Visualizing the extended electron and its spin & radiation in magnetic field

(The spin-acceleration-radiation coupling)

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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 [(1)]

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 ($-q_0$) 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 ($-q_0$, -q , +q) to give rise to various features of the electron such as its effective electric charge , spin & radiation and other consequences .

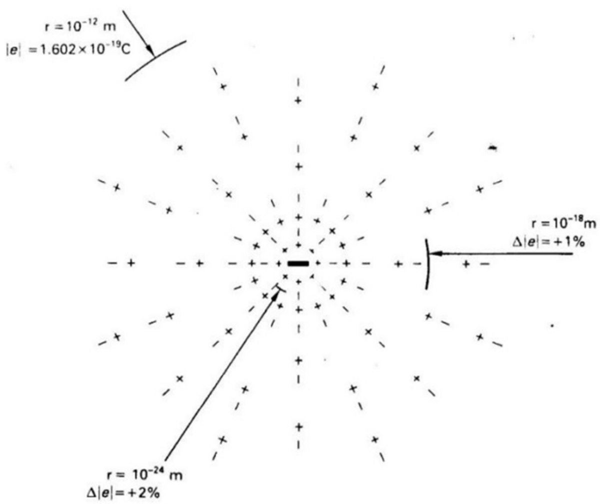

Fig.1 : The electron is screened by virtual pairs (e^- , e^+) in the concept of vacuum polarization of QED . (This figure is scanned from Fig. 13.1 in the textbook "Nuclear and Particle Physics " by W.S.C. William) .

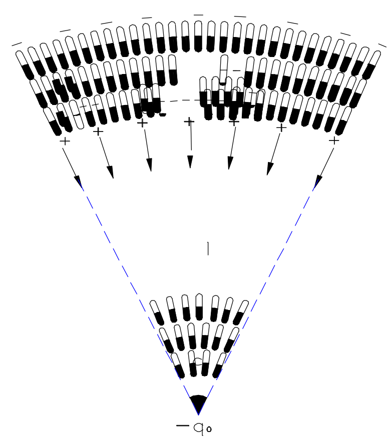

Fig.2 : This is the sketch of a sector of the extended electron (Fig.1) . Countless electric dipoles (+q , -q) gather around the core ($-q_0$) . The arrows represent cohesive forces **G** which attract all dipoles towards the core .

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(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 fs** that rotate (spin) the electron and the **radial** (**radiating**) **forces fr** 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 **fr** . If **fr > 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 :

$$\mathbf{G} = [(1/\varepsilon) - 1]\, q\mathbf{E_0} \qquad \text{where } \boldsymbol{\varepsilon} \text{ is the relative permittivity of the electron .} \qquad (1)$$

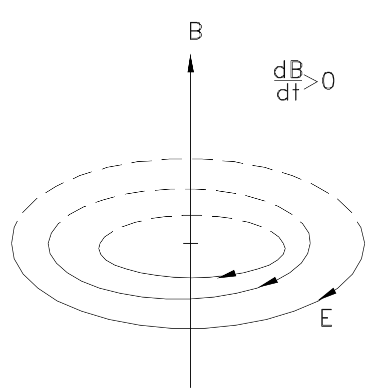
So , **G** depends on the self electric field $\mathbf{E_0}$ of the electron . Since the electron is stable , **G** must be centripetal like $\mathbf{E_0}$; i.e., $[(1/\varepsilon) - 1] > 0$ or $\varepsilon < 1$.

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** ($d\mathbf{B}/dt > 0$ or $d\mathbf{B}/dt < 0$) produces the rotational electric field **E** : Figs. 3 &4



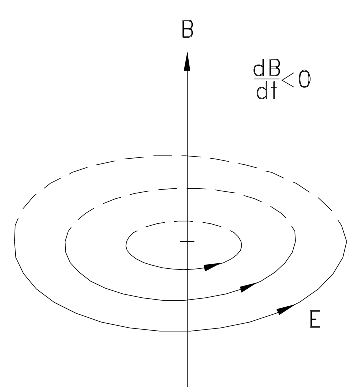
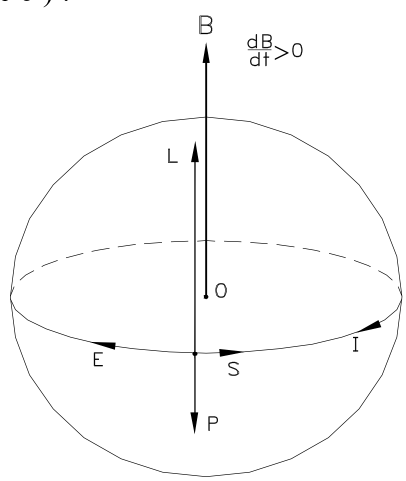


Fig.3 . Direction of the induced electric field **E** produced by the magnetic field **B** when it increases with time : d**B**/dt > 0

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

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) .



