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Visualizing the Spin & Radiation of the Extended Electron in Magnetic Field

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Abstract

This article presents illustrations of an extended model of the electron to visualize how it spins and radiates in the external magnetic field. A time-varying magnetic field **B** produces a rotational induced electric field **E** which rotates (spins) the electron about its axis. In time-constant magnetic field: the electron radiates the cyclotron radiation. In time-varying magnetic field: synchrotron radiation is generated. The couplings between spin, acceleration and radiation will be discussed.

Keywords

Spinning Forces, Spin by Inertia, Radiating Forces, Photon or Static Electric Dipole, Cloud of Photons, Spin - Radiation Coupling

1. Visualizing the Extended Electron

A new model of the extended electron [1] can be visualized as a spinning spherical particle which is ***a version* of the screened electron** created by the vacuum polarization according to the concept of QED: the electron is a spherical extended particle composing of a negatively charged core ($-q_0$) which is surrounded by an assembly of static electric dipoles ($-q$, $+q$) (**Figure 1** and **Figure 2**). When the extended electron is subject to an external EM field, electric/magnetic forces are produced on these point charges ($-q_0$, $-q$, $+q$) giving rise to various features of the electron such as **its spin & radiation and its effective electric charge** and other consequences.

Figure 1 and **Figure 2** show the structure of the extended electron. They suggest two ideas:

1) Since the surrounding assembly of electric dipoles ($-q$, $+q$) always exists around the core as a cloud of photons, the electron must be considered as an ex-

tended particle, instead of a point charge with the sole core ($-q_0$). When the electron emits these electric dipoles into outside medium, this implies that ***the electron is radiating***; this event identifies **photons as electric dipoles**.

2) ***The electric charge of the electron*** is an **effective charge**, which depends on external physical conditions (*i.e.*, the applying field and the energy of the electron) and internal properties of the electron: its permittivity (ε) or its permeability (μ). **Figure 1** shows the changes in the electric charge **e** with the distance **r**. In another article (not this one) we demonstrated that the electric charge **e** of the electron is a function of its permittivity (ε) or its permeability (μ) [3]; and hence ε or μ is emerged in most mathematical expressions of the extended electron as in Equation (1) below.

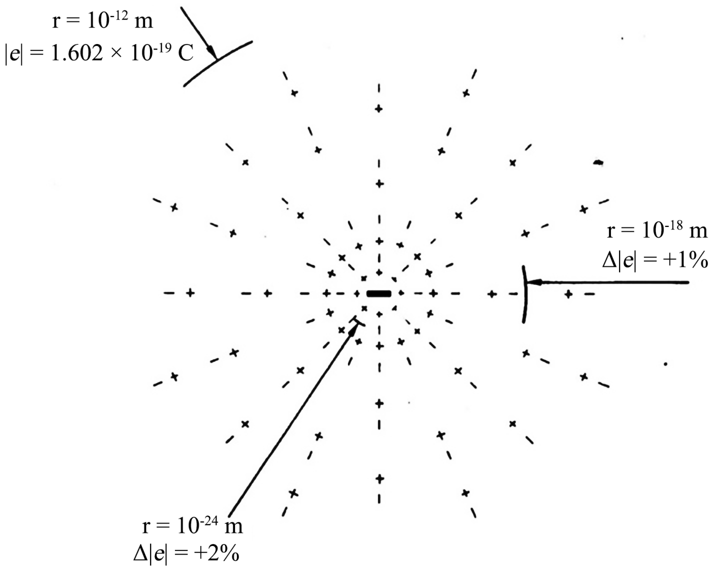

Figure 1. The electron is screened by virtual pairs (e^-, e^+) in the concept of vacuum polarization of QED. (This figure is scanned from Figure 13.1 in the textbook "Nuclear and Particle Physics" by W. S. C. William) [2].

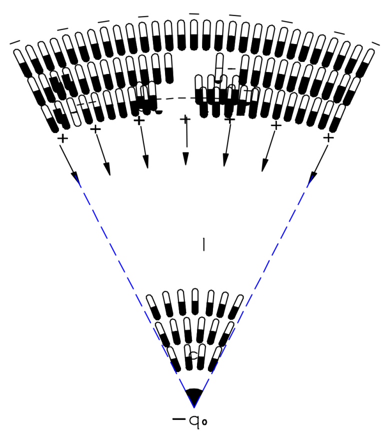

Figure 2. This is the sketch of a sector of the extended electron (from **Figure 1**). Countless electric dipoles (+q, −q) gather around the core ($-q_0$). The arrows represent cohesive forces **G** which attract all dipoles towards the core.

