RECAP OF THE THEORY OF THE EXTENDED ELECTRON

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I have published online a theory of the extended model of the electron which were presented in six articles [1]. The present article is the recap of this theory , which focuses on three novel features of the extended electron : the variability of its electric charge and the mechanisms of its spin and radiation in external electromagnetic fields .
These six articles are condensed in the following pages .

<u>Article 1</u> : A New Extended Model For The Electron [2]

First , let's talk about the extended model for the electron . In QED , the electron is conceived as a negative point charge surrounded by a cloud of virtual proton-electron pairs ($e^+ - e^-$) , Fig. 1 . Physicists call it a screened electron and use its screening effect to explain the effective electric charge of the electron . The extended model (used in my theory) is a version of this screened electron , in which all virtual proton-electron pairs ($e^+ - e^-$) are converted into permanent , real tiny electric dipoles ($q^+ - q^-$) . The extended electron is thus a real particle consisting of a central negative core ($- q_0$) surrounded by an assembly of real electric dipoles ($q^+ - q^-$) , Fig. 2.

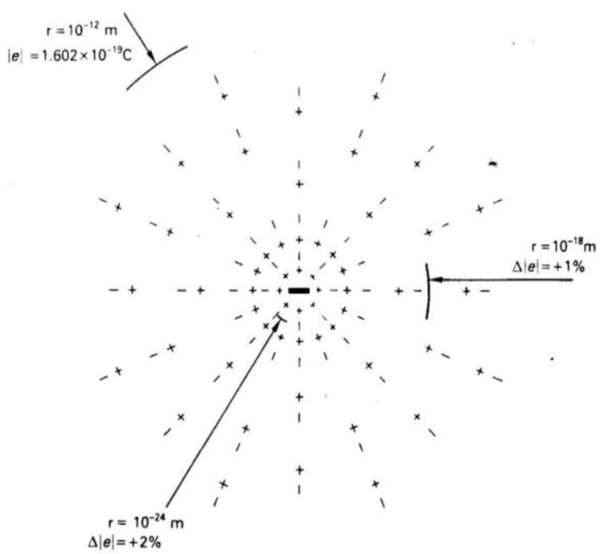

Fig.1 : This is the screened electron in QED . The virtual pairs ($e^+ - e^-$) are produced by the vacuum polarization .

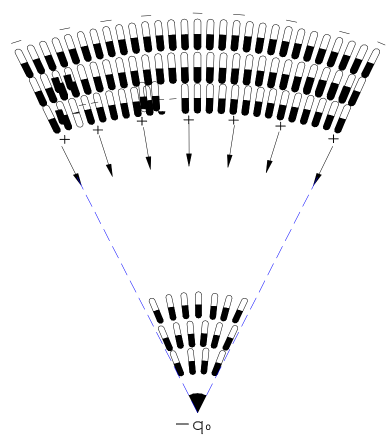

Fig. 2 : The extended model for the electron is a version of the screened electron , composing of a central core ($- q_0$) surrounded by an assembly of real electric dipoles ($q^+ - q^-$) .

The interactions of these charged components ($-q_0$, $q^+ - q^-$) with the external field give rise to various properties of the electron . This extended and structured model can be used to calculate **the effective electric charge** and demonstrate **the mechanisms of spin and radiation** of the electron in external electric / magnetic field with the aid of the classical electromagnetic laws.

In Fig.2 , the arrows which converge on the core ($-q_0$) represent the cohesive forces **G** that attract all electric dipoles towards the core . The cohesive forces **G** are generated by the interaction of the self-field $\mathbf{E_0}$ of the electron on itself ; they secure the stability of the electron .

Readers are invited to read the article **1** (Ref. **2)** for more details , in which the attractive , cohesive forces **G** are calculated to be equal to $\mathbf{G} = [(1/\varepsilon) - 1]\, q\, \mathbf{E_0}$ **,** where $\varepsilon < 1$ is the relative permittivity of the electron . **G** are thus in the same direction as $\mathbf{E_0}$ which are centripetal because the core $-q_0$ is a negative point charge .

Following are two quotations from Nobel laureates who favoured the extended electron :
" In order to overcome the difficulty of an infinitely large electromagnetic mass , ***Lorentz*** *considered the electron not to be point-like but to have a finite size "* **.**

Lamb pointed out in his Nobel lecture (1955) that " *the electron does not behave like a point charge as implied in Dirac's equation "* **.**

Conclusion : Considering the electron as a point charge (or a wave) is merely for mathematical purposes , not a physical view of the real electron . (The same as for astronomers : they view stars on the night sky as " point objects" although they are actually extended ones !) .

