric charge density and electric current density with respect to free quantized magnetic charge. We would then get the modified Maxwell's equations as duality symmetry and the modified Lorentz force law considering both electric and magnetic charges, where the electric and magnetic

parameters are being invariant under the duality transformation exchanges in all respect.

Keywords: Quantum electrodynamics, Properties of particle physics, Pin, Spin, Magnetic moment, Electric moment, Gauss's Law and Coulomb's Law in electrostatics, Standard Maxwell equations.

Signs and Symbols

We would use in this paper some special symbols as ρ and s to mean pin and spin of subatomic particles, such that, μ_ρ and μ_s would mean the intrinsic electric moment related to pin and the intrinsic magnetic moment related to spin of subatomic particles respectively, other than the usual Signs and Symbols.

1. INTRODUCTION

Electric charge is the fundamental quantity of electricity, which is in integer multiples of individual small unit as the elementary electric charge e, which can exist freely, so electric charge is considered as quantized in classical electrodynamics (CED). But quantum electrodynamics (QED) would consider quantized electric charge otherwise and would in quest to search the same, because it is still a mysterious fact of nature that why such a quantization occurs.

Maxwell elegantly described in 1873 his equations in succinct form in CED and noted that the laws governing electricity and magnetism are identical. [1- 4] The Maxwell equations in CED with electric and magnetic fields in vacuum obey duality symmetry. This duality symmetry in CED also demand the existence of isolated magnetic monopoles as free magnetic charges besides the existence of isolated electric monopoles as free electric charges. We are already familiar with the existence of isolated electric monopoles in the form of positive and negative electric charges, but not with the existence of isolated magnetic monopoles in the form of positive and negative magnetic charges. Since magnetism seems analogous to electricity in governing the laws of physics, therefore, we may expect isolated magnetic monopoles in the form of positive and negative magnetic charges analogous to electric charges.

In 1894, Pierre Curie speculated on the possibility of free magnetic charges, but did not find reason to discount its existence. Then Paul Dirac introduced in 1931 the magnetic monopoles in order to explain the quantization of electric charge considering the existence of at least one free magnetic charge. [5-7] Afterwards, Gerard ’t Hooft and Alexander Polyakov discovered in 1974 the hedgehog solutions for quantum field theories: when the electromagnetic field loses its identity at the center of the lumps, the lumps acquire magnetic charges and the small enough such lumps appear as point-like magnetic monopoles.

However, since then researchers have hunted for magnetic monopoles to the skies, in seawater, in ice, in rock samples from the Arctic and Antarctica, in meteorites and moon dust, and in ores dating back nearly a billion years, even through the Large Hadrons Collider (LHC) experiments. And some experimenters claim the existence of magnetic charge and current in spin-ice in solid state physics, though not in the isolated state. [8-14]

But, so far, all efforts are unsuccessful to find out positive results in search for the existence of isolated magnetic monopoles in the form of positive and negative magnetic charges carried by specific particles. [15, 16]

Introducing pin, like a tiny string, as a further quantum property with the general nature of an intrinsic linear momentum of subatomic particles besides spin as a quantum property with the general nature of an intrinsic angular momentum of subatomic particles in quantum electrodynamics (QED), [17] we would find that pin together with an associated intrinsic electric moment (IEM) along with spin together with an associated intrinsic magnetic moment (IMM) would represent observable quantum states of subatomic particles in QED. Therefore, we may obtain spin, pin, magnetic moment and electric moment, the four intrinsic quantum properties of subatomic particles in quantum mechanics and particle physics.

Remembering Maxwell’s realization that the laws governing electricity and magnetism are identical, the quantized electric monopoles as free electric charges carried by some particles, as well as, the quantized magnetic monopoles as free magnetic charges carried by some specific particles may be possible to obtain theoretically in QED with support of these four intrinsic quantum properties of sub-atomic particles following a mathematical process.

As such, we would obtain the Gauss's law and the Coulomb's law in magnetostatics analogous to the same laws in electrostatics, and also magnetic charge density and magnetic current density counterpart of electric charge density and electric current density with respect to free quantized magnetic charge. We would then get the modified Maxwell's equations as duality symmetry and the modified Lorentz force law considering both electric and magnetic charges, where the electric and magnetic parameters are being invariant under the duality transformation exchanges in all respect.