These two figures illustrate new patterns of the extended model of the electron: **the internal structure of the electron** (Figure 1) and **the nature of the photon**: **it is a tiny static electric dipole** (Figure 2). (These are two domains that Quantum Physics avoids to undertake because it has not come up with these two patterns). In this article, the electron will be treated by following principles of classical physics.

Note on the cohesive forces G shown in Figure 2.

The cohesive forces **G** (shown as centripetal arrows in Figure 2) are electric forces which attract all electric dipoles towards the core. They also act as antagonistic forces against the magnetic radial forces **fr** which are produced by the spin (rotation) of the electron.

When **fr** > **G**, the surface dipoles can break free from the electron; *i.e.*, the electron is radiating.

In the previous article [1], the strength of **G** has been calculated as equal to:

$$\mathbf{G}=\left[\left(1/\varepsilon\right)-1\right]q\mathbf{E_0} \tag{1}$$

where $\boldsymbol{\varepsilon}$ is the relative permittivity of the electron.

Since the electron is *stable*, **G** must be *centripetal* like the self electric field $\mathbf{E_0}$ of the electron, *i.e.*, $[(1/\varepsilon) - 1] > 0$ or $\boldsymbol{\varepsilon} < \mathbf{1}$.

Cohesive forces **G** originate from the core ($-q_0$) of the electron and the cloud of electric dipoles around the core.

In short, the purpose of the following illustrations is to demonstrate how the electron spins and radiates by the external magnetic field. They help visualize the mechanisms of spin and radiation; and thereby, the electron should be treated as an extended particle instead of a point charged without smaller constituents: [4] [5] [6].

2. Visualizing the Spin of the Electron in Time-Varying Magnetic Field B

According to Maxwell's electromagnetic induction theory, a time-varying magnetic field **B** (d**B**/dt > 0 or d**B**/dt < 0) produces the rotational induced electric field **E**: Figure 3 and Figure 4.

When an extended electron is subject to a time-varying magnetic field **B**, it is also subject to the rotational induced electric field **E**. This induced electric field **E** generates ***electric couples of forces* (*torques*)** [7] on the surface dipoles of the electron causing the electron to spin in the direction **S** (Figure 5 and Figure 6).

Remarks on features of the spin of the extended electron in the magnetic field:

1) The rotational induced electric field **E** causes the electron to spin while the magnetic field **B** affects on its orbital motion; *i.e.*, the electron has two motions at the same time: spin and translational motions.

2) Spin angular momentum **L** flips up and down when the time rate d**B**/dt changes from positive to negative and vice versa. The spin magnetic moment $\boldsymbol{\mu}$**s** is always opposite to **L**.

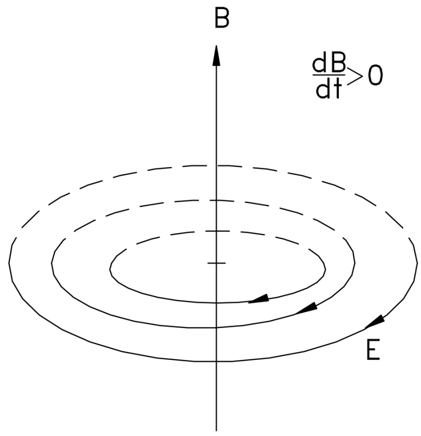

Figure 3. Direction of the induced electric field **E** produced by the magnetic field **B** when it increases with time: d**B**/dt > 0.

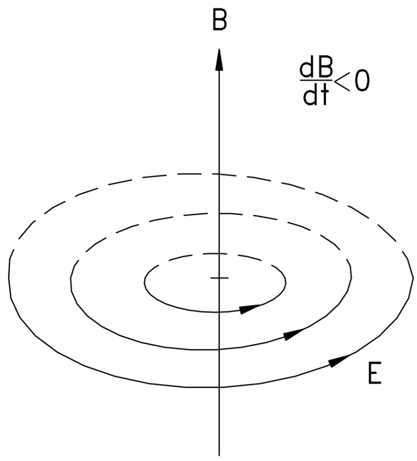

Figure 4. Direction of the induced electric field **E** produced by the magnetic field **B** when it decreases with time: d**B**/dt < 0.