<u>Article 2</u> : Electron's Mass And Electric Charge , Which One Changes With Velocity? [3]

In the physical literature we learn that the mass of an elementary particle changes with its velocity . This revolutionary idea came from the theory of the electron of Lorentz at the beginning of the 20th century , which provided the famous expression

$$m = m_0 (1 - v^2/c^2)^{-1/2}$$

But in the current literature we also find many physicists who maintain that the mass of a particle always remains constant in all physical situations . Let's read some of their statements :

i) **Okun**[4] , ' The concept of mass' , Physics Today ,1989
" In the modern language of relativity theory there is one mass , the Newton mass m , which does not vary with velocity ".

ii) **Sternheim & Kane**[5] , 'General Physics ' , 1991
" The correct definition of the relativistic momentum of an object of mass m and velocity v is $p = mv (1 - v^2 / c^2)^{-1/2}$ *. In this equation , m is the ordinary mass of the object as measured by an observer in its rest frame . (Some books refer to this quantity as the rest mass and also define a velocity-dependent mass . We do not do this)"* .

iii) **Marion & Thornton**[6] , 'Classical Dynamics of Particles and Systems', 1995 , p.555

" Scientists spoke of the mass increasing at high speeds . We prefer to keep the concept of mass as an invariant , intrinsic property of an object . The use of two terms relativistic and rest mass is now considered old-fashioned . We therefore always refer to the mass m , which is the same as the rest mass ".

Now if we believe in the constancy of the mass , we have to replace the concept of changing mass , which has been appearing so far in the literature , with a novel concept to explain certain physical events . We notice that in most equations of motion of the electron in the external field , the mass m and the electric charge e of the electron always appear in the ratio e /m . This ratio prompts the idea that <u>an increase in the mass m</u> produces the same effect as <u>a decrease in the electric charge e</u> if the ratio e /m remains unchanged .
So , in the motion of the electron in the cyclotron , the increase in the mass by velocity has the same physical effect as a decrease in the electric charge caused by the applying field .

A heuristic reasoning on its equation of motion leads to the general expression

$$\boxed{q = \gamma^{-N} e = (1 - v^2 / c^2)^{N/2} e} \qquad (1)$$

which describes the variation of the effective electric charge q of the electron with the velocity and the applying field which is represented by the real number $N \geq 0$.

Following are some consequences from this expression :

* For $v \ll c$, $q \approx e$ for all values of N : this is the case of the oil droplet experiment of Millikan [7] (the velocity of the droplet is **a fraction of a millimeter per second in the electric field of 6000 volts per cm**) . So , e is the value of the electric charge of the electron at low velocities . At higher velocities , the electric charge of the electron becomes less than e .

* The higher the velocity, the smaller the charge becomes . So , as $v \to c$, $q \to 0$: the electric charge vanishes and the electron becomes a free particle , having no (or very weak) interaction with other particles .

* In free space : N = 0 ; i.e., there is no applying field , the electron has constant electric charge q = e for all velocities .

* The stronger the field (for large N) , the smaller the charge becomes . So , in an extremely strong field , $q \to 0$: the electron becomes a free particle .

The variability of the electric charge of the electron is a novel concept , which we do not come across in the literature because physicists are still considering e as a fundamental constant of electric charge , no matter how strong the applying field is .

Readers are invited to read the article **2** (Ref.**3**) in which a thought experiment is proposed to test the possibility of change in the electric charge of the electron in an external magnetic field .

In the appendices of the article **2** , the following three experimental phenomena are thought to be related to the variability of the electric charge of the electron :

A) the fine-structure constant α ,
B) the Rutherford's nuclear experiment ,
C) the Lamb's shift .

Conclusion : The concept of varying charge can replace the concept of varying mass in explaining those physical phenomena that involve charge and mass .

Article 3: Extended Electron In Constant Electric Field : Radiation by Forces [8]

In this article we determine the electric force **Fe** produced on the extended electron (A).
We will find why and how it differs from the electric force produced on the point electron .
From this , the variability of the electric charge of the extended electron can be deduced (B) .
And in (C) a new concept of radiation will be introduced : radiation by forces .

