Abstract

This article presents illustrations of an extended model of the electron to visualize how the electron spins and radiates by an external magnetic field. The coupling of three physical features of the electron: spin, acceleration and radiation will be discussed.

1. Visualizing the extended electron

The model of the extended electron 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 (-q₀) which is surrounded by an assembly of static electric dipoles (-q, +q) (Figs.1 & 2). When the extended electron is subject to an external field, electric/magnetic forces are produced on these point charges (-q₀, -q, +q) to give rise to various features of the electron such as its effective electric charge, spin & radiation and other consequences.

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

Fig.2: This is the sketch of a sector of the extended electron (Fig.1). Countless electric dipoles (+q, -q) gather around the core (-q₀). The arrows represent cohesive forces G which attract all dipoles towards the core.

(1) For more details, please read the article "A new extended model for the electron" at www.vixra.org/author/hoa_van_nguyen
Figs. 1 & 2 show the visualization of the structure of the extended electron by QED. It suggests two ideas: i) **the electric charge of the electron** depends on external physical conditions (applied field, velocity...); i.e., it is an effective electric charge. ii) since the surrounding assembly of electric dipoles (+, -) is viewed as a cloud of photons around the core, the outward emission of these dipoles means **the radiation of the electron**.

While determining the electric and magnetic forces that are developed on the surface dipoles of the electron, we reveal the **spinning forces** $f_s$ that rotate (spin) the electron and the **radial (radiating) forces** $f_r$ that cause the electron to radiate.

The cohesive forces $G$ (showed by arrows in Fig. 2) attract all electric dipoles towards the core. They also act as antagonistic forces against the radial forces $f_r$. If $f_r > G$, the surface dipoles can break away from the electron; i.e., the electron is radiating.

In a previous article [see foot note (1)], the strength of $G$ has been calculated as equal to:

$$G = [(1/\varepsilon) - 1] qE_0$$

where $\varepsilon$ is the relative permittivity of the electron. (1)

So, $G$ depends on the self electric field $E_0$ of the electron. Since the electron is stable, $G$ must be centripetal like $E_0$; i.e., $[(1/\varepsilon) - 1] > 0$ or $\varepsilon < 1$.

The purpose of the illustrations is to demonstrate how and why the electron can spin and radiate 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 wave or a point charged particle.

**Visualizing Spin & Radiation in magnetic field**

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 $B$ ($dB/dt > 0$ or $dB/dt < 0$) produces the rotational electric field $E$; Figs. 3 & 4
When an extended electron is subject to a time-varying magnetic field $B$, it is also subject to the rotational electric field $E$. This rotational induced electric field $E$ generates *electric couples of forces (torques)* on the surface of the electron that spin the electron in the direction $S$ (Figs. 5 & 6).

Remarks on features of the spin:

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 $dB/dt$ changes from positive to negative and vice versa.
3) If the time-varying magnetic field $B$ suddenly 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 of the electron becomes zero: $T = dL/dt = 0$ or $L = \text{constant}$. This means that the electron continues to spin with no motive torques: this is the *spin by inertia* in a constant (in time) magnetic field (or in free space).
4) The magnitude of the spinning force $f_s$ depends on the induced electric field $E$ which is
given by the Maxwell's equation \( \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \). So, \( \mathbf{f_s} \) depends on the magnitude of \( \mathbf{B} \) and the time rate of change \( \frac{d\mathbf{B}}{dt} \).

5) When the electron spins by spinning forces \( \mathbf{f_s} \) (which generate the motive torques \( \mathbf{T} \)), \( \mathbf{L} \) is parallel (or anti-parallel) to \( \mathbf{B} \) as shown in two Figs. 5 & 6. But when the electron spins by inertia in a constant (in time) magnetic field \( \mathbf{B}_{\text{const}} \), \( \mathbf{L} \) precesses around \( \mathbf{B}_{\text{const}} \) (as shown in Fig. 7) instead of lining up with the magnetic field.

3. Visualizing the radiation of the electron in constant magnetic field \( \mathbf{B} \): cyclotron radiation.

When \( \mathbf{V} \parallel \mathbf{B} \) the magnetic force \( \mathbf{f_m} \) produced on surface dipoles of the extended electron is shown in Fig. 8; their net force \( \mathbf{F_m} = \Sigma \mathbf{f_m} = 0 \) and their net torque \( \mathbf{T} = \Sigma \tau = 0 \).

We conclude that when the electron moves parallel to the external magnetic field, magnetic forces \( \mathbf{f_m} \) exist but cannot cause the radiation because they are not antagonistic to the cohesive forces \( \mathbf{G} \) that are centripetal.
Fig. 8: $\mu > 1$, $V \parallel B$ : on the upper hemisphere $\text{fm}$ tend to rotate the electron clockwise; while on the lower hemisphere $\text{fm}$ tend to rotate the electron counter-clockwise: the electron cannot radiate.