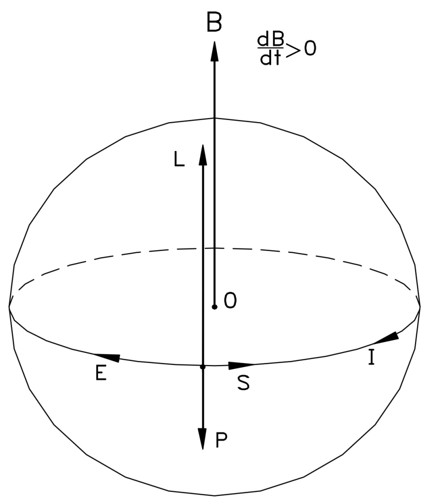

Figure 5. Direction of spin **S** of the electron in the time-varying **B** when d**B**/dt > 0. The electron spins up: **L** ↑↑ **B**. The spin magnetic moment: μs ↓↓ **P**. **P** is generated by current I from Lentz law.

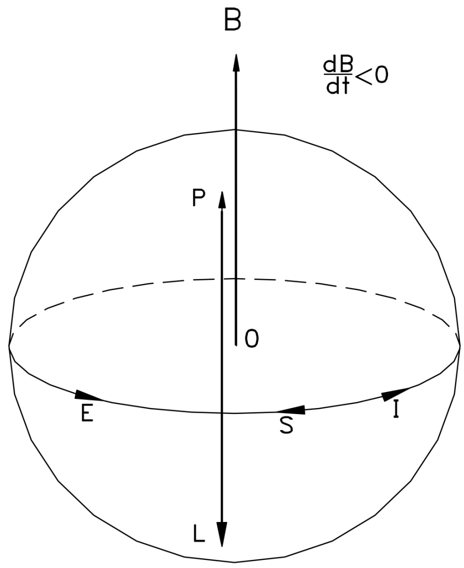

Figure 6. Direction of spin **S** of the electron in the time-varying **B** when d**B**/dt < 0. The electron spins down: **L** ↓↑ **B**. The spin magnetic moment: μ**s** ↑↑ **P**.

3) Vector **P** (in Figure 5 and Figure 6) represents the magnetic field which is produced by the current I that is generated by **Lentz law**: **P** opposes the variation of the magnetic flux through the electron. *i.e.*, when **B** increases with time (d**B**/dt > 0): **P** opposes **B** (Figure 5); and when **B** decreases with time (d**B**/dt < 0): **P** in line with **B** (Figure 6). The spin magnetic moment **μs is kind of linked to P which is created by Lentz law. Both of them are in opposite direction to the spin angular momentum L.**

4) If the time-varying magnetic field **B** abruptly stops varying (*i.e.*, **B** becomes constant in time), then the rotational induced electric field **E** disappears and hence the net ***electric couples of forces* (*torques*)** on the surface dipoles of the electron also disappears:

T = d**L**/dt = 0 or **L** = constant. This means that the electron continues to **spin with no active torques**: this is the **spin by inertia** of the electron in a time-constant magnetic field.

5) The magnitude of the spinning force **fs** depends on the induced electric field **E** which is given by the Maxwell's equation ∇ × **E** = −∂**B**/∂t. So, **fs** depends on the magnitude of **B** and the time rate of change d**B**/dt.

6) In a time varying magnetic field **B**, the electron ***spins by spinning forces*** fs (which generate the motive torque **T**): **L** is parallel (or anti-parallel) to **B** as shown in two Figure 5 and Figure 6. But when the electron ***spins by inertia*** in a time-constant magnetic field $\mathbf{B}_{const.}$, **L** can precesse around $\mathbf{B}_{const}$ (As shown in Figure 7).

Notes: 1) In the case # 4) cited above: the electron spins by inertia after the magnetic field is switched to constant in time: **L does not precess around B but lines up with B**, (*i.e.*, the angle of precession Ø (shown in Figure 7) is zero) because it spins by spinning forces **fs** before the magnetic field is switched.

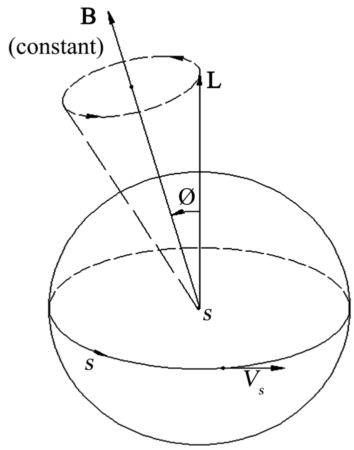

Figure 7. Spin angular momentum **L** precesses around the time-constant magnetic field **B**.

2) In the **imaging machine MRI used in hospitals**: **an oscillating magnetic field** is used to alternatively flip **the spin magnetic moment** μ**s** of the electron up and down; these flips give out energetic signals that can be captured by a detector to locate the position of the electron in the living cells.