A . Determination of the electric force Fe produced on the extended electron .

Because the electron is an extended particle consisting of a central core ($-q_0$) which is surrounded by an assembly of tiny electric dipoles ($q^+ - q^-$) , the net electric force **Fe** is not simple as **Fe** = q**E** (given by the Lorentz forces equation) , but more complex .

The net electric force **Fe** is the resultant of two opposite forces **F** and **F'** , i.e., **Fe = F + F' ,**

where $\mathbf{F} = (\frac{1}{\varepsilon} - 1)\, a\, q_0 \mathbf{E}$ is the net force produced on the assembly of electric dipoles ($q^+ - q^-$)

and $\mathbf{F'} = -\,(1/\varepsilon)\, q_0 \mathbf{E}$ is the electric force produced on the core ($-q_0$) .

So $$\boxed{\mathbf{Fe} = \mathbf{F} + \mathbf{F'} = \left(\frac{a-1}{\varepsilon} - a\right) q_0\, \mathbf{E}} \qquad (2)$$

a > 1 is the dimensionless number representing the structure of the extended electron .

ε < 1 is the relative permittivity of the extended electron to the vacuum ($\varepsilon = \varepsilon' / \varepsilon_0$) .

In the interval $(1-1/a) < \varepsilon < 1$: **F** points in the direction of **E** ; **F'** points in the opposite direction to **E** ; and the net force **Fe** points in the opposite direction to **E** ; this means that the extended electron behaves like a real (experimental) electron .

If we consider the electron as *a point particle* then **F** = 0 because the assembly of electric dipoles ($q^+ - q^-$) does not exist ; only the force **F'** on the core ($-q_0$) exists and **ε = 1 ,** so Eq(2) is reduced to **Fe** = $-q_0$ **E** (this is the electric force on the point electron) . Therefore , **ε = 1** represents the case of the point electron ; for the extended electron **ε < 1 .**

B. The effective electric charge of the extended electron .

Let q be the effective electric charge of the electron ; Eq(2) can be rewritten as **Fe** = q **E** .

That is

$$\boxed{q = \left(\frac{a-1}{\varepsilon} - a \right) q_0} \tag{3}$$

This is another expression of the effective electric charge which involves the structure (ε and a) of the extended electron . Since ε varies in the interval $(1-1/a) < \varepsilon < 1$, q varies in the corresponding interval $-q_0 < q < 0$.

Conclusion : the electric charge of the electron changes while it is accelerated in the electric field **E** , this causes the electric force **Fe** changes accordingly . The physical cause of this is the change in the permittivity ε of the electron by the applying electric field **E** .

C. Radiation of the extended electron in constant electric field : radiation by forces .

Now , we will discuss the radiation process that occurs on the surface of the extended electron . In this theory , we consider light as particles (called photons) , as conceived by **Feynman** *. Light is assumed to be emitted from the electron and because the extended electron (Fig.2) consists of an assembly of real electric dipoles ($q^+ - q^-$) around its core , we identify these dipoles with particles of light . When the electron emits its electric dipoles into the surrounding space , we say it is radiating **. In this section we will introduce to the readers *a novel way to explaining the mechanism of radiation process : this is radiation by forces* .

When the electron is subject to the applying field **E** , all the surface dipoles are exerted upon by the electric forces **fe** , which are centrifugal on the upper hemisphere , but centripetal on the lower hemisphere (Fig.3) while the cohesive forces **G** are all centripetal (Fig.4) .

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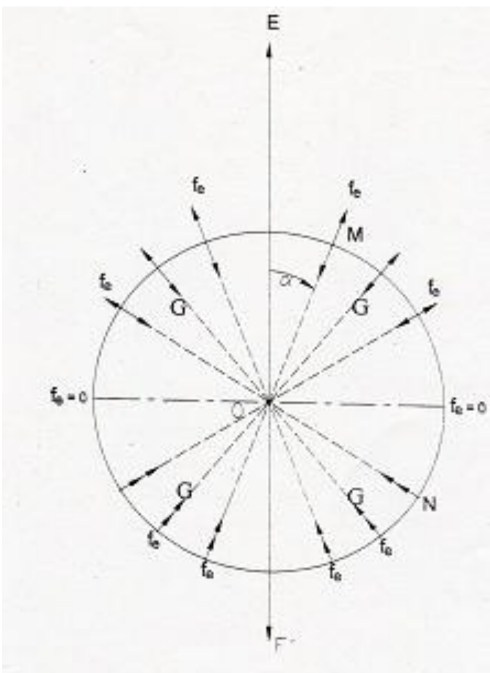
* **Feynman** : " *I want to emphasize that light comes in this form – particles . It is very important to know that light behaves like particles , especially for those of you who have gone to school , where you were probably told something about light behaving like waves . I'm telling you the way it does behave – like particles* . ”
(Optics , E.Hecht , p.138)

** Let us note that this theory discusses **the radiation of light** of the electron (concretely , visible light) ; it does not consider **the radiation of EM waves** (or fields) of electric charges from various types of antennas .