We organize this paper as follows: Section 2 contains Overview. Section 3 contains Method and Procedures, where we would determine the directions with definite discrete values of pin and spin, and electric and magnetic moments; we would also theoretically calculate the isolated electric monopoles as free quantized charges carried by some fundamental particles, as well as, the isolated magnetic monopoles as free quantized magnetic charges carried by some specific fundamental particles, then we would extend our obtained results to other important nucleons like proton and neutron; we would thus specify the SI units of electric and magnetic charges and currents and their equivalence relations; we would also compare the properties of electric and magnetic charges. Section 4 contains Results and Discussions with specification of the modified Maxwell's equations as duality symmetry and the modified Lorenz force Law. Section 5 contains Conclusion.

2. OVERVIEW

Introducing pin, like a tiny string, besides spin, we have stated in [17] that any observable quantum state in phase-space in any reference frame at an instant of time would be represented by its own two intrinsic properties, viz., only one of the spin observables (s_x, s_y, s_z) in the Cartesian coordinates having a definite discrete value along a specified axis of rotation to the plane of rotation, and only one of the pin observables (ρ_x, ρ_y, ρ_z) in the Cartesian coordinates having a definite discrete value about the same axis of rotation on the plane of rotation. As such, these two intrinsic quantum properties spin and pin, by acting at right angle to each other with respect to a specified axis, being quantized, would exhibit an observable quantum state in phase-space in any reference frame at an instant of time.

It would be certain that both spin and pin are vector quantities, so they must have their respect-tive directions other than their definite discrete values. Regarding the spin along a specified axis of rotation to the plane of rotation, we would find that there are two possible directions, viz. the upward and downward directions, consequently, regarding the pin about the same specified axis of rotation on the plane of rotation, we may find that there are again two directions, viz. the counter clockwise (CCW) or right-handed and the clockwise (CW) or left-handed directions. Now, obeying the right hand screw sense, by convention, if the upward spin and the upward magnetic moment, and the CCW pin and the CCW electric moment would be considered as the positive spin and the positive magnetic moment, and the positive pin and the positive electric moment respectively, then the downward spin and the downward magnetic moment, and the CW pin and the CW electric moment would be considered as the negative spin and the negative magnetic moment, and the negative pin and the negative electric moment respectively.

Thus, the subatomic particles contain spin, pin, magnetic moment and electric moment, the four intrinsic quantum properties of their own. As such, we may signify an electron, one of the subatomic particles, that:

(a) An electron contains only one spin either upward or downward direction in phase-space in any reference frame, but not the both at an instant of time, since it would exclusively related to the angular momentum of the electron in QED.

(b) An electron contains only one pin either CCW or CW in phase-space in any reference frame, but not the both at an instant of time, since only one spin having a definite discrete value and direction with only one pin having a definite discrete value and direction, by acting at right angle to each other with respect to a specified axis, being quantized, would exhibit an observable elementary quantum state in QED.

(c) An electron contains only one intrinsic magnetic moment either downward or upward direction in phase-space in any reference frame, but not the both at an instant of time, because only one intrinsic magnetic moment would be associated together with only one spin at antiparallel.

(d) Analogously, an electron contains only one intrinsic electric moment either CCW or CW direction in phase-space in any reference frame, but not the both at an instant of time, because only one intrinsic electric moment would be associated together with only one pin at antiparallel.

3. METHOD AND PROCEDURES

Since, the fermions as subatomic particles contain spin, pin, magnetic moment and electric moment, the four intrinsic quantum properties of their own, then to determine the definite directions with definite discrete values of pin, spin, electric moment and magnetic moment, and to obtain theoretically the isolated electric and magnetic monopoles as free quantized electric and magnetic charges of fermions, we would restrict ourselves in the first generation of leptons (e^+, e^-, υ_e , $\bar{\upsilon}_e$) as our sample particles, which are distinguishable in intrinsic quantum properties to each other irrespective of their mass and momentum, and then we would extend our obtained results to two most important nucleons, proton and neutron.