In short, in a time-constant magnetic field, **the electron spins by inertia** (no motive torques) and in a time-varying magnetic field, **the electron spins by spinning forces fs** which are generated by the induced electric field **E**.

3. Visualizing the Radiation of the Electron in Constant Magnetic Field B: Cyclotron Radiation

In the magnetic field **B** the electron can move at any angle relative to the field **B**. Following illustrations show the directions of the magnetic forces **fm which are produced by B on surface dipoles of the electron** in two particular motions: **V // B** and **V** ⊥ **B**.

When **V // B** the magnetic force **fm** produced on surface dipoles of the extended electron is shown in Figure 8; their net force **Fm** = Σ**fm = 0** and their net torque **T** = Στ = 0. We conclude that when the electron moves parallel to the external magnetic field, magnetic forces **fm** exist but cannot cause the radiation because they are not antagonistic to the cohesive forces **G** that are centripetal [8].

But when the electron moves normally to **B** (**V** ⊥ **B**), all produced magnetic forces **fm** point kind of towards the right hand side of the observer (Figure 9): they can cause the electron to radiate. Figure 10 shows two opposite forces **F** and **F'** produced on the electron: **F** is the resultant of all magnetic forces **fm** produced on surface dipoles of the electron (**F** = Σ**fm**); and **F'** is the magnetic force produced on the core ($-q_0$) of the electron. The net magnetic force **Fm = F + F'** causes the electron to move on a circular orbit while it is radiating by magnetic forces **fm**. This is **cyclotron radiation**: the beam points to the right of the observer (who stands in the direction of **B** and looks at the electron in the direction of **V**).

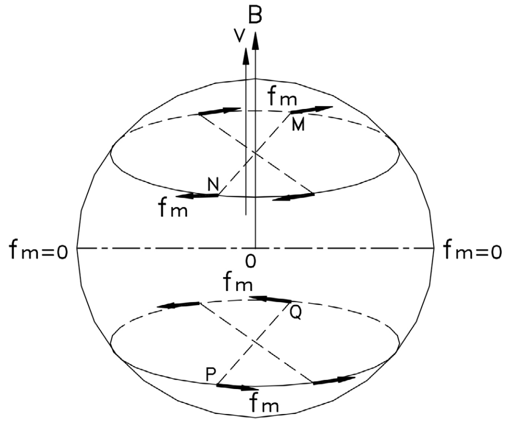

Figure 8. $\mu > 1$, **V**∥**B**: on the upper hemisphere **fm** tend to rotate the electron clockwise; while on the lower hemisphere **fm** tend to rotate the electron counter-clockwise: the electron cannot radiate.

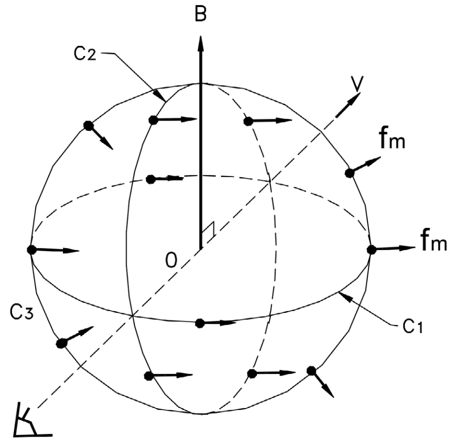

Figure 9. $\mu > 1$, **V** ⊥ **B** all magnetic forces **fm** produced on surface dipoles lying on three great circles C_1, C_2, C_3 point to the right of the observer: they can cause the electron to radiate.

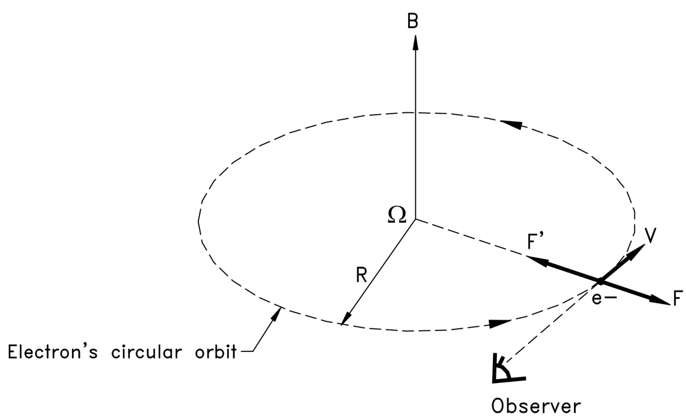

Figure 10. Cyclotron radiation (CR): circular orbit of the electron in constant **B** when **V** ⊥ **B**; **F** and **F'** point in opposite directions: **F** points to the right while **F'** to the left of the observer. The electron radiates when **fm** > **G**; the beam is emitted outwards in the direction of the force **F**.