On the upper hemisphere , if the magnitude of **fe** on a surface dipole is stronger than **G** (**fe > G**) , this dipole breaks free from the surface of the electron ; that is, the electron emits this dipole upwards ; or in other words , the electron radiates in the upward direction (Fig.4) . Meanwhile , on the lower hemisphere, since **fe** and **G** are both centripetal , the surface dipole cannot break away from the electron ; that is , there is no radiation from the lower hemisphere. Therefore , the extended electron does not radiate from its entire surface , but only from a zone around the north pole , on the upper hemisphere of the electron . Meanwhile the electron is accelerated downwards by the force **F'** which is produced on the core ($-q_0$) as shown in Fig.4



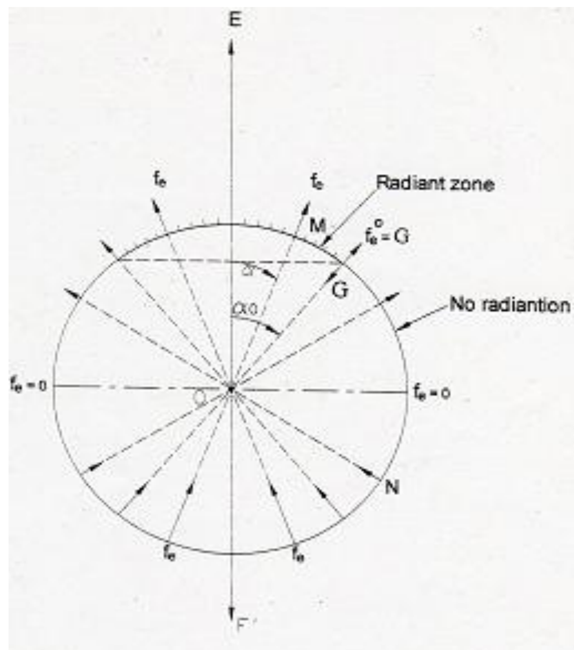


Fig.3 **:** **fe** are centrifugal on the upper hemisphere , but centripetal on the lower hemisphere , while all cohesive forces **G** are centripetal .

Fig.4 : The electron radiates only from a zone around the north pole of the electron , and there is no radiation from the lower hemisphere .

The condition for radiating of the extended electron is discussed in Part 2 of the article **3 (Ref.8) .** It introduces a novel way of explaining the radiation process of the extended electron : this is radiation by forces . When the extended electron is subject to an external field **E** which is stronger than the self-field $\mathbf{E_0}$ of the electron , the electron radiates in the direction of **E** by the electric forces **fe** that exert on the surface dipoles of the upper hemisphere of the electron .
The radiation does not depend on the acceleration of the electron .
Following are statements of three physicists about the relationship between the radiation and the acceleration :

* **Pearle**[9] : " *A point charge must radiate if it accelerates , but the same is not true of an extended charge distribution* ."

****Jackson**[10] : " *Radiation is emitted in ways that are obscure and not easily related to the acceleration of a charge ."*

*** **Feynman** : " *We have inherited a prejudice that an accelerating charge should radiate . "*

Conclusion : Using the extended electron , we can show that the electron radiates by forces which are produced by the external (applying) field on the surface dipoles of the electron . Readers are invited to read the article **3** for detailed discussions on the conditions for radiation .

<u>Article 4</u> : Extended Electron In Time-Varying Electric Field : Spin and Radiation [11]

When the electron is accelerated by a time-varying electric field **E** , it is subject to two fields at the same time : the electric field **E** and the induced magnetic field **B** , which is generated by this time-varying electric field **E** .

