

# Spin Mystery Resolved : Mechanical Spin Modeling of Fermions & Photons Based on Quaternion-Mass Concept

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## Abstract

Though quantum-mechanics has been a great pillar of modern-physics; but since its inception almost about a century ago, quantum mechanics has generated quite a bit of mysteries. One such mystery is about the 'spin' of elementary particles, which is considered not-real but abstract and is said to be intrinsic-spin, but 'what exactly is the *spin*' is not clearly known as yet. Earlier mechanical models of the spin, assuming electron to be tinier than nucleus, were discouraged by apparent electron's equatorial circumferential-velocity  $v$  greater than  $c$ . In the present paper a mechanical spin modeling of fermions & photons have been successfully made. The physical mechanical spin model not only clears the spin-mystery but also suggests a few interesting explanations & predictions. The suggested model is based on the novel concept of 'quaternion mass' given by the author in an earlier paper to explain the wave-particle duality of quantum-mechanics. The proposed model is meaningful in physical-sense and incorporates the essence of quantum-mechanics & relativistic-mechanics via quaternion-mass.

## **1 Introduction:**

Difficult questions usually have simple answers, but simple questions are normally difficult to be answered clearly. The examples of simple questions are: (i) What is a relativistic moving-mass, a scalar or a vector quantity? (ii) What is photon, a particle or a wave? (iii) Why, after-all, there is wave-particle duality? (iv) What exactly is 'spin' of elementary particles, in physical sense? (v) Is the heavier proton smaller (in size) than the lighter electron and vice-versa? (vi) Why is ' $h$ ' not zero and ' $c$ ' not infinite? The answers of the first three questions are attempted to be given / suggested by the author in the earlier paper ([www.arxiv.org/abs/physics/0305024](http://www.arxiv.org/abs/physics/0305024)), whereas answers to the last three questions are tried to be given in the present paper, which is based on the 'quaternion mass' concept of the earlier paper. The concept of quaternion mass is briefly reported in section-2 and is extended further in section-3 to provide a base for the mechanical spin modeling done in section-4 - which is the main text of this paper.

## **2. Concept of Quaternion Mass:**

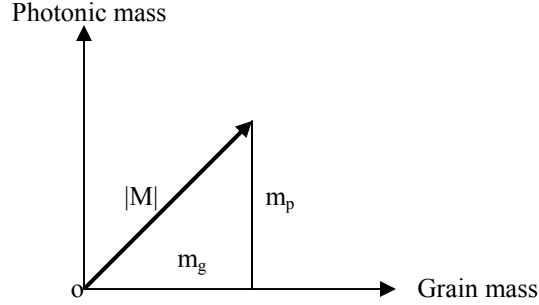
In a fundamental paper [1] the author has suggested that a moving mass is neither a scalar nor a vector but in fact it is, in a way, sum of the two as a quaternion. The 'quaternion mass' concept thus introduced by the author successfully explains the wave-particle duality; the scalar-part governs the particle-aspect and the vector-part exhibits the wave-behavior. The '*quaternion mass*'  $M$  (or alternatively as '*complex mass*' for its universal-familiarity and ease of writing, comprehension & common-

understanding) is suggested by the author [1] as follows, where  $m_g$  is the grain(scalar or real) mass,  $m_p$  is the photonic(vector or imaginary) mass.

$$M = m_g + i m_p \quad (1)$$

Magnitude-wise, magnitude  $|M|$  of the quaternion (or the complex) mass  $M$  is given as (in a Pythagorean way),

$$|M|^2 = m_g^2 + m_p^2 \quad (2)$$



**Fig. 1 Quaternion Mass (alternatively, Complex mass) Representation**

It is considered [1] that rest mass does not take any momentum, all is taken up by the photonic mass  $m_p$ . Hence  $m_p \cdot c = |M| \cdot v$ , where  $v$  is the particle-velocity &  $c$  is the velocity of light, which leads to