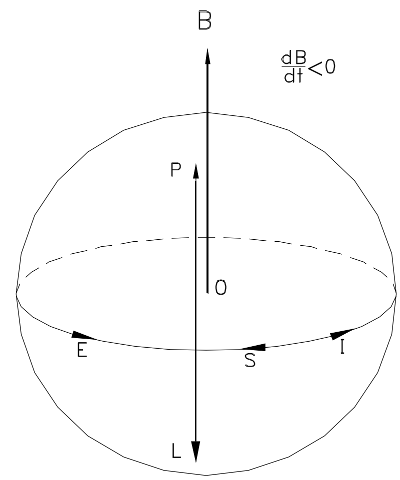


Fig .5 : Direction of spin S of the electron in the time-varying **B** when d**B** /dt > 0 .
The electron spins up : $\mathbf{L} \uparrow\uparrow \mathbf{B}$.
The spin magnetic moment : $\boldsymbol{\mu}\mathbf{s} \downarrow\downarrow \mathbf{P}$.

Fig. 6 : Direction of spin S of the electron in the time-varying **B** when d**B** /dt < 0 .
The electron spins down : $\mathbf{L} \downarrow\uparrow \mathbf{B}$.
The spin magnetic moment : $\boldsymbol{\mu}\mathbf{s} \uparrow\uparrow \mathbf{P}$.

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 d**B** /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** = d**L** / dt = 0 or **L** = 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 **fs** depends on the induced electric field **E** which is

given by the Maxwell ' s equation $\nabla\times\mathbf{E} = -\partial\mathbf{B}/\partial t$. So , **fs** depends on the magnitude of **B** and the time rate of change $d\mathbf{B}/dt$.

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

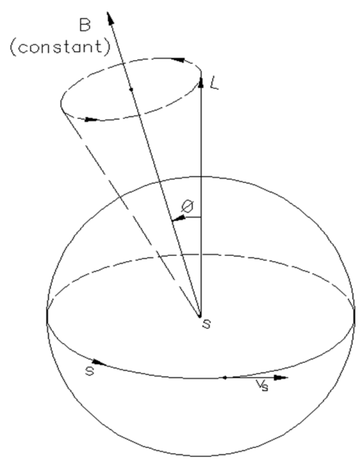


Fig. 7 : Spin angular momentum **L** precesses around the constant magnetic field **B**

3. Visualizing the radiation of the electron in constant magnetic field B : cyclotron radiation .

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

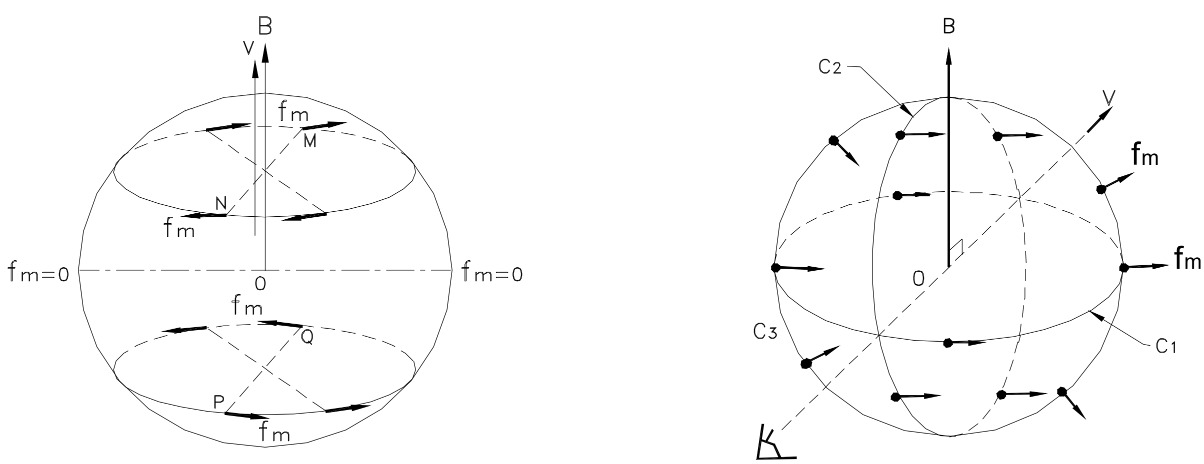


Fig.8 : $\mu > 1$, **V // B :** on the upper hemisphere **fm** tend to rotate the electron clockwise ; while on the lower hemisphere **fm** tend to rotate the electron counter-clockwise : the electron cannot radiate .