In the previous article , we discussed the action of the electric field **E** on the electron : it causes the electron to radiate if **E** is stronger than the self-field $\mathbf{E_0}$ of the electron . The electron radiates in the direction of **E** by electric forces **fe** which are stronger than cohesive forces **G** (Fig.4) . Now in this article , we investigate the actions of the induced magnetic field **B** on the electron which is accelerated through the time-varying field **E** .

In **E** , the electron can move parallel or obliquely to the direction of **E** .
When it moves obliquely to **E** , its velocity **V** can be decomposed into two components : **V'** perpendicular to **E** and **V"** parallel to **E** .
The induced magnetic field **B** produces two different magnetic forces on the electron due to two components **V'** and **V"** of the velocity **V** :

1/ Component **V'** (⊥ **E**) produces spinning forces **fs** which cause **the electron to spin** ,
2/ Component **V"** (// **E**) produces radiating forces **fm** which cause **the electron to radiate** .

In short , when the extended electron moves through a time-varying electric field **E** , two different types of magnetic forces can be developed on the electron and cause it to spin and /or radiate .

Readers are invited to read the article **4 (Ref.11) ,** in which the **spinning forces fs** and the **radiating forces fm** are determined separately . The results are as follows :

The perpendicular component **V'** of the velocity **V** produces magnetic forces **fs** on all surface dipoles of the electron . These **spinning forces fs** form couples of forces (torques) which

cause the electron to spin about the axis **OS** that is normal to the plane (**E , V**) , Fig.5 .
The magnitude of **fs** produced on a surface dipole is $fs = (\mu - 1)\, q\, V'\, B \sin\beta$.

The parallel component **V''** produces radiating forces **fm** on all surface dipoles of the electron (Figs. 6) , which contribute to the radiation process of the electron by the electric field **E** (Fig.4) , which we already discussed in the previous article .
The magnitude of **fm** is $fm = (\mu - 1)\, q\, V''B$
where μ is the relative permeability of the extended electron and q is the electric charge of the dipole .

Conclusion : when the extended electron is accelerated through a time-varying electric field **E** , it spins by magnetic forces **fs** which are produced by the perpendicular component **V'** , and/or it radiates by magnetic forces **fm** which are produced by the parallel component **V''** .

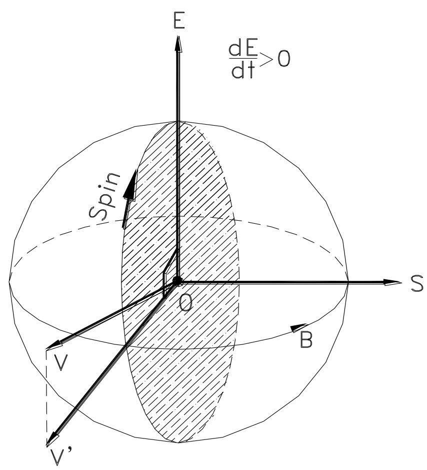


Fig.5 : The spin of the electron in an increasing time-varying **E** (d**E** /dt > 0) is produced by the perpendicular component **V'** (⊥ **E**). Spin axis **OS** is normal to the plane (**E , V).** When **E** decreases with time (d**E** /dt < 0) , spin reverses its direction .

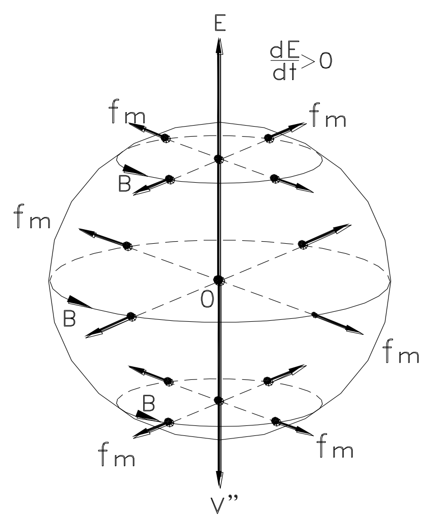


Fig.6 : Magnetic forces **fm** are produced by the parallel component **V''** (// **E**) . They contribute to the radiation process of the electron .

A special note and comment :
A team of physicists in the Netherlands , led by **L . Vandersypen** [12] , reported in the Science Magazine (Nov. 2007) that they have experimentally controlled the spin of a single electron by using an oscillating electric field . " *We demonstrate coherent single spin rotations induced by an oscillating electric field* .