$$m_p = |M| v/c \quad (3)$$

Using Eq.(3) in Eq.(2),

$$|M| = m_g / (1 - v^2/c^2)^{1/2} \quad (4.a)$$

or,  $m_g = |M| \cdot (1 - v^2/c^2)^{1/2} \quad (4.b)$

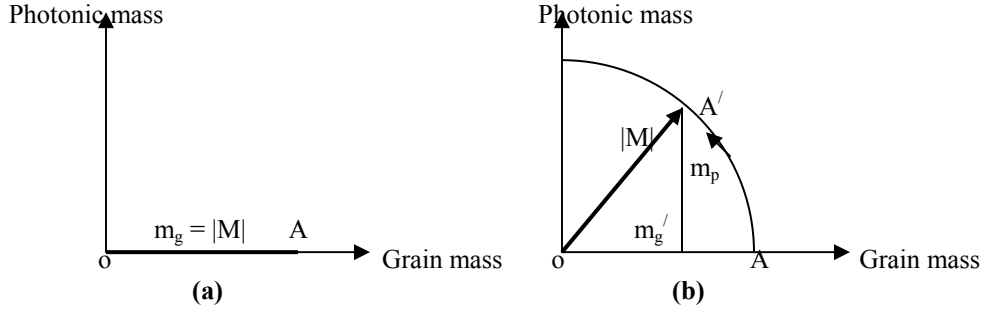
The theory [1] of quaternion-mass (or the complex-mass) *explains successfully the 'wave-particle duality'*. Its real-part represents the real grain-like particle and the imaginary-part as wave-like aspect (say, wavecle) giving a *mathematical blend to de-Broglie's hypothesis*. It is shown in the earlier-paper [1] that the 'quaternion(complex) mass' concept provides a bridge-link between the quantum-mechanics and relativistic-mechanics as well as between the micro-world and macro-world. Equations 4.b & 4.a are same but have *quite-different* interpretations as described in the following sections 3.(i) & 3.(ii) .

### **3. Quaternion-Mass (Complex-Mass) of Non-Spinning Particle and The Two Ways of its Transformation:**

#### **(i) Self-inspired self-conversion of rest-mass to photonic-mass without any external-agency**

Consider a non-spinning particle at rest (point A in Fig.2a) having only the material-like grain-mass and no wave-like photonic-mass. So, total mass  $|M| = m_g$ . Now think that this stationary particle suddenly (self-inspired) starts moving at velocity  $v$  (point A' in Fig,2b) thus gaining photonic mass  $m_p = |M| \cdot v/c$  at the expense of its own grain-mass which is reduced to a new lower value  $m_g'$ ; total mass  $|M|$  remains same as no external agency is involved in it. Complex mass (for Fig.2b) is thus expressed as,

$$M = m_g' + i m_p \quad (5)$$



**Fig. 2 Self-inspired self-conversion of rest mass to photonic mass**

$$\text{Magnitude wise, } |M|^2 = m_g'^2 + m_p^2 = m_g'^2 + (|M|.v/c)^2$$

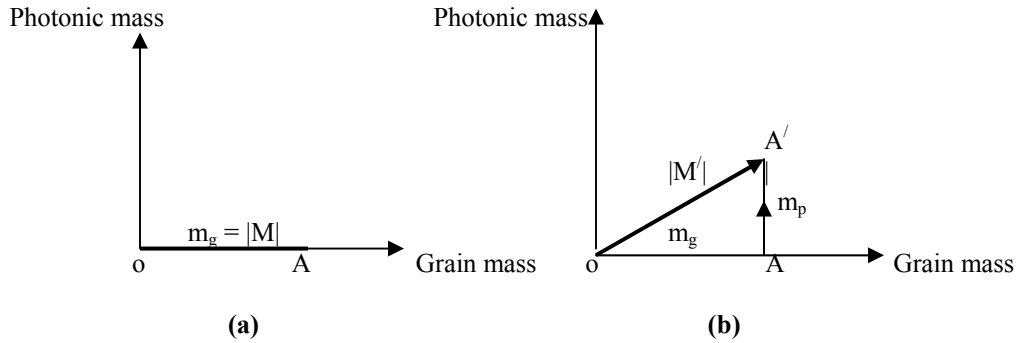
$$\text{or } m_g' = |M|. (1 - v^2/c^2)^{1/2} = m_g. (1 - v^2/c^2)^{1/2}, \quad (\text{since } |M| = m_g \text{ (Fig.2a) }) \quad (6)$$

Note that  $m_g$  is the (rest) grain-mass of a stationary-particle whereas  $m_g'$  is the reduced grain-mass of the self-inspired moving particle, also note that in the case of self-inspired self-conversion of (rest) grain-mass, the grain-mass decreases (from  $m_g$  to  $m_g'$ ) as the particle moves faster. Equations (6) & (4.b) are similar. Self-conversion of grain-mass to photonic-mass and vice-versa are manifested *fully* in 'annihilation' and 'pair-production' processes. Self-inspired self-conversion of grain-mass to photonic-mass will be used again in the subsequent section-4 while spin-modeling of fermions, considering that spin-motion is self-generated in a non-spin particle at the expense of its grain-mass; in a way, a part of the grain-mass 'leaks' to become the photonic-mass of spinning-particle.