3.1. The Directions of Pin and Spin of e^+, e^-, υ_e and $\bar{\upsilon}_e$

We may suppose that the direction of pin and spin of fundamental particles may be determined from their respective helicity (***H***). In particle physics, the helicity of a particle is a measure of the angle between the spin direction of the particle and its momentum direction. Thus,

$$\boldsymbol{H} = \boldsymbol{s}.\ \boldsymbol{p},$$

where ***s*** and ***p*** are unit vectors in the respective direction of spin and momentum respectively and ***H*** is the helicity. The eigenvalues of helicity are ***H*** = ±1, so the quantity of helicity is conserved. [18, 19]

The phenomenon in the beta-minus decay is that electrons are emitted mostly with negative helicity or left-handed direction or negative longitudinal polarization and electron antineutrinos are emitted with positive helicity or right-handed direction. Conversely, the phenomenon in the beta-plus decay is that positrons are emitted mostly with positive helicity or right-handed direction or positive longitudinal polarization and electron neutrinos are emitted with negative helicity or left-handed direction. [20 - 22]

Therefore, the direction of pin of electron would be left-handed or clockwise (CW) and the direction of spin of electron would be downward due to the spin direction of electron is CW with respect to the direction of helicity, where as, the direction of pin of positron would be right-handed or counter clock-wise (CCW) and the direction of spin of positron would be upward due to the spin direction of positron is CCW with respect to the direction of helicity.

By careful observation the directions of pin and spin of positron and electron here, we would find that they follow the right hand screw sense or right hand (grip) rule (RHR) such that a positron would obey direct RHR and an electron would obey inverse RHR. Since, the four particles of the first generation of leptons (e^+, e^-, υ_e , $\bar{\upsilon}_e$) are distinguishable in intrinsic quantized properties to each other irrespective of their mass and momentum, then obviously an electron antineutrino and an electron neutrino would follow the left hand screw sense or left hand (grip) rule (LHR) in accordance with the distinguishable characters of the four particles (e^+, e^-, υ_e , $\bar{\upsilon}_e$).

Thus, a positron would contain CCW pin and upward spin obeying direct RHR, an electron would contain CW pin and downward spin obeying inverse RHR, whereas, an electron neutrino would contain CW pin but upward spin obeying direct LHR and an electron antineutrino would contain CCW pin but downward spin obeying inverse LHR.

Now taking into consideration the definite discrete values of pin with directions as $\rho = \pm \frac{1}{2} \hbar$, and definite discrete values of spin with directions as $s = \pm \frac{1}{2} \hbar$, we may get the directions of pin and spin of our four sample particles (e^+, e^-, υ_e , $\bar{\upsilon}_e$) with respect to their helicity $H = \pm 1$as

A positron contains pin as $\rho = +\frac{1}{2} \hbar$ and spin as $s = +\frac{1}{2} \hbar$ with respect to $H = +1$ obeying direct RHR,

An electron contains pin as $\rho = -\frac{1}{2} \hbar$ and spin as $s = -\frac{1}{2} \hbar$ with respect to $H = -1$ obeying inverse RHR, A neutrino contains pin as $\rho = -½\ \hbar$ and spin as $s = +½\ \hbar$ with respect to $H = -1$ obeying direct LHR,

An antineutrino contains pin as $\rho = +½\ \hbar$ and spin as $s = -½\ \hbar$ w. r. t. $H = +1$ obeying inverse LHR.

3.2. The Directions of Electric and Magnetic Moments of e^+, e^-, υ_e and $\bar{\upsilon}_e$

As a spin (s) is associated together with an intrinsic magnetic moment (IMM) μ_s related at antiparallel and a pin (ρ) is associated together with an intrinsic electric moment (IEM) μ_ρ related at antiparallel, then the directions of IMM (μ_s) of our four particles would be the opposite directions that of their spin directions, but the directions of IEM (μ_ρ) of our four particles would be the same directions that of their pin directions, since both pin and IEM are about the specified axis of rotation on the plane of rotation, though they are related at antiparallel.

Now, considering the definite discrete values with directions of pin related electric moment as $\mu_\rho = \pm½\ \mu_B$ and the definite discrete values with directions of spin related magnetic moment as $\mu_s = \pm½\ \mu_B$ respectively, we may get the IEM (μ_ρ) and IMM (μ_s) of our four sample particles as

A positron contains $\rho = +½\ \hbar$ and $s = +½\ \hbar$, as such it contains $\mu_\rho = +½\ \mu_B$ and $\mu_s = -½\ \mu_B$,

An electron contains $\rho = -½\ \hbar$ and $s = -½\ \hbar$, as such it contains $\mu_\rho = -½\ \mu_B$ and $\mu_s = +½\ \mu_B$,

A neutrino contains $\rho = -½\ \hbar$ and $s = +½\ \hbar$, as such it contains $\mu_\rho = -½$ and $\mu_s = -½\ \mu_B$, and

An antineutrino contains $\rho = +½\ \hbar$ and spin as $s = -½\ \hbar$, as such it contains $\mu_\rho = +½\ \mu_B$ and $\mu_s = +½\ \mu_B$.