M . Banks [13] reported this work of Vandersypen et al., in Physicsworld.com ; he wrote :
“ It is possible to control the spin of a single electron by using an electric field rather than an magnetic field , as is usually the case ”.

Comment : In both reports , these physicists did not explain why and how the electric field can cause the electron to spin , and hence they could not explain the reason why the electron can reverse (flip) its spin by an oscillating electric field . Moreover , they did not distinguish the spin by an electric field from the spin by a magnetic field ; actually , these are two different types of spin by different types of forces . The only plausible way of explaining the flipping of the spin is to consider the electron as an extended particle , not a point particle .

<u>Article 5</u> : Extended Electron Moving in Constant Magnetic Field : Cyclotron Radiation [14]

In this article we will calculate the magnetic forces produced on the extended electron when it moves parallel (A) and normally (B) to the magnetic field , and finally in (C) we discuss the radiation of the electron by magnetic forces when it moves normally to the constant magnetic field : this is cyclotron radiation .

A . The net magnetic force Fm produced on the extended electron is equal to zero when V//B .

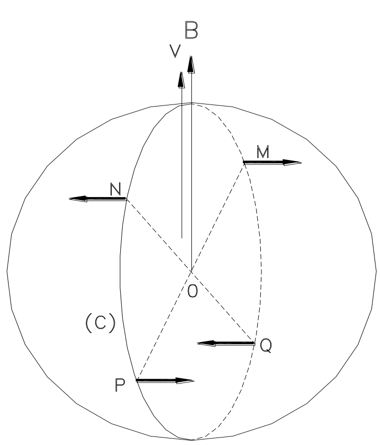
Because the extended electron has three different components : the surface dipoles , the interior dipoles and the core ($-q_0$) , the net magnetic force **Fm** is the resultant of all forces produced on these three components .

1 . Magnetic forces fm produced on <u>surface dipoles</u> of an extended electron moving parallel to B (V//B)

The *magnitude* of the magnetic force **fm** produced on a surface dipole of the extended electron is calculated to be equal to $\text{fm} = (\mu - 1) \, q \, V \, B \sin\alpha \cos\alpha$

where $\mu > 1$ and $0 \le \alpha \le \pi$ is the angular position of the surface dipole .
On the equator of the electron : $\alpha = \pi/2$, $\cos\alpha = 0$, so fm = 0 .
At two poles of the electron : $\alpha = 0$ and $\alpha = \pi$, $\sin\alpha = 0$, so fm = 0 .

The *directions* of four magnetic forces **fm** acting on four surface dipoles M , N , P , Q are shown in Figs. 7 & 8 **:** **fm** are tangent to the spherical surface of the electron .



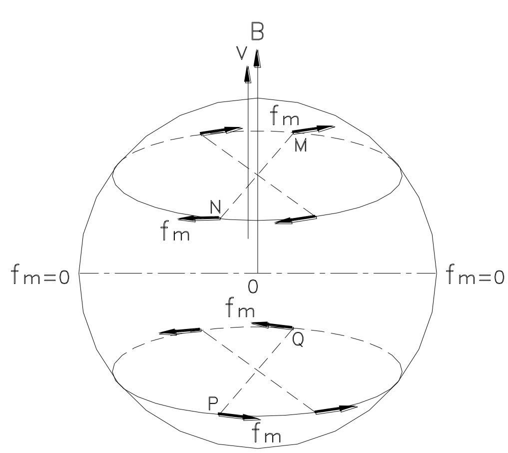


Fig.7. **$\mu > 1$** , **V // B** : the directions of **fm** on four surface dipoles M , N , P , Q on the great circle (C) .

Fig.8 **:** **$\mu > 1$** , **V // B** : directions of **fm** on the surface dipoles of the electron .

All **fm** on the upper hemisphere form torques which tend to rotate the electron clockwise ; while **fm** on the lower hemisphere form torques which tend to rotate the electron counter-clockwise . And as a result , the overall effect of **fm** on the electron is cancelled out .

In short , when an extended electron moves parallel to the applying magnetic field **B ,** magnetic forces **fm** are developed on *all surface dipoles* but they have no effect on the motion of the electron (**V // B**).

2 . The resultant of magnetic forces produced <u>on all interior dipoles</u> of the extended electron is cancelled out , (**V // B**).