**(ii) Induced-motion due to addition of energy to the particle by external-agency**

Consider a non-spinning particle at rest (point A in Fig.3a) having only a grain-mass  $m_g$  with total mass  $|M| = m_g$ . Now consider that this mass is pushed or worked-upon or given an energy to move forward with a velocity  $v$ . Thus a photonic-mass is added (Pythagorean way) onto the grain-mass (Fig.3.b) due to the work or energy supplied to it. The total mass thus increases to a higher value  $|M'|$ , given by,

$$M' = m_g + i m_p \quad (7)$$



**Fig. 3 Addition of energy (by external agency) to the particle as photonic mass**

$$\text{Magnitude wise, } |M'|^2 = m_g^2 + m_p^2 = m_g^2 + (|M'| \cdot v/c)^2$$

$$\text{or } |M'| = m_g / (1 - v^2/c^2)^{1/2} \quad (8)$$

Thus, there is an overall increase in the total Mass from  $|M|$  to  $|M'|$  due to addition of energy. Note that the mass of the stationary-particle is  $|M| = m_g$ , whereas when-after addition of work or energy ( $W = E = m_p c^2$ ) the particle gains photonic mass  $m_p$  it starts moving with greater total mass  $|M'|$ . Equations (8) & (4.a) are similar. Also, note that the Eq.(8 or 4.a) is similar & equivalent to the famous Relativity-formula  $m = m_0 / (1 - v^2/c^2)^{1/2}$ , where  $m_0$  is the rest-mass and  $m$  is the total moving mass.

#### 4. Mechanical Spin Modeling:

Science is supposed to remove mystery. If a theory removes a major chunk of mysteries while introducing a little new mystery, it may, however, be acceptable. But, since its inception almost a century ago, quantum mechanics has generated more than its share of mystery. For one such mystery ‘wave-particle duality’, the author has tried to explain[1] it with a novel concept of ‘quaternion-mass’ which is briefly discussed & extended in the previous sections 2 & 3 of this paper. Another unexplained major mystery of quantum mechanics is the mystery of ‘spin’ of elementary particles, which in absence of any realistic physical model is mysteriously said as abstract or intrinsic. Earlier mechanical modeling of spin were discouraged (as mentioned therein [2-7]) by (apparent) equatorial circumferential-velocity  $v$  greater than  $c$ , because the electron-size was (falsely) presumed to be tinier than nucleus & of the order  $10^{-16}$  m.

It seems that physics has no longer remained simply as physics [8], it has gone into the realm of philosophy (quantum mechanics) and mathematics (string theory). Earlier the physics was used to be the *engineer's tool*, but now gradually it is becoming the *mathematician's toy*. Though one of the most modern concept of physics, the super-symmetry [9], entirely relies on the particle's ‘spin’; it is surprising, however, that ‘what exactly is *spin*’, is not clearly known [9] as yet.

In this paper a meaningful mechanical spin modeling of fermions & photons is made, as follows in the sections 4.1 to 4.4. The physical mechanical spin model would not only clear the spin-mystery, but would further lead to a few interesting predictions and explanations. It is considered here (in section - 4.1) that the spin-motion is *self-generated* since-birth in an originally primordial non-spinning particle at the expense of its grain-mass due to its self-conversion (which is just introduced in section 3(i))

##### 4.1 Photonic mass of a spinning fermion

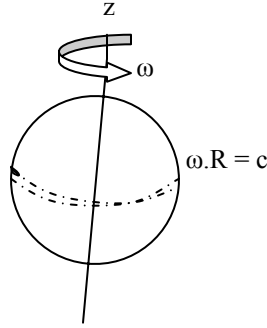
In differential-form the quaternion (complex) mass  $\Delta M$  for an elementary-element ( $r \, d\theta \cdot dr \, \cos\theta \, d\Phi$ ) inside a spinning ball-like fermion in spherical-coordinates-system is written as follows. (Note the use of a different complex-symbol  $j$  instead of  $i$ , just simply to denote ‘spin rotational’ motion instead of ‘linear transnational’ motion).