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

![Diagram of electron's circular orbit](image)

We notice that in Fig.8, since $V \parallel B$, the electron has **no acceleration** and it does not radiate. While in Fig.9, since $V \perp B$, the **acceleration of the electron is normal to the velocity $V$**, causing it to circulate around the field $B$ and radiate as shown in Fig.10. This observation proves that there is a link (or coupling) between the acceleration and the radiation of the electron\(^{(2)}\).

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\(^{(2)}\) In the physical literature, physicists assumed that the acceleration was the physical cause of the radiation, although the relation was obscure:
- **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*” (Classical Electrodynamics, 2nd Ed., Chap.15, p. 702)
- **Pearle**: “*A point charge must radiate if it accelerates, but the same is not true of an extended charge distribution.*” (When can a classical electron accelerate without radiating?)

(Foundations of Physics, Vol.8, No. 11/12, 1978, p. 879)
4. Visualizing the radiation of the electron in time-varying magnetic field \( B \) : synchrotron radiation.

An important consequence of the spin of the electron (whether by forces or by inertia) in the external magnetic field \( B \) is that it produces radial forces \( \mathbf{fr} \) 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 \( \mathbf{OB} \) produces radial magnetic force \( \mathbf{fr} \):

- when \( \frac{dB}{dt} > 0 \) : \( \mathbf{fr} \) are centrifugal, they enhance the radiation (Fig.11)
- when \( \frac{dB}{dt} < 0 \) : \( \mathbf{fr} \) are centripetal, they restrain the radiation (Fig.12)

![Fig.11: dB/dt > 0, magnetic forces fr produced on surface dipoles are centrifugal, in opposite directions to the cohesive force G [inside the electron (Fig.2) that are centripetal]. fr enhance the radiation of the electron.](image)

![Fig.12: dB/dt < 0, magnetic forces fr produced on surface dipoles are centripetal, in the same directions as cohesive forces G. fr restrain the electron from radiating.](image)

Depending on the strengths of \( G \) and \( \mathbf{fr} \), the electron radiates only from a limited zone on its spherical surface as shown in Figs.13 & 14.
Fig. 13: The radiant zone on the surface of the electron:
- at two angles $\alpha_0$ and $\pi - \alpha_0$, $f_r^0 = G$
- inside the radiant zone $(\alpha_0, \pi - \alpha_0)$: $f_r > G$
- outside the radiant zone (no radiation): $f_r < G$

Fig. 14: $\frac{dB}{dt} > 0$: Radiant zone of an electron that moves parallel to $B$

Here, the electron radiates in a time-varying magnetic field with $\frac{dB}{dt} > 0$, owing to the radiating forces $f_r$ that are produced by the spinning motion of the electron.

Figs. 11, 13, 14 show that the electron can radiate although it is not accelerated (since $V \parallel B$). This proves that there is a coupling between the spin and radiation.

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

\[ \text{Fr} = G + fm + fs + fr \]

Fig. 15. Synchrotron Radiation (SR): the beam of radiation is not emitted straight outwards as in the cyclotron radiation (Fig. 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.
5. The spin-acceleration-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:

\[
\begin{align*}
B & \rightarrow E \rightarrow \text{fs (spin)} \rightarrow \text{fr (radiation)} \quad (\text{Figs. 5 & 6}) \quad (\text{Figs. 11 & 13})
\end{align*}
\]

(time-varying) (induced) (Figs. 5 & 6) (Figs. 11 & 13)

That is, a time-varying magnetic field $B$ generates an induced electric field $E$ which produces spinning forces $\text{fs}$ that spin the electron. The spinning motion of the electron under the action of $B$ creates radial forces $\text{fr}$ which can be centrifugal or centripetal (Figs. 11 & 12). Only the centrifugal forces $\text{fr}$ can cause the radiation (when $\text{fr} > G$). As the radiating forces $\text{fr}$ are generated by the spinning motion of the electron, $\text{fr}$ depend on the spinning forces $\text{fs}$. 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 Figs. 11 & 13 when $V // B$ (no acceleration) but $B$ is time-varying with $dB/dt > 0$ (spin).

In short, in the presence of an external field, either the spin or the acceleration can initiate the radiation of the electron; conversely, in the absence of the external field, the electron cannot radiate despite it may be spinning or moving by inertia: e.g., in the interstellar space, there is no field (or the field is too weak) to initiate the radiation of charged particles, hence interstellar space is completely dark.

6. Discussions and conclusion.

Discussion 1: What is the physical factor that couples spin and radiation?