We notice that in Figure 8, since **V // B**, the electron has *no acceleration* and it does not radiate. While in Figure 9, since **V** ⊥ **B**, the *acceleration is normal to the velocity* **V**, causing it to circulate around the field **B** and radiate as shown in Figure 10. This observation suggests that **there may be a link (or coupling) between the acceleration and the radiation of the electron**. But we will see in the next section that **an electron can radiate even when it is not accelerated**: this is the case when the electron moves parallel to an increasing time-varying magnetic field **B** (d**B**/dt > 0) (Figure 11).

4. Visualizing the Radiation of the Electron in Time-Varying Magnetic Field B: Synchrotron Radiation

In the *time-varying magnetic field* **B** the electron can have two motions at the same time: 1) the orbital motion, caused by its velocity **V**: two particular cases are **V // B** and **V** ⊥ **B**; this orbital motion gives rise to magnetic forces **fm** as we see in section 3 above (Figure 8 and Figure 9), 2) the spinning motion, caused by the induced electric field **E** (which is generated by the time-varying magnetic field **B**): the spinning (rotating) motion of surface dipoles (−q, +q) in **B** gives rise to magnetic **radial forces fr** which can be centripetal or centrifugal as we will see in the Section 4 below (Figure 11 and Figure 12).

An important consequence of the spin of the electron in the magnetic field **B** is that it produces magnetic **radial forces fr** on all surface dipoles of the electron which can cause the electron to radiate. This is because the rotational motion of two point charges −q and +q of a surface dipole about the axis **OB** produces **radial magnetic force fr** [7]:

- When d**B**/dt > 0: **fr** are centrifugal, they cause the electron to radiate (Figure 11).
- When d**B**/dt < 0: **fr** are centripetal, they prevent the radiation (Figure 12).

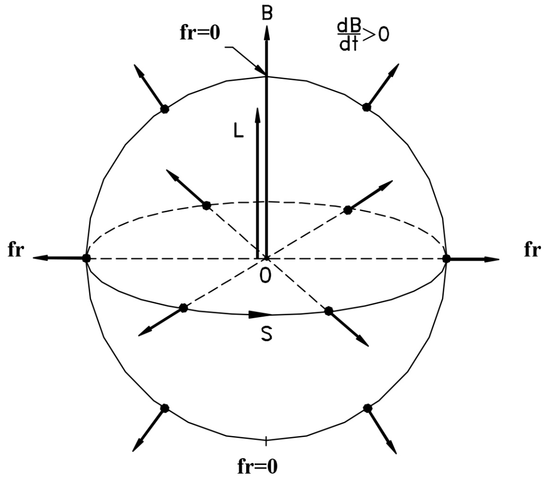

Figure 11. d**B**/dt > 0, magnetic forces **fr** produced on surface dipoles are centrifugal, *i.e.*, in opposite directions to the cohesive force **G** [inside the electron (Figure 2): they are centripetal]. **fr** can cause the electron to radiate.

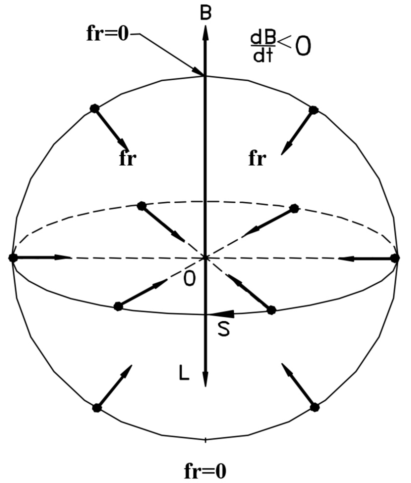

Figure 12. dB/dt < 0, magnetic forces **fr** produced on surface dipoles are centripetal, *i.e.*, in the same directions as cohesive forces **G**: **fr** prevent the electron from radiating.

Figure 11 shows that the magnetic forces **fr** produced on all surface dipoles are centrifugal, *i.e.*, they are in opposite direction to the cohesive forces **G**. And hence, whenever **fr** > **G** these surface dipoles can break free from the surface of the electron: that is, the electron is radiating.