$$\Delta M = \Delta m_g' + j \Delta m_p = \Delta m_g' + j |\Delta M| \cdot v/c \quad (9)$$

Thus the reduced grain-mass  $\Delta m_g'$  is given by

$$\Delta m_g' = |\Delta M| \cdot (1 - v^2/c^2)^{1/2} \quad (10)$$

The photonic-mass of the self-inspired spinning fermion (with angular velocity  $\omega$  about z-axis), is as follows, assuming a density  $\rho=|M|/(4\pi R^3/3)$ , and taking  $v = \omega.r \cos\theta$  & the max equatorial velocity  $\omega.R = c$  (refer Fig.4).



**Fig. 4 Spin-ball like fermion (photonic-mass spinning around grain-mass)**

$$\Delta m_p = |\Delta M|.v/c = (\rho r d\theta. dr. r \cos\theta d\Phi). \omega.r.\cos\theta /(\omega.R) \quad (11)$$

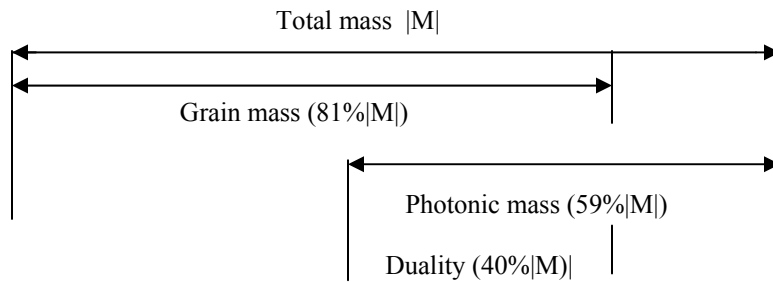
$$m_p = \int_0^R \int_{-\pi/2}^{\pi/2} \int_0^{2\pi} \rho r^3 \cos^2\theta dr d\theta d\Phi / R \quad (12)$$

$$= 3\pi/16 . |M| = 0.589 |M| \approx 59\% |M| \quad (13)$$

Furthermore, the reduced grain-mass  $m_g'$  of the self-inspired spinning fermion is thus given as follows (by *Pythagorean* subtraction), since (as of Eq.5) the complex mass  $|M| = m_g' + j m_p$ ,

$$m_g' = (|M|^2 - m_p^2)^{1/2} = 0.808 |M| \approx 81\% |M| \quad (14)$$

Thus, for the spin-fermion; photonic-mass is 59% and grain-mass is 81% of the total mass  $|M|$ , clearly showing a duality of 40% (Fig.5) indicating that even a *non-moving but only-spinning electron* too is *partly* cloudy or wave-like. Or, as if, a spin-fermion is like a grain-like rest-ball surrounded by photonic spinning-ring (as shown in Fig. 4).



**Fig. 5 Photonic mass (59%) and Grain mass (81%) of a Spin-Fermion**

From Eq.(3)  $m_p c = |M|.v$  ; which too indicates / dictates that, as if, the photonic-mass  $m_p$  is moving with velocity of light  $c$ , and thus the fermion can be idealized & modeled as ‘photonic-ring spinning with light-speed  $c$  on equatorial-circumference around a material (rest) grain-ball’ (Fig. 4) . A photon, however, could be considered simply ‘only as a photonic-ring’ since it has no (zero) grain or rest mass.

## 4.2 Energy and Angular momentum evaluation of spinning Fermions & Photons

### (i) For Spin-Fermions:

In physical analogy , a fermion is considered like a typical spinning ‘ball’, idealized & modeled as spinning double-ring on equatorial-circumference of photonic-mass  $m_p = 59\%|M|$  around a material (rest) grain-mass  $m_g = 81\%|M|$ , the total mass  $|M|$  being the Pythagorean sum of these two component of masses. The photonic ring is in *two* loops each of mass  $m_p/2$  for upper & lower hemispheres of the fermion ‘ball’. The photonic energy of fermion is given as under. For the energy  $hc/\lambda$  , it may be considered that the wavelength  $\lambda$  is *twice* the equatorial circumference i.e.,  $4\pi R$ , as if the photonic-wave around the spinning particle is ‘biting its tail in *two* loops’ (Fig. 4).