We would summarized the intrinsic properties of e^+, e^-, υ_e, $\bar{\upsilon}_e$ in Table I.

Table I. Summary of Intrinsic Properties of e^+, e^-, υ_e, $\bar{\upsilon}_e$:-

Particles	ρ in $\hbar$	s in $\hbar$	μ_ρ in μ_B	μ_s in μ_B
Positron (e^+)	+½	+½	+½	–½
Electron (e^-)	–½	–½	–½	+½
Neutrino (υ_e)	–½	+½	–½	–½
Antineutrino ($\bar{\upsilon}_e$)	+½	–½	+½	+½

3.3. Isolated Electric and Magnetic Monopoles as free quantized Charges

We would follow the identical laws or calculations to find theoretically the isolated electric and magnetic monopoles as free quantized electric and magnetic charges as per Maxwell's realization that the laws governing electricity and magnetism are identical with the support of the four intrinsic quantum properties of subatomic particles.

In calculating the small unit of quantized electric and magnetic charges, we may apply the linear unitary vector addition algebra with infinitesimal vectors in different axes having definite discrete values with the same units in QED as

$$\hat{c} = \bar{c}/||c|| = [(a + b)/N\sqrt{(a^2 + b^2)}], \tag{3.3.1}$$

where c is the specified charge, a and b are the two specified infinitesimal vectors in different axes having definite discrete values with the same units respectively, and N is the normalization factor.

3.3.1. Quantized Electric Monopoles in the form of Positive and Negative Electric Charges

Electric charge is considered as the fundamental quantity of electricity, but not as the intrinsic quantity of electricity. Therefore, to obtain the small unit of quantized electric charge q or e in QED, we may suppose that an electric charge is formed with two intrinsic quantum properties pin having the definite discrete values and directions as $\rho = \pm \frac{1}{2} \hbar$ and spin having the definite discrete values and directions as $s = \pm \frac{1}{2} \hbar$, which are infinitesimal vectors in different axes with the same units $\hbar$ as obtained from Table I, and applying the linear unitary vector addition algebra in the relation (3.3.1) putting $c = q$, $a = \rho$ and $b = s$ as

$$\hat{q} = \bar{q}/||q|| = [(\rho + s)/N \sqrt{(\rho^2 + s^2)}],$$

i.e.,

$$\hat{q} = [(\rho + s)/\sqrt{2}\sqrt{(\rho^2 + s^2)}], \tag{3.3.1.1}$$

where q is the element electric charge e, ρ is the pin, s is the spin of fermions respectively and $N = \sqrt{2}$ is a normalization factor.

Thus, we would find here that the carrier of positive electric charge (+1) is positron, the carrier of negative electric charge (–1) is electron, and neutrino and antineutrino carry no electric charge, where q is the unitless quantized electric charge as

$$q = \pm 1, \tag{3.3.1.2}$$

so that

$$q^2 = 1. \tag{3.3.1.3}$$

3.3.2. Quantized Magnetic Monopoles in the form of Positive and Negative Magnetic Charges

Magnetic charge, if exist, may also be considered as the fundamental quantity of magnetism, [25] but not as the intrinsic quantity of magnetism. Therefore, to obtain the small unit of quantized magnetic charge g in QED, we may suppose that a magnetic charge is formed with two intrinsic quantized properties of fermions IEM having discrete values and direction as $\mu_\rho = \pm½\, \mu_B$ and IMM having the definite discrete values and directions *as* $\mu_s = \pm½\, \mu_B$, which are infinitesimal vectors in different axes with the same units μ_B as obtained from Table I, and applying the linear unitary vector addition algebra in the relation (3.3.1) putting $c = q$, $a = \mu_\rho$ and $b = \mu_s$ as

$$\hat{g} = \bar{g}/||g|| = [(\mu_\rho + \mu_s)/N\sqrt{(\mu_\rho^2 + \mu_s^2)}],$$

i.e.,

$$\hat{g} = [(\mu_\rho + \mu_s)/\sqrt{2}\sqrt{(\mu_\rho^2 + \mu_s^2)}], \tag{3.3.2.1}$$

where g is the element magnetic charge, μ_ρ is the IEM, μ_s is the IMM of fermions respectively and $N = \sqrt{2}$ is a normalization factor.