Fig.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 .

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 (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 **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 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**) .

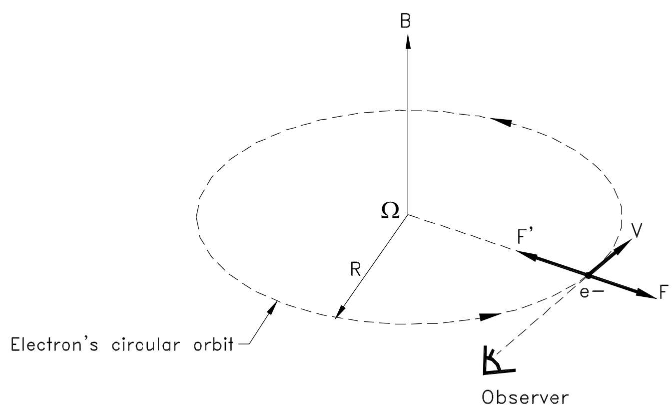


Fig.10 : **Cyclotron radiation** (CR) : circular orbit of the electron in constant **B** when **V ⊥ B** ; **F** and **F'** point in opposite directions **:** **F** points to the right while **F'** to the left of the observer . The electron radiates when **fm** > **G** ; the beam is emitted outwards in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

We notice that in Fig.8 , since **V // B** **,** the electron has *no acceleration* and it does not radiate . While in Fig.9 , since **V ⊥ 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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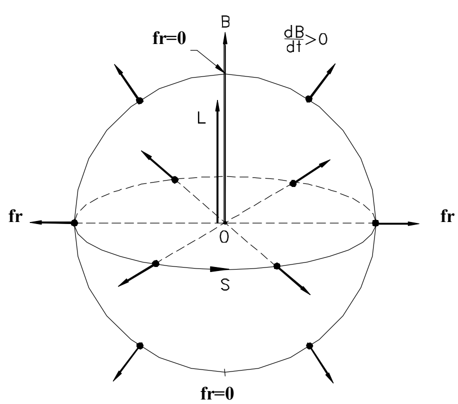
(2) In the physical literature , physicists assumed that the acceleration was the physical cause of the radiation , although the relation was obscure :
- **Feynman** : " *We have inherited a prejudice that an accelerating charge should radiate .* "
- **Jackson** : " *Radiation is emitted in ways that are obscure and not easily related to the acceleration of a charge"* (Classical Electrodynamics , 2 nd 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 ?)
(Foundation 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 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** :

- when d**B**/dt > 0 : **fr** are centrifugal , they enhance the radiation (Fig.11)
- when d**B**/dt < 0 : **fr** are centripetal , they restrain the radiation (Fig.12)



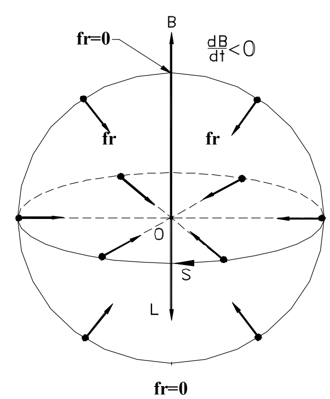
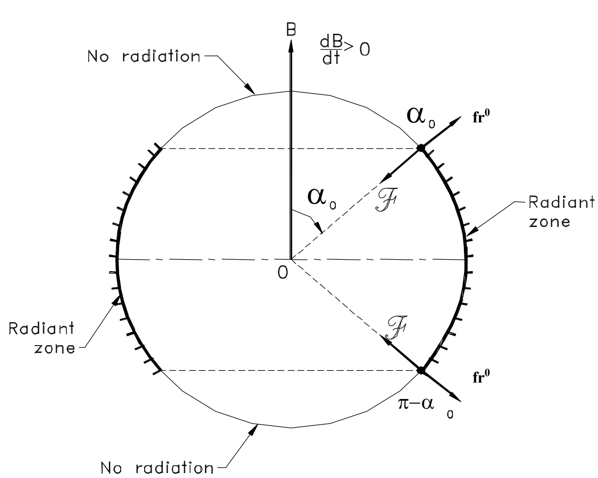


Fig.11 : d**B** / dt > 0 , magnetic forces **fr** produced on surface dipoles are centrifugal , in opposite directions to the cohesive force **G** [inside the electron (Fig.2) that are centripetal] . **fr** enhance the radiation of the electron .

Fig.12 : d**B** / 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 .