All *interior dipoles* have the same velocity **V** and are subject to the same magnetic field **B'** inside the electron . Two magnetic forces produced on two ends of an interior dipole (-q , +q) are thus equal and opposite ; they cause a slight "*rotation on-the-spot* " of all interior electric dipoles , and thus affect the permeability μ of the electron , but the resultant force is zero . So , the resultant of all magnetic forces produced on all interior dipoles is cancelled out .

3 . **Magnetic force produced <u>on the core (</u> $-q_0$) of the extended electron is zero ,** (**V // B**).

The core ($-q_0$) is a point charge at the center of the electron where the magnetic field **B'** is created by the external field **B .** Because of the spherical symmetry of the structure of the electron , **B'** must be parallel to **B** . So when the electron moves parallel to **B** , the core ($-q_0$) moves parallel to **B'** and hence the magnetic force that **B'** produces on the core is zero (according to the Lorentz 's force equation when **V // B**) .

Conclusion : although magnetic forces **fm** developed on surface dipoles exist , there is no net magnetic force **Fm** appear on the extended electron when it moves parallel to the external magnetic field **B** .

Note : This result appears to be the same as the Lorentz magnetic force $\mathbf{F_L}$ produced on a point electron (of electric charge e) that moves parallel to the external magnetic field **B** (**V // B**) :

$$\mathbf{F_L} = e\,(\mathbf{V} \times \mathbf{B}) = 0$$

This expression simply means that the magnetic force $\mathbf{F_L}$ is not produced on the point electron . But for the extended electron , although the net magnetic force $\mathbf{Fm} = \Sigma\, \mathbf{fm} = 0$, the magnetic forces **fm** exist as shown in Figs.7 & 8 . These non-zero forces **fm** cause all surface dipoles of the electron to be slightly re-oriented , leading to a change in its permeability μ **;** this change affects the effective electric charge of the electron .

Readers are invited to read the *thought experiment* described in section 4 of the article **2 (Ref.3)** which is intended to prove the variability of the effective electric charge of the extended electron by the magnetic field.

B . The net magnetic force Fm produced on the extended electron when it moves normally to B : V ⊥ B

As before , the net force **Fm** is the resultant of all forces which are produced on three components of the extended electron : 1/ surface dipoles , 2/ interior dipoles and 3/ the core $(-q_0)$.

1. The magnetic force **fm** produced on <u>an arbitrary surface dipole</u> has magnitude

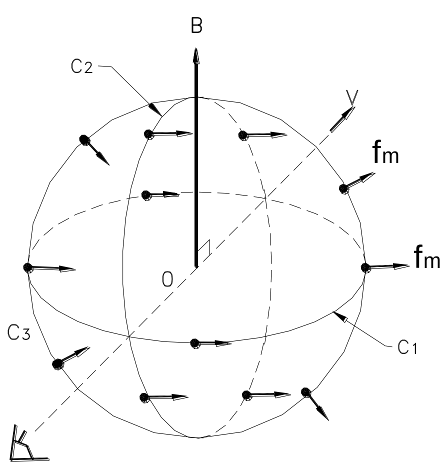
$$fm = (\mu - 1)\ q\ V\ B \sin\alpha \sin\beta \cos\gamma$$

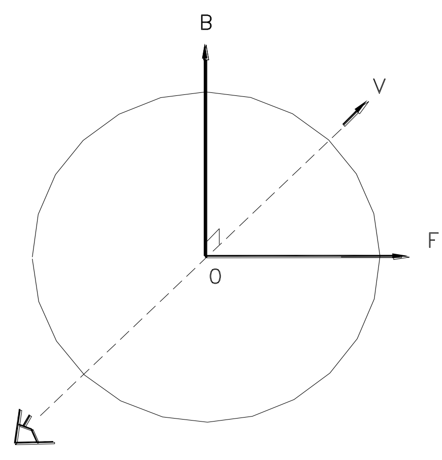
The directions of **fm** produced on the surface dipoles of the electron are shown in Fig.9 .

The resultant **F = Σ fm** is shown in Fig. 10 ; its magnitude is

$$F = (\mu - 1)\ b q_0\ V\ B \qquad (\mathbf{V} \perp \mathbf{B})$$

where $\mu > 1$ is the relative permeability of the electron ; $b > 1$ is the parameter defining the structure of the electron . For the actual interval of variation of μ : $1 < \mu < \dfrac{b}{b-1}$, the magnetic force **F** points to the right- hand side of the observer as shown in Fig.10





Observer

Fig.9 : **V** ⊥ **B** , $\mu > 1$: all magnetic forces **fm** produced on the surface dipoles point to the right-hand side of the observer .