$$E = m_p \cdot c^2 = h \nu = h c / \lambda \quad (15)$$

$$\lambda = 4\pi R \quad (16)$$

The angular-momentum of a spinning-particle about z axis is  $S_z = I.\omega$  The ‘contributing’ moment-of-inertia  $I$  of the spin-particle for angular-momentum is due to its photonic (rotating) mass only and not by its grain (rest) mass. As if, as per the model, only the photonic-mass is in motion (spinning) and not the grain-mass. Hence, the contributing moment-of-inertia of a fermion for angular-momentum can simply be written as follows, considering the photonic-mass spinning on equatorial circumference over the non-contributing core grain-mass

$$I = m_p.R^2 \quad (17)$$

Spin angular momentum of the ‘spin ball-like fermion’ about z axis is given as follows, & using the equations (Eqs. 17, 15 & 16) for  $I$ ,  $m_p$  &  $\lambda$  and that  $\omega = c/R$  ,

$$S_z = I.\omega = m_p.R^2.\omega \quad (18.a)$$

$$= h c / \lambda / c^2 \cdot R^2 \cdot c / R = R / \lambda \cdot h = 1 / (4\pi) \cdot h = \frac{1}{2} \hbar \quad (18.b)$$

Thus it is shown that fermions are ‘*half*’ spin elementary particles.

### (ii) For Spin-Photons:

Photon is, not like a ball but, only like a ‘single-ring’ of photonic-mass on equatorial circumference with zero (no) rest-mass. Its wavelength  $\lambda$  may thus be considered as  $2\pi R$ , as if the wave is ‘biting its tail in one loop’; the energy  $E$  of photon is again given by similar Equation (15).

Moment of inertia of spin-ring photon  $I = m_p.R^2$  , and the spin angular momentum of the ‘spin-ring photon’ about z axis is found as follows (using Eq. 15 and  $\lambda = 2\pi R$  and that  $\omega = c/R$ ),

$$S_z = I.\omega = |M| R^2.\omega = h c / \lambda / c^2 \cdot R^2 \cdot c / R = R / \lambda \cdot h = 1 / (2\pi) \cdot h = \hbar \quad (19)$$

Thus it is shown that the photons have ‘*unit*’ integer spin.

## 4.3 Mass-to-Size Formula

The angular momentum about z axis for fermions, as derived just-earlier (Eqs. 18.a & 18.b) in the previous section - 4.2 (i), is equal to the well known value of  $\frac{1}{2} \hbar$  ; is rewritten as,

$$S_z = I.\omega = \frac{1}{2} \hbar \quad (20)$$

From Eqs. (17 & 20),

$$m_p.R^2.\omega = \frac{1}{2} \hbar \quad (21)$$

From Eqs (13 & 21)

$$0.59|M|.R^2.\omega = \frac{1}{2} \hbar \quad (22)$$

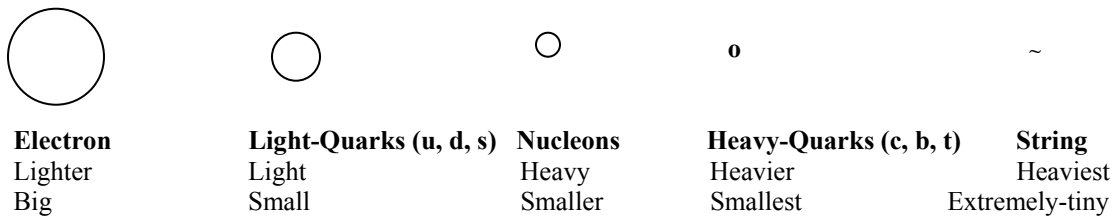
And that the max equatorial velocity  $v_{\max} = c$  as relativistic restriction, thus,

$$R.\omega = c \quad (23)$$

From these two equations (22 & 23), a very interesting as well as important yet simple relationship (*mass-to-size formula*) is found as under (Eq.24). Similar relationship is found by Kadin [6] and by Giese [10] for electron in somewhat simpler-ways but with different approaches. Note that the factor 0.85 is not *that* important, because it could come out to slightly different for different modeling-approaches; the important thing is the ‘*inverse*’ *mass-to-size relationship* of Eq. (24).