We notice that the resultant Σ**fr** = 0 and the magnetic force produced on the core ($-q_0$) is also zero if we suppose that the electron is travelling parallel to the magnetic field **B**; hence there is no force acting on the electron. Therefore, even when it is not accelerated, the electron can radiate in a time-varying magnetic field with d**B**/dt > 0 (*i.e.*, **B** increases with time).

We conclude that **radiation can occur with no acceleration**. In other words, the acceleration is not the real physical cause of the radiation. Figure 11, Figure 13 and Figure 14 show the electron that radiates with no acceleration (since **V // B**). **So, it is not the acceleration but the net forces acting on the electron that decide whether or not the electron can radiate**.

Depending on the strengths of **G** and **fr**, the electron can radiate only from a limited zone on its spherical surface as shown in Figure 13 and Figure 14. (In Figure 13 the cohesive force **G** is denoted as $\mathfrak{F}$)

Here, the electron radiates in a time-varying magnetic field with d**B**/dt > 0, owing to the radiating forces **fr** that are produced by the spinning motion of the electron. Figure 11, Figure 13 and Figure 14 show that the electron can radiate although it is not accelerated (since **V // B**).

This means that there is **no coupling between acceleration and radiation**. But there is a **coupling between spin and radiation**.

In the **synchrotron accelerator** electrons are first accelerated normally (**V** ⊥ **B**) to the magnetic field and eventually exit through the **bending magnet which is an increasing time-varying magnetic field** (dB/dt > 0). These two physical factors together cause the electron to radiate: this is **synchrotron radiation** (Figure 15).

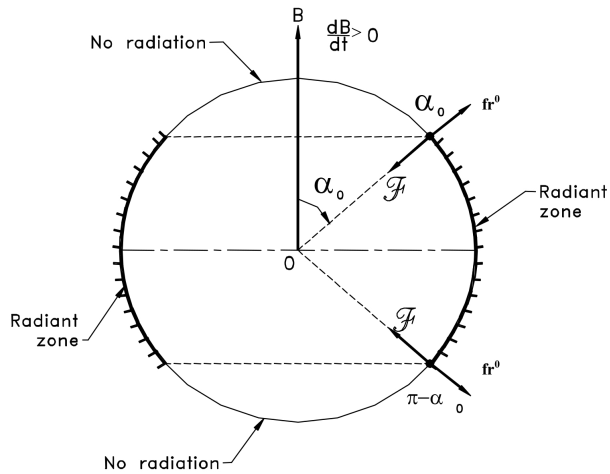

Figure 13. The radiant zone on the surface of the electron: 1) at two angles α_0 and $\pi - \alpha_0$, $fr^0 = G$; 2) inside the radiant zone (α_0, $\pi - \alpha_0$): fr > G; 3) outside the radiant zone (no radiation): fr < G.

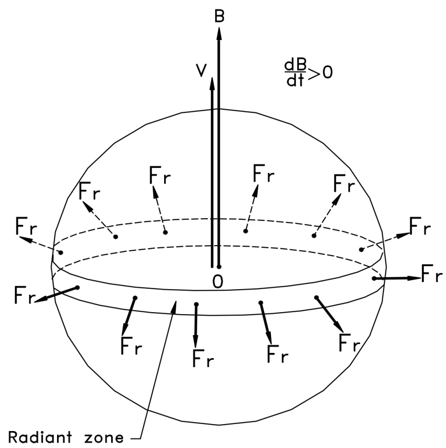

Figure 14. dB/dt > 0: Radiant zone of an electron that moves parallel to **B**. **Fr** is the net force acting on a surface dipole: **Fr = G + fm + fs + fr**.

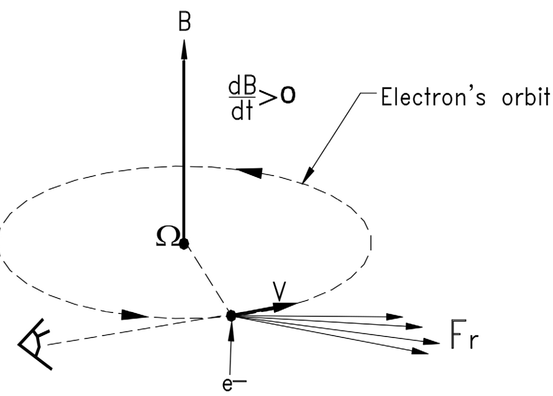

Figure 15. **Synchrotron Radiation** (SR): the beam of radiation is not emitted straight outwards as in the cyclotron radiation (**Figure 10**). SR bends forwards due to spinning forces **fs** and forms a cone of radiation. **Fr** is the net force acting on a surface dipole: **Fr = G + fm + fs + fr**.