Thus, we would find here that the carrier of positive magnetic charge (+1) is antineutrino, the carrier of negative magnetic charge (–1) is neutrino, and electron and positron carry no magnetic charge, where g is the unitless quantized magnetic charge as

$$g = \pm 1, \tag{3.3.2.2}$$

so that

$$g^2 = 1. \tag{3.3.2.3}$$

We would summarize properties and quantized electric and magnetic charge of e^+, e^-, υ_e, $\bar{\upsilon}_e$ in Table II.

Table II. Summary of Properties and Quantized Electric and Magnetic Charges of e^+, e^-, υ_e, $\bar{\upsilon}_e$:-

Particles	ρ in $\hbar$	s in $\hbar$	μ_ρ in μ_B	μ_s in μ_B	Electric charge, q	Magnetic charge, g
Positron (e^+)	+½	+½	+½	–½	+1	0
Electron (e^-)	–½	–½	–½	+½	–1	0
Neutrino (υ_e)	–½	+½	–½	–½	0	–1
Antineutrino ($\bar{\upsilon}_e$)	+½	–½	+½	+½	0	+1

It would also be possible to get intrinsic properties and free electric and magnetic charges of first generation mesons pions having zero spin. [see Appendix]

3.3.3. Intrinsic Quantum Properties and Electric and Magnetic Charges of Proton and Neutron

Now, we would have to get the intrinsic properties and free quantized electric and magnetic charges of two most important nucleons, proton and neutron.

We may find in the properties of particle physics that proton is the carrier of positive electric charge (+1), whereas, we may observe in Table II that positron is the carrier of positive electric charge (+1). Therefore, we may consider that proton is analogous to positron in all the intrinsic properties and electric charge irrespective of their mass and momentum.

We may find in the properties of particle physics that neutrino, antineutrino and neutron are carriers of no electric charge, though we would observe in Table II that a neutrino is the carrier of negative magnetic charge (–1), but no electric charge, whereas, an antineutrino is the carrier of positive magnetic charge (+1), but no electric charge. Therefore, to find the intrinsic properties and magnetic charge of neutron, we may have to take support of the radioactive beta-decays as

$$n_{?} \longrightarrow p^{+} + e^{-} + \bar{\upsilon}_{e+}, \tag{3.3.3.1}$$

and

$$p^{+} \longrightarrow n_{?} + e^{+} + \upsilon_{e-}, \tag{3.3.3.2}$$

To get the conservation of magnetic charge of the above two relations besides their conservation of electric charge, we would find in both the above relations that the magnetic charge of neutron $n_{?}$ to be as n_{+}, this would mean that the magnetic charge of neutron is +1. That is that neutron is analogous to antineutrino in all the intrinsic properties and magnetic charge irrespective of their mass and momentum. Therefore, the above two relations of radioactive beta-decays with electric charge and magnetic charge may be written as

$$n_{+} \longrightarrow p^{+} + e^{-} + \bar{\upsilon}_{e+}, \tag{3.3.3.3}$$

and

$$p^{+} \longrightarrow n_{+} + e^{+} + \upsilon_{e-}. \tag{3.3.3.4}$$

It would be noted here that electric charges of particles are generally positioned in the right upper case, as such, we would be positioned magnetic charges of particles in the right lower case as neutrino as υ_{e-}, antineutrino as $\bar{\upsilon}_{e+}$ and neutron as n_{+} in the relations (3.3.3.1) and (3.3.3.2) and in the relations (3.3.3.3) and (3.3.3.4).

Thus, the proton is analogous to positron in all the intrinsic properties and electric charge irrespective of their mass and momentum, and the neutron is analogous to the antineutron in all the intrinsic properties and magnetic charge irrespective of their mass and momentum.

We would summarize properties and electric and magnetic charges of e^+, e^-, υ_e, $\bar{\upsilon}_e$, proton and neutron in Table III.