$$R = 0.85 \hbar / (|M|.c) \quad (24)$$

which reveals that ‘heavier in mass *is* smaller in size’. In a philosophical sense, it can be said that ‘Size is the poorest test of a man or a country and for *mass* too’ ! The new-found interesting fact that ‘smaller is heavier’ is illustrated in the Fig.6. The Eq.(24) is a simple & important ‘*mass-to-size relationship*’ and is useful in many ways, specially for pictorial and physical modeling. Free light-quarks (u, d, s) seem to be bigger than nucleons, but a few such quarks would peculiarly coalesce, bind & condense to form the smaller compact nucleons. Heavy-quarks (c, b, t) are much smaller than the light-quarks (u, d, s). Moreover, if for R & |M| one thinks dimension-wise as  $l_p$  &  $m_p$  and uses the expressions for the Planck’s length  $l_p = (G.\hbar/c^3)^{1/2}$  and Planck’s mass  $m_p = (\hbar c/G)^{1/2}$  which are commonly referred in string theory [11], a relationship  $l_p.m_p = \hbar/c$  somewhat-similar to Eq.24 or Eq.25 is noticed, confirming further its validity even beyond strings to Planck’s scale. The Eq.(24) in fact can be used as ‘test’ for elementary particle i.e., to ascertain whether a particle is *elementary* or not. The Eq.(24) is satisfied *only* for elementary-particle’s mass & size, whereas the equation is not satisfied for non-elementary particles such as ‘alpha-particles’, ‘atoms’, ‘molecules’ etc. .



**Fig. 6 Pictorial depiction of ‘Smaller is heavier’ is true for elementary particles**

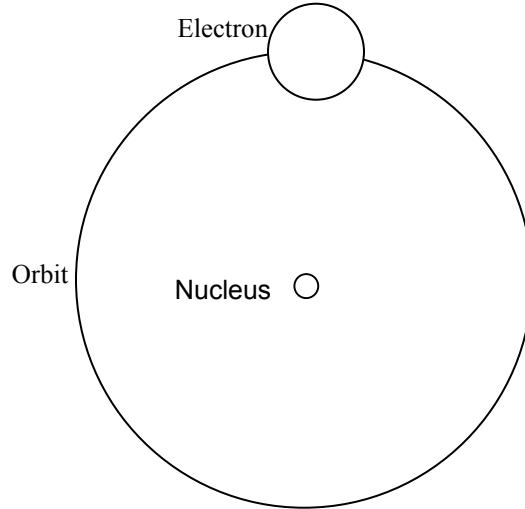
The Eq.(24) gives estimates of radius of electron ( $R_e$ ), proton ( $R_p$ ) and neutron ( $R_n$ ) as follows, using the known masses of the respective fermions;

For Electron       $R_e = 0.328 \times 10^{-12} \text{ m} = 0.328 \text{ pico.metre} \quad \sim 0.3 \text{ pm}$

For Proton       $R_p = 0.1927 \times 10^{-15} \text{ m} = 0.193 \text{ fermi.metre} \quad \sim 0.2 \text{ fm}$

For Neutron       $R_n = 0.1926 \times 10^{-15} \text{ m} = 0.193 \text{ fermi.metre} \quad \sim 0.2 \text{ fm}$

which are perfectly compatible and accommodated very-well into the ‘angstrom-sized atom’ and into ‘fermion-sized nucleus’, as shown in the Fig.7.



**Fig. 7 An atom showing a pico-sized electron (0. 3 pm) in angstrom-sized orbit (1 Å) with a fermi-sized nucleon (0. 2 fm) at the center, well compatible and accommodative**

#### **4.4 Why $\hbar$ is not zero and $c$ is not infinite ?**

The Eq.(24) is written as,

$$R \cdot |M| = 0.85 \hbar / c \quad (25)$$

Note that if  $\hbar (=2\pi\hbar)$  is zero or  $c$  is infinite, then from Eq.(25) either  $R$  is zero or  $|M|$  is zero i.e., the absence or non-existence of fermions and in turn non-existence of the universe itself. Thus, the anthropic principle [12], in a way, restricts and demands ‘ $\hbar$  not to be zero and  $c$  not to be infinite’.

If someone finds another relationship relating  $\hbar$  &  $c$ , then using it with Eq.(25) the *exact* values of  $\hbar$  and  $c$  can be found. Though there seems indeed to be such a relationship  $e^2/(4\pi\epsilon)(\hbar c) = \alpha$ , the fine structure constant formula, but that is an experimental / empirical one and is *not* a ‘analytical formula’.