Now, let's try to identify the physical factor that is common to both $\text{fs}$ and $\text{fr}$; this factor will be defined as the "coupling factor" between $\text{fs}$ and $\text{fr}$. We find more than one of such factors that link $\text{fs}$ with $\text{fr}$.

As mentioned in remark #4 of section 2, the strength of $\text{fs}$ depends on the magnitude of $B$ and the time rate of change $dB/dt$. Spinning forces $\text{fs}$ form electric couples of forces (torques) on surface dipoles and rotate the electron about its axis. Thereby the linear velocity $V_s$ of a spinning surface dipole (as shown in Fig. 7) is a function of $\text{fs}$.

While the strength of the radiating force $\text{fr}$ which exerts on a surface dipole of the electron has been determined in a previous article\(^{(3)}\) as:

\[
\text{fr} = (\mu - 1) q V_s B \sin \alpha, \quad \text{shown in Figs. 11 & 13}
\]
where $\mu > 1$, $0 \leq \alpha \leq \pi$, $V_s$ 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 $dB/dt > 0$.

Therefore, $f_s$ and $f_r$ are related together by the strength of the magnetic field $B$, the time rate $dB/dt$ and $V_s$. Now if $B$ is a constant (int time) magnetic field (i.e., $dB/dt = 0$), then the electron spins by inertia in $B$, so $V_s \neq 0$ and hence from Eq.(2) $f_r \neq 0$; 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 by experiments the relationship of spin and radiation:

1. The electron can radiate when it moves parallel to the magnetic field ($V // B$) which increases with time ($dB/dt > 0$).
2. The electron can radiate when it moves parallel to a constant magnetic field ($V // B$) if it spins by inertia in this field (3).

In short, when the electron moves in a time-varying magnetic field $B$, in addition to magnetic forces $f_m$ due to the orbital (translational) motion, spinning forces $f_s$ and radiating forces $f_r$ are also produced on a surface dipole of the spinning electron. The resultant force $F_r$ that exerts on a surface dipole is in general equal to $F_r = G + f_m + f_s + f_r$ (Fig.14).

Four forces are linked together to cause the electron to move, spin and radiate in the external magnetic field.

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(3) Let's try the following thought experiment: we set two different solenoids on the same axis. The first solenoid carries a time-varying electric current, it produces a time-varying magnetic field along the axis. The second solenoid carries a constant current: it creates a constant magnetic field on the same axis. A beam of electrons is shot along the axis through both solenoids. When electrons pass the first solenoid, they spin and radiate in the time-varying magnetic field (when $dB/dt > 0$). When they enter the second solenoid, they spin by inertia and keep on radiating (as we speculate).

This experiment proves that electrons radiate when spinning by forces or by inertia in the magnetic field. In other words, the spin of the electron causes it to radiate, not the acceleration, (because no net magnetic forces are produced on electrons that travel parallel to the magnetic field, thus there is no acceleration).
Discussion 2: What is the physical factor that couples spin and orbit (acceleration)?

The orbital motion of the electron in the magnetic field generates the magnetic force $f_m$ on the surface dipoles, which is maximum on the equator (4):

$$f_m = (\mu - 1) q V B,$$

shown in Fig.9 when $V \perp B$ (3)

where $\mu > 1$, $V$ : velocity of the orbital motion of the electron in $B$.

Therefore, the strength of the magnetic field and its time rate $dB/dt$ and the energy (velocity) of the electron are coupling factors involving in the spin-orbit coupling and the spin-radiation coupling.

Discussion 3: Why does the electron emit photons (electric dipoles) of different energies (colors).

Eq.(2) gives the strength of the radiating force $f_r$ that exerts on a surface dipole of a spinning electron (Figs. 9). On the equator of the electron: spinning velocity $V_s$ is maximum and $\sin \alpha = 1$ ($\alpha = 90^\circ$), so $f_r$ is maximum on the equator. On either sides of the equator, the strength of $f_r$ gradually decreases till $f_r = 0$ on two poles of the electron since $\sin \alpha = 0$ (the angle $\alpha = 0^\circ$ or $180^\circ$). So, when the electron radiates (i.e., when it emits its surface dipoles outwards) the surface dipoles on the equator become photons of 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 (frequencies or colors) from visible light of Northern light to invisible X-rays.

Conclusion:

The extended electron has two different motions at the same time: rotational and translational (orbital) like a spinning top. Under the action of the magnetic field, these two motions cause the electron to spin and radiate. If we visualize it as an extended particle as showed in this article, we are able to reveal the mechanisms of its spin & radiation and the 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 (Aurora Borealis).

(4) For more details, please read the article: "Extended electron in time-varying magnetic field: spin and radiation" at www.vixra.org/author/hoa_van_nguyen
energies