Table III. Summary of Properties, Electric and Magnetic Charges of e^+, e^-, υ_e, $\bar{\upsilon}_e$, proton and neutron:-

Particles	ρ in $\hbar$	s in $\hbar$	μ_ρ in μ_B	μ_s in μ_B	Electric charge, q	Magnetic charge, g
Positron (e^+)	+½	+½	+½	– ½	+1	0
Electron (e^-)	–½	–½	–½	+ ½	–1	0
Neutrino (υ_{e-})	–½	+½	–½	–½	0	–1
Antineutrino ($\bar{\upsilon}_{e+}$)	+½	–½	+½	+½	0	+1
Proton (p^+)	+½	+½	+ ½	–½	+1	0
Neutron (n_+)	+½	–½	+½	+½	0	+1

However, comparing spin, pin, magnetic moment, electric moment, electric and magnetic charges of particles in Table III, we would find that the intrinsic properties and magnetic charge of neutrino are opposite that of antineutrino other than their equal mass and momentum, therefore, neutrino and antineutrino are not the Majorana particles, but they are the Dirac particles. [23]

Moreover, we would not find any particle in Table III such as dyon, [24 - 26] which would carry both the electric and magnetic charges as proposed by Julian Schwinger in 1969.

3.4. SI Units of Electric and Magnetic charges and currents

By obtaining the small unit of element of quantized electric and magnetic charges from relations (3.3.1.2) and (3.3.2.2), we would have their unitless values as $q = \pm 1$ and $g = \pm 1$ respectively, so we may write their unitless relation as

$$q = g = \pm 1, \tag{3.4.1}$$

i.e.

$$q^2 = g^2 = 1. \tag{3.4.2}$$

The phenomena of electricity and magnetism are different physical consequences with different properties of electromagnetism, therefore, the units of electric charge (q) and magnetic charge (g) would be different, as well as, the units of electric current (i) and magnetic current (k) would also be different.

The SI unit of electric charge is given as Coulomb (C) with respect to the force per unit electric field E and the SI unit of electric current (i) is given Ampere (A), such that A = C/s where C = A.s, analogously, the SI unit of magnetic charge may be given as Weber (Wb) with respect to the force per unit magnetic field H and the SI unit of magnetic current (k) may be given as Volt (V) such that V = Wb/s where Wb = V.s.

Therefore, we may obtain the equivalence units of Coulomb (C) and Weber (Wb) with respect to relation (3.4.1) as

$$q \approx g = 1.6021766 \times 10^{-19}\ \mathrm{C} \approx 1.6021766 \times 10^{-19}\ \mathrm{Wb}, \tag{3.4.3}$$

which would mean that if one unit of electric charge is $e = 1.6021766 \times 10^{-19}$ Coulomb, then one unit of magnetic charge might be $g = 1.6021766 \times 10^{-19}$ Wb, though we would find in literature that one unit of magnetic charge as g = $6.035884407 \times 10^{-17}$ Wb as claimed in [27] and one unit of magnetic charge as g = 1.47×10^{-35} Wb as claimed in [28].

As such, the quantization condition of electric and magnetic charges is e = g, or $e^2 = g^2$, though they are different physical consequences with different properties.

Thus, the equivalence relations between electric charge and magnetic charge, and electric current and magnetic current in SI units may be written as

$$\text{electric charge } (e) \text{ in Coulomb} \approx \text{magnetic charge } (g) \text{ in Weber}, \tag{3.4.4}$$

$$\text{electric current } (i) \text{ in Ampere} \approx \text{magnetic current } (k) \text{ in Volt}. \tag{3.4.5}$$

3.5. Properties of Electric and Magnetic Charges

The properties of electric charge and magnetic charge are almost the same in deep sense, though they are different consequence of electromagnetism. Some of their properties are:

i) The electric charge and the magnetic charge are fundamental properties of respective elementary particles but not the intrinsic properties of particles as electric charge and magnetic charge are constitute with some definite intrinsic properties of elementary particles.

ii) The intrinsic magnetic moment of particles is the source of magnetic field, force and energy, whereas, the intrinsic electric moment of particles is the source of electric field, force and energy.

iii) An electric field exerts a force on an electric charge, whereas, a magnetic field exerts a force on a magnetic charge.

iv) Opposite electric charges attract and like electric charges repel, and similarly opposite magnetic charges attract and like magnetic charges repel.

v) Magnetic fields exert forces on electric charges, whereas electric fields exert forces on magnetic charges.

vi) Electric charges produce electric fields and the moving electric charges generate magnetic fields, and magnetic charges produce magnetic fields and the moving magnetic charges generate electric fields.

vii) The parallel electric currents attract and the antiparallel electric currents repel, and similarly the parallel magnetic currents attract and the antiparallel magnetic currents repel.

viii) The energy stored in the electric field is proportional to the square of the magnitude of field, and the energy stored in the magnetic field is proportional to the square of the magnitude of field.

ix) A changing electric field is accompanied by a magnetic field, and a changing magnetic field is accompanied by an electric field.

x) Both the electric and the magnetic charges are elementary unit charges, therefore, fractional electric and magnetic charges of fermions would not exist in free state in physical nature as per quantum mechanics and particle physics.