#### **5. Stern-Gerlach Experiment – Revisited & Re-interpreted**

The Stern-Gerlach experiment [3,13] is briefly revisited here and re-interpreted in somewhat different way. To accept the new proposed, rather seemingly unbelievable, re-interpretation or explanation, however, a change of mind-set is needed. (But, in case of serious doubt/objection/confusion/controversy on the proposed *re-interpretation*, this section-5 on the Stern-Gerlach experiment may be considered omitted or removed from the ‘present-paper - which focuses mainly on the *mechanical* modeling of spin’).

The silver atom possesses a net magnetic moment equal to the spin magnetic moment of the last 47<sup>th</sup> electron, so may be considered as a tiny magnet. When the beam of atoms passes through inhomogeneous magnetic field  $B_z$ , there would be a ‘torque’ on the tiny magnet as well as a ‘net force’ on

it. The ‘torque’ on the tiny magnets would try to soon *align* it *but* in  $\pm Z$  directions depending on anticlockwise or clockwise spin (spin space *quantization* with  $\theta \rightarrow 0^\circ$  or  $180^\circ$  ! ). Total spin angular momentum thus  $S = S_z$ , and the formula  $S_z = S \cos\theta$  is neither needed nor required. The beam splits into two streams in fact due to the applied inhomogeneous magnetic field ( $dB_z/dz \neq 0$ ) because of the ‘net force’ acting on the tiny magnets. It has to be mentioned that in the Stern-Gerlach experiment, the deflection distribution did not build 2 sharp peaks but a somewhat washed-out distribution [10]. The two lines are not sharp but are of washed-out type is considered to be due to thermal velocity, but quite likely it may be primarily due to the fact that it takes some time for the electron’s spin-magnets to align to the applied field. The dull lines supports this explanation, the dullness would increase if the length (region) of magnetic ( $B_z$ ) is smaller, as spin alignment-time in the field would *then* be comparable to the separation-time for the two splitting-streams. The torque on tiny-magnet (spinning electron) creates a gyroscopic precision-rotation also, which nearly-vanishes (as much as permissible by the uncertainty principle) if the torque tends to zero when the tiny-magnets try to aligns itself as much as to the applied field.

The new explanation *also* considers the spin space quantization as the existing explanation does, but the main difference between the existing & new explanations is that : from the existing explanation  $\theta \sim 35^\circ$  &  $145^\circ$ , whereas from the new explanation  $\theta \rightarrow 0^\circ$  &  $180^\circ$  with slight gyroscopic precision-rotation (as much as allowed / permissible by the uncertainty principle). Even though if this uncertainty in spin-angular-momentum  $S$  is almost near-zero but since there is known significant uncertainty in the orbital-angular-momentum  $L$ , there will be a significant uncertainty in total-angular-momentum  $J$  because  $J = L + S$ .

Even if the new explanation may seem rather radical & unbelievable, but if there is a slightest possibility of truth, it should be explored positively rather than discarding it negatively

## 6. Discussions:

It is well known that, as per Relativity-theory, total moving mass is more than its rest mass, which is also evident from Eq.8 of section-3.(ii) . But this is only a part of the story; the rest (grain) mass itself can even decrease if the motion is self-inspired on its own as given in Eq.(6) of section-3.(i). Note that the equations 4.a & 4.b (similar to equations 8 & 6 respectively) are basically the ‘two facets of the same coin’ but have *different* meanings as explained in sections-3.(ii) & (i) respectively.

The two ways of mass transformation (self-inspired and induced) are studied in section-3. It is visualized that while electron spin is self-inspired, some of its mass is self-transformed into photonic-mass. A mechanical spin modeling is developed (with a relativistic-restriction that max equatorial velocity  $\omega.R = v_{\max} \leq c$ ) and it is found (section-4.1) that photonic-mass is 59% $|M|$  and grain mass is 81% $|M|$  clearly showing a new wave-particle duality of a ‘position-wise stationary’ but ‘spinning’ fermion.

Fermions are considered to be somewhat like a typical spin ball but with a central grain–mass (81%) and a photonic-mass (59%) spinning around it. Photons, however, are not ball-like but rather empty ‘ring-like’ only around equatorial circumference. Mechanical spin modeling (section-4.4) leads to the known values of spins: half-spin for fermions (like electron, proton, neutron) and one-spin for photons. Spin-up (+) and spin-down (-) are for anticlockwise and clockwise rotations respectively. Note that velocity, no-where, exceeds the velocity of light; since the maximum velocity condition is imposed at equatorial circumference as  $R.\omega = v_{\max} \leq c$ .