Depending on the strengths of **G** and **fr** , the electron radiates only from a limited zone on its spherical surface as shown in Figs.13 &14



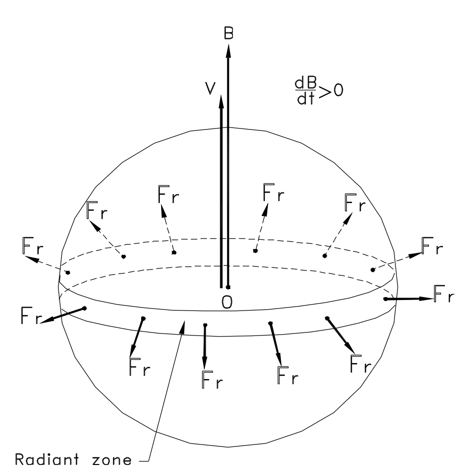


Fig. 13 : The radiant zone on the surface of the electron :
- at two angles α_0 and $\pi - \alpha_0$, $fr^0 = G$
- inside the radiant zone (α_0 , $\pi - \alpha_0$) : fr > G
- outside the radiant zone (no radiation) : fr < G

Fig.14 : d**B**/dt > 0 : Radiant zone of an electron that moves parallel to **B**

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 .
Figs.11, 13 , 14 shows that the electron can radiate although it is not accelerated (since **V // B**). This proves that there is a **coupling between the 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** (d**B** / dt > 0) . These two physical factors together cause the electron to radiate : this is **synchrotron radiation** .

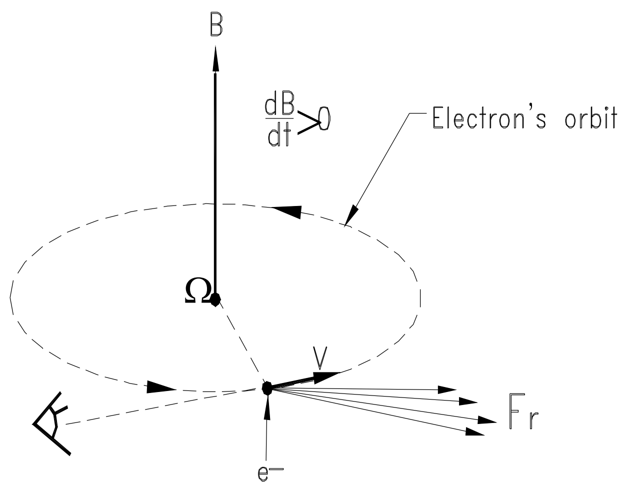


Fig.15 . **Synchrotron Radiation** (SR) : the beam of radiation is not emitted straight outwards as in the cyclotron radiation (Fig.10) . SR bends forwards due to spinning forces **fs** and forms a cone of radiation . **Fr** is the net force acting on a surface dipole : **Fr = G + fm + fs + fr**

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 :

B	$\rightarrow$	**E**	$\rightarrow$	**fs (spin)**	$\rightarrow$	**fr (radiation)**
(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 **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 (Figs.11 & 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 Figs.11 &13 when **V** // **B** (no acceleration) but **B** is time-varying with d**B** /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 **fs** and **fr** ; this factor 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 remark #4 of 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 Fig.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 :

$$fr = (\mu - 1)\, q\, Vs\, B \sin\alpha \quad , \text{ shown in Figs. 11 \&13} \qquad (2)$$

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 related together by the strength of the magnetic field **B** , the time rate d**B** / dt and **Vs** . Now if **B** is a constant (in time) magnetic field (i.e., d**B** / dt = 0), then the electron spins by inertia in **B** , so **Vs** $\neq 0$ and hence from Eq.(2) **fr** $\neq 0$: 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 (d**B** / 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 **fm** due to the orbital (translational) motion , spinning forces **fs** and radiating forces **fr** are also produced on a surface dipole of the spinning electron . The resultant force **Fr** that exerts on a surface dipole is in general equal to **Fr** = **G** + **fm** + **fs** + **fr** (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 d**B** / 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 **fm** on the surface dipoles , which is maximum on the equator [4] :

$$fm = (\mu - 1)\, q\, V\, B \quad , \qquad \text{shown in Fig.9 when } \mathbf{V} \perp \mathbf{B} \qquad (3)$$

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 d**B** / 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 **fr** that exerts on a surface dipole of a spinning electron (Figs. 9) . On the equator of the electron : spinning velocity **Vs** is maximum and $\sin \alpha = 1$ ($\alpha = 90^0$) , so **fr** is maximum on the equator . On either sides of the equator , the strength of **fr** gradually decreases till **fr** = 0 on two poles of the electron since $\sin \alpha = 0$ (the angle $\alpha = 0^0$ or 180^0) . 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) .

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[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

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energies