4. RESULTS AND DISCUSSIONS

By obtaining definite discrete values and directions of the four intrinsic quantum properties of some fermions (e^+, e^-, υ_e, $\bar{\upsilon}_e$, p and n) and theoretically obtaining the isolated quantized electric monopoles in the form of small unit of element of electric charges and the isolated quantized magnetic monopoles in the form of small unit of element of magnetic charges, we may obtain the modified Maxwell equations as duality symmetric in QED.

The Modified Maxwell's Equations and Lorentz Force Law

We may express the Coulomb's Law in magnetostatics in scalar form analogous to the same law in electrostatics in scalar form as

$$|F_{\mathrm{m}}| = k_{\mathrm{m}}[(|g_1 g_2|)/r^2],$$

where F_{m} is the magnetostatic force, g_1 and g_2 are the signed magnitudes of the magnetic charges, the scalar r is the distance between the magnetic charges and k_m is the constant of proportionality, so that $k_m = \mu_0/4\pi$, μ_0 is the magnetic constant or permeability in vacuum.

And we may also express the Gauss's Law in magnetostatics in SI units, analogous to the same law in electrostatics as

$$\nabla.\, \boldsymbol{B} = \mu_0 \rho_{\mathrm{m}}\,,$$

this may be the divergence of magnetic field in SI units, i.e., the differential form of modified Maxwell's second equation in SI units for the existence of magnetic charge.

So, we may obtain magnetic charge density (ρ_{m}) and magnetic current density ($\mathbf{j}_{\mathrm{m}}$) counterpart of electric charge density (ρ_{e}) and electric current density ($\mathbf{j}_{\mathrm{e}}$).

Therefore, considering both electric charge and magnetic charge, we may obtain the modified Maxwell's Equations in SI units [1, 29] as

$$\boldsymbol{\nabla}.\, \mathbf{E} = \rho_{\mathrm{e}}/\varepsilon_0 \tag{4.1}$$

$$\boldsymbol{\nabla}.\, \mathbf{B} = \mu_0 \rho_{\mathrm{m}} \tag{4.2}$$

$$\boldsymbol{\nabla}\times \mathbf{E} + (\partial \mathbf{B}/\partial t) = -\mu_0 \mathbf{j}_{\mathrm{m}} \tag{4.3}$$

$$\boldsymbol{\nabla}\times \mathbf{B} - \mu_0 \varepsilon_0 \,(\partial \mathbf{E}\,/\partial t) = \mu_0 \mathbf{j}_{\mathrm{e}}\,, \tag{4.4}$$

where ε_0 and μ_0 are permittivity and permeability of free space respectively in electrodynamics.

And the modified Lorentz force law may be expressed in SI units as

$$\mathbf{F} = q\,(\mathbf{E} + \mathbf{v}\times\mathbf{B}) + g\,(\mathbf{B} - \mathbf{v}\times \mathbf{E}/c^2). \tag{4.5}$$

Now, we may find that the modified Maxwell Equations are duality symmetric in all respect such that the electric and magnetic parameters are being invariant under the duality transformation exchanges as

$$\mathbf{E} \to \mathbf{B} \quad , \quad \mathbf{B} \to -\mathbf{E};$$
$$\rho_e \to \rho_m \quad , \quad \rho_m \to -\rho_e;$$
$$\mathbf{j}_e \to \mathbf{j}_m \quad , \quad \mathbf{j}_m \to -\mathbf{j}_e. \tag{4.6}$$

Naturally, we may expect the duality transformation exchanges between quantized electric charge q and quantized magnetic charge g also.

5. CONCLUSION

Knowing the characteristics of neutrinos as the carrier of magnetic charges and getting the knowledge of electric and magnetic charges are being invariant under the duality transformation exchanges, it may be possible to convert the magnetic charges of neutrinos of cosmic radiation outer-space into electric charges. As such, the scientists and technologist may feel great interest in advancing suitable materials and technology that would capable to convert abundant magnetic charges carried by neutrinos into electric charge/current as green energy source for sustainable future of human civilization.

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Author Contributions

We, are jointly exchange our thoughts, knowledge and decisions in preparation of this theoretical paper, and so we are equally responsible for this paper in performing our jobs.