Consideration of spin angular momentum about z axis  $S_z = I.\omega$  of fermions with the condition that max equatorial velocity  $v_{\max} = c$  leads to an important and interesting relation (Eq.24 in section-4.3):  $|M|.R = 0.85 \hbar / c$ . This implies that the product: *mass x radius* of the elementary particle is *constant*; that means *heavier the particle the smaller is the radius* or in other words briefly ‘smaller is heavier’. This leads to an interesting and somewhat counter-intuitive & unbelievable (but true) conclusion that ‘electron is bigger in *size* than proton & neutron’. It is estimated that the nucleon radius is  $0.2 \times 10^{-15}$  m which can be well accommodated in fermi-sized nucleus, and that the electron which is surprisingly much bigger having radius of  $0.3 \times 10^{-12}$  m can also well fit into the angstrom-sized atom.

The ‘inertia’ not only lies with matter (mass) but also with gray-matter (brain); the ‘inertia’ of our rigid-believes, therefore, resists search of new avenues & newer-findings and tries to adhere to the century-old myths to which we are taught & attuned with. The key finding (from Eq.24) that the ‘electron, though lighter, is *bigger* than nucleons’, would be rather unbelievable because of our old rigid mind-set and also because experimental results seem to be against this finding ; the author, however without arguing much, would mention that it (Eq. 24) is the mathematical-outcome and would confidently say that the experiments could be *simply wrong* in either doing or interpretations and thus suggests for (un-biased) re-experimentation to re-examine the electron-size in the new light. ‘*All avenues for search of Truth must always be kept open*’ !

‘The *inverse dependence* of size (length) on the mass (energy)’, is in a way already known & true; since it is well known that: for probing smaller-size, higher-energy particle accelerators are required. This inverse- dependence (Eq.24, Fig.6) applies well from electron to string and beyond.

Similar relationship as in Eq.24 is also found by Kadin [6] for electron in a simpler-way but with different approach based on the concept of electron as rotating-vortex. It appears that the Kadin’s proposed vortex [6] is nothing but the hereby suggested (Eq. 12) photonic-mass of the spinning particle.

The basic foundations of quantum-mechanics rests on the fact that *h is not zero*, and that of the relativistic-mechanics depends on the fact that *c is not infinite*. In the present paper it is answered ‘why *h* is not zero and *c* is not infinite’, because otherwise the fermions would be absent indicating non-existence of the universe itself, which is against the well known anthropic-principle [12].

Though some considerations and assumptions in the mechanical spin modeling may be debatable, but the *meaningful physical analogy* not only removes the spin-mystery but also estimates spin correctly. In addition, it reasonably estimates the radii of common fermions and answers some fundamental issues.

In books & literature [13-15] mostly the ‘spin’ is considered weird, unreal, intrinsic, mysterious and non-classical; but in the present paper a simple, real, meaningful and semi-classical approach is successfully introduced for *better physical understanding*. A few other attempts, such as by Albrecht Giese [10] and by Alan Kadin [6], to ‘explain’ the spin classically or semi-classically have also been reported [6,10].

Though successful for most common half-spin fermions (& quarks) and integer-spin photons, yet the author’s proposed-model needs to be extended to clear-off a few gaps such as: spin-explanations of 3/2-spin fermions, zero-spin mesons and spin-2 gravitons. Further works are needed in these directions and for the other aspects of spin.

## 7. Conclusions:

The concept of ‘*quaternion (complex) mass*’ is re-explained and extended which encapsulates the essence of classical, quantum & relativistic mechanics. A mechanical modeling, based on the quaternion (complex) mass concept, of fermions & photons is possible and this *physical analogy* not only clears the mystery of the particle’s *spin* but also estimates it quite rightly. The modeling also leads to an interesting result that for *elementary* particles : *mass x radius = constant* ; thus electron ( $\approx 0.3$  pm) is bigger than proton & neutron ( $\approx 0.2$  fm) all of which are well compatible & accommodative with the angstrom-size atom and with fermi-size nucleus. Also, fundamental questions such as ‘why *h* is not zero and *c* is not infinite’ are answered scientifically. It seems possible to have a *meaningful* physical mechanical-model of ‘spin’ while retaining the aspects of quantum-mechanics and relativistic-mechanics in it .

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