5. The Spin-Radiation Coupling

The spin and radiation of the extended electron in the time-varying magnetic field **B** can be summed up in the following diagram:

B → E → fs (spin) → fr (radiation)

(time-varying) (induced electric field) (spin) (radiation) (Figure 5 and Figure 6) (Figure 11 and Figure 13)

That is, a time-varying magnetic field **B** generates an induced electric field **E** which produces spinning forces **fs** that spin the electron. The spinning motion of the electron under the action of **B** creates radial forces **fr** which can be centrifugal or centripetal (Figure 11 and Figure 12). Only the centrifugal forces **fr** can cause the radiation (when **fr** > **G**). As the radiating forces **fr** are generated by the spinning motion of the electron, **fr** depend on the spinning forces **fs**. This means that there is **a physical coupling between the spin and the radiation of the electron**. In other words, spin initiates the radiation of the electron, no matter it is accelerated or not. This is the radiation depicted in Figure 11 and Figure 13 when **V // B** (no acceleration) and **B** is time-varying with d**B**/dt > 0 (spin).

In summary, *in a magnetic field*, either the spin or the acceleration can initiate the radiation of the electron; conversely, *if the magnetic field is absent*, the electron *cannot radiate* despite it may be spinning (or moving) *by inertia*: this is the reason why in the interstellar space (where there is no field or the field is too weak) charged particles cannot radiate, and hence interstellar space is completely dark.

6. Different Views on the Relationship between the Acceleration and the Radiation

In the physical literature, physicists assumed that **acceleration** was the physical cause of **radiation**, but this relationship was not clear; they had different viewpoints:

- **Feynman: "*We have inherited a prejudice that an accelerating charge should radiate.*"**
- **Jackson: "*Radiation is emitted in ways that are obscure and not easily related to the acceleration of a charge.*"** [9]
- **Pearle: "*A point charge must radiate if it accelerates, but the same is not true of an extended charge distribution.*"** [10]

In the first part of his quote: **"A point charge must radiate if it accelerates"** Pearle relied on the **Lamor formula** for the power radiated by a non-relativistic point charge which is accelerated with **acceleration a**:

$$P = \mu_0 q^2 a^2 / 6\pi c \text{ or } P = q^2 a^2 / 6\pi\varepsilon_0 c^3 \quad (\textbf{SI} \text{ units})$$

So, for point charges, the radiation and the acceleration are coupled together.

In the second part of his quote: **"but the same is not true of an extended charge distribution"** which means: **"there are classical electron models with extended charge distributions which can accelerate and/or deform without**

radiating".

But when the extended charge distribution is a single electron with radius r_e and mass m_e then the power radiated is given by:

$$P = 2m_e r_e a^2 / 3c$$, (Wikipedia Encyclopedia: Lamor formulas)

which means that for extended electrons, if accelerated, they radiate.

Conclusion: Physicists (Pearle and Lamor) have not agreed with one another on the physical cause of the radiation of extended electrons: is it true that it is the acceleration that causes the radiation? Both of them have not thought of another possible cause: the spin of the electron.

7. Thought Experiment on Spin and Radiation of the Extended Electron in Magnetic Field

Let's try this experiment: we set a solenoid carrying the current **I** in vertical position to create a uniform vertical magnetic field **B** along its axis (as shown in all figures of this article). When we inject a thin beam of electron along the axis, we assume that all electrons are **not accelerated** because the velocity **V** is parallel to the magnetic field **B**.

First experiment: we set current **I** constant, so the magnetic field **B** is constant in time: Expected result: electrons do not radiate since **V//B** (**Figure 8**).

Second experiment: we set current **I** increased with time, *i.e.*, d**B**/dt > 0: Expected result: electrons spin and radiate because **fr** are centrifugal (**Figure 11**).

Third experiment: we set current **I** decreased with time, *i.e.*, d**B**/dt < 0: Expected result: electrons spin but not radiate because **fr** are centripetal (**Figure 12**).

Similar experiments can be carried out to prove the **existence of the spin by inertia** when it causes the electron to radiate in a time-constant magnetic field.

These experiments prove that electrons first spin by forces **fs** then radiate in the magnetic field **B** by centrifugal radial forces **fr**. Therefore, the spin causes the electron to radiate, not the acceleration, (because in all three experiments there is no acceleration).

So, it is not the acceleration but the net forces acting on the electron that decide whether or not the electron can radiate.

8. Discussions

Discussion 1: What are the physical factors that couple spin and radiation?