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Tables

Table I. Summary of Intrinsic Properties of e^+, e^-, υ_e, $\bar{\upsilon}_e$:-

Particles	ρ in $\hbar$	s in $\hbar$	μ_ρ in μ_B	μ_s in μ_B
Positron (e^+)	+½	+½	+½	–½
Electron (e^-)	–½	–½	–½	+½
Neutrino (υ_e)	–½	+½	–½	–½
Antineutrino ($\bar{\upsilon}_e$)	+½	–½	+½	+½

Table II. Summary of Properties and Quantized Electric and Magnetic Charges of e^+, e^-, υ_e, $\bar{\upsilon}_e$:-

Particles	ρ in $\hbar$	s in $\hbar$	μ_ρ in μ_B	μ_s in μ_B	Electric charge, q	Magnetic charge, g
Positron (e^+)	+½	+½	+½	–½	+1	0
Electron (e^-)	–½	–½	–½	+½	–1	0
Neutrino (υ_e)	–½	+½	–½	–½	0	–1
Antineutrino ($\bar{\upsilon}_e$)	+½	–½	+½	+½	0	+1

Table III. Summary of Properties, Electric and Magnetic Charges of e^+, e^-, υ_e, $\bar{\upsilon}_e$, proton and neutron:-

Particles	ρ in $\hbar$	s in $\hbar$	μ_ρ in μ_B	μ_s in μ_B	Electric charge, q	Magnetic charge, g
Positron (e^+)	+½	+½	+½	– ½	+1	0
Electron (e^-)	–½	–½	–½	+ ½	–1	0
Neutrino (υ_{e-})	–½	+½	–½	–½	0	–1
Antineutrino ($\bar{\upsilon}_{e+}$)	+½	–½	+½	+½	0	+1
Proton (p^+)	+½	+½	+ ½	–½	+1	0
Neutron (n_+)	+½	–½	+½	+½	0	+1

Appendix

Quantized Free Electric and Magnetic Charges of Pions with Zero Spin

So far in this paper we would obtain the electric and magnetic monopoles as free quantized electric and magnetic charges applying the unitary linear vector addition algebra of some fermions with fractional spin as ½ . The unitary linear vector addition algebra may also be applicable in fermions having fractional spins as 3/2, 5/2, etc. and bosons having integral spin as 1, 2, etc. as they are all cardinal numbers.

To find the free quantized electric and magnetic charges of the first generation of mesons with zero spin are not likewise particles with spin as cardinal numbers by applying the unitary linear vector addition algebra, though we would get their positive and negative electric charges from the properties of particle physics.

That is why to find the isolated electric and magnetic monopoles in the form of free quantized electric and magnetic charges of pions with 0 spin following the same formalism as our sample particles (e^+, e^-, υ_e, $\bar{\upsilon}_e$), we may suppose the imaginary number '*i*' equal to √(–1) which is zero with respect to cardinal numbers, though i^2 is equal to cardinal numbers –1.

As such, remembering that pions are bosons, we may consider the definite discrete values with directions of pin and spin of pions as $\rho = \pm i\hbar$ and $s = \pm i\hbar$ respectively, and then applying the unitary linear vector addition algebra, we may find the free quantized electric charges of π^+ as +1 and π^- as –1, but that of π^0 and $\bar{\pi}^0$ as 0; similarly, considering the definite discrete values with directions of IEM and IMM of pions as $\mu_\rho = \pm i\boldsymbol{\mu}_B$ and $\mu_s = \pm i\mu_B$ respectively, and applying the unitary linear vector addition algebra, we may find that the free quantized magnetic charges of π^0 as –1 and $\bar{\pi}^0$ as +1, but that of π^+ and π^- as 0.

We would summarize properties and quantized electric and magnetic charges of pions in Table IV.

Table IV. Intrinsic Properties and Quantized Electric and Magnetic Charges of Pions:

Particles	ρ in $\hbar$	s in $\hbar$	μ_ρ in μ_B	μ_s in μ_B	Electric charge, q	Magnetic charge, g
π^+	$+i$	$+i$	$-i$	$+i$	+1	0
π^-	$-i$	$-i$	$+i$	$-i$	–1	0
π^0	$-i$	$+i$	$-i$	$-i$	0	–1
$\bar{\pi}^0$	$+i$	$-i$	$+i$	$+i$	0	+1

Similarly, we may find intrinsic properties and free electric and magnetic of kaons having zero spin.

The Isolated Magnetic Monopoles as Free Quantized Magnetic Charges

by

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