Now, let's try to identify the physical factors that are common to both **fs** and **fr**; these factors will be defined as the "**coupling factor**" between **fs** and **fr**. We find more than one of such factors that link **fs** with **fr**.

As mentioned in Section 2, the strength of **fs** depends on the magnitude of **B** and the time rate of change d**B**/dt. Spinning forces **fs** form electric couples of forces (torques) on surface dipoles and rotate the electron about its axis. Thereby the **linear velocity Vs** of a spinning surface dipole (as shown in **Figure 7**) is a function of **fs**.

While the strength of the radiating force **fr** which exerts on a surface dipole of the electron has been determined in a previous article **(3)** as:

$$\mathbf{fr} = (\mu - 1) \cdot \mathbf{q} \cdot \mathbf{Vs} \cdot \mathbf{B} \cdot \sin\alpha \,, \quad (2)$$

fr are showed in Figure 11 and Figure 13.

Where $\mu > 1$, $0 \le \alpha \le \pi$, **Vs** is the linear velocity of a surface dipole due to the spinning motion of the electron, and **B** is the magnitude of the magnetic field with d**B**/dt > 0.

Therefore, **fs** and **fr** are coupled together by the strength of the magnetic field **B**, the time rate d**B**/dt and **Vs**.

Now if **B** is suddenly turned to be constant in time (*i.e.*, d**B**/dt **=** 0), then the electron spins by inertia in constant **B**, so **Vs** ≠ 0 and hence from Equation (2) **fr** ≠ 0: this means that the electron can radiate in a constant magnetic field if ***it spins by inertia*** in this field.

So, we come to two results that can be used to test the relationship of spin and radiation [11]:

1) The electron can radiate when it moves parallel to the **time-varying** magnetic field (**V // B**) which increases with time (d**B/**dt > 0). 2) The electron can radiate when it moves parallel to a **constant** magnetic field (**V // B**) if it beforehand spins by inertia in this field.

In these two experiments, electrons are assumed to move linearly and uniformly in **B** since **V // B**.

In short, when the electron moves in a time-varying magnetic field **B**, in addition to magnetic forces **fm** due to the orbital (translational) motion, spinning forces **fs** and radiating forces **fr** are also produced on surface dipoles of the spinning electron. The resultant force **Fr** that exerts on a surface dipole is equal to **Fr** = **G** + **fm + fs + fr** (Figure 14). Four forces are linked together to cause the electron to move, spin and radiate in the external magnetic field.

Discussion 2: **Why can an electron emit photons of different energies (frequencies or colors**).

Equation (2) gives the strength of the radiating force **fr** that exerts on a surface dipole of the spinning electron (Figure 13):

$$\mathbf{fr} = (\mu - 1) \cdot \mathbf{q} \cdot \mathbf{Vs} \cdot \mathbf{B} \cdot \sin\alpha \,,$$

where α is the angular position of the surface dipole; **Vs** is its linear velocity due to the spinning motion of the electron.

On the equator of the electron: spinning velocity **Vs** is maximum and sin α = 1 (α = 90˚), so **fr** is maximum on the equator. On either sides of the equator, the strength of **fr** gradually decreases untill **fr** = 0 at two poles of the electron since sin α = 0 (the angle α = 0˚ or 180˚). So, when the electron radiates (*i.e.*, when it emits its surface dipoles outwards) the surface dipoles on the equator become photons with maximum energy, while all dipoles on either sides of the equator become photons with less energies. And thus, depending on the strength of the external field and the energy of the electron, a single electron can emit photons of different energies in the whole range from visible light to invisible X-rays and gamma rays.

9. Conclusions

1) The extended electron can have two different motions at the same time in the magnetic field: rotational and translational (orbital) like a top. Under the action of the magnetic field, these two motions cause the electron to spin and radiate. If we consider it as an extended particle, we are able to visualize the mechanisms of its spin & radiation and their couplings in the magnetic field. These findings help account for the mechanisms of CR (Cyclotron Radiation), SR (Synchrotron Radiation), FEL (Free Electron Laser) and Northern Light and more.

2) Electron is an enigmatic particle; its spin and radiation are the most secret questions of physics. To explain or understand them, we have to contrive a new assumption or theory that can lead to explanations of current observed phenomena and predict testable predictions. In this article, I speculate that the electron is an extended particle with a negative core ($-q_0$), surrounded by a cloud of photons, and a photon is a tiny static electric dipole ($-q$, $+q$). These speculative ideas lead to visualizing the spin and radiation of the extended electron in the external magnetic field. Thought experiments (which are proposed in Section 7) will help test the validity of the theory [11].

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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