Fig.10 : **F** is the resultant force of all forces **fm** produced on the surface dipoles of the electron **.** **F** points to the right- hand side of the observer .

2. By reasoning as before , the resultant force produced on <u>all interior dipoles</u> cancels out . They cause a slight "*rotation on-the-spot* " of all interior electric dipoles , and thus affect the permeability μ of the electron . This causes a change in the effective charge of the extended electron .

3. The magnetic force **F'** produced on the core (- q_0) has magnitude

$$F' = -\mu q_0 V B \qquad (\mathbf{V} \perp \mathbf{B})$$

F' is negative , i.e., **F'** points to the left- hand side of the observer as shown in Fig. 11

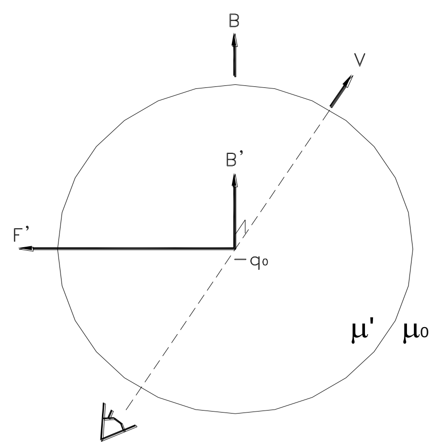


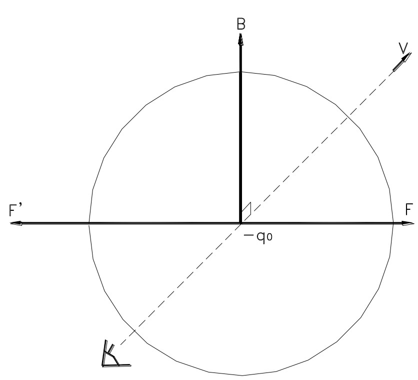
Fig.11 : **F '** is the force produced on the core (- q_0).

F ' is always negative **:** it points to the left-hand side of the observer **.**

4. The net magnetic force **Fm** produced on the extended electron when it moves normally to **B** is the resultant of **F** and **F'** : **Fm = F + F' .** Its magnitude is

$$\boxed{Fm = [\, \mu (b-1) - b \,]\, q_0 V B} \qquad (\mathbf{V} \perp \mathbf{B})$$

Conclusion : When the extended electron moves normally to the external magnetic field **B** , two opposite forces **F** and **F'** are produced on the electron as shown in two Figs. 12 & 13 .



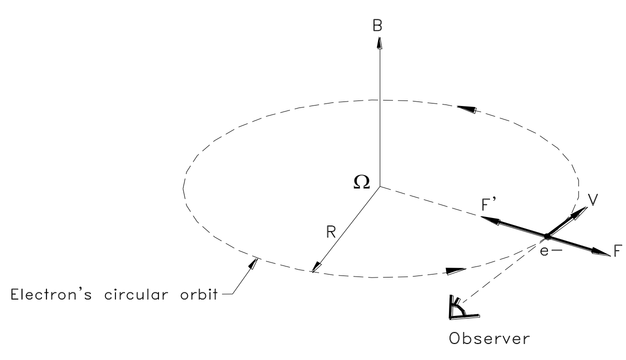


Fig. 12 : $\mu > 1$: **F** and **F'** are in opposite directions . **F** points to the right-hand side **, F '** to the left-hand side of the observer .

Fig.13 : The net force **Fm (= F + F')** is negative. The beam of cyclotron radiation directs in the direction of the force **F** , normal to the orbit of the electron .

Readers are invited to read the article 5 (Ref.14) for the discussion which leads to the actual interval of variation of μ : $1 < \mu < \frac{b}{b-1}$. In this interval F and F' are in opposite directions as shown in two Figs. 12 & 13 , and the net force Fm **(= F + F')** is negative , which points to the left-hand side of the observer , and hence the electron deflects to the left of the observer as shown in Fig.13 .

The effective electric charge q of the extended electron can be deduced from the above expression of Fm:

$$q = [\, \mu\,(b-1) - b\,]\, q_0$$

For the interval $1 < \mu < \frac{b}{b-1}$, q varies in the interval $-q_0 < q < 0$.

Note : If we set $\mu = 1$, we get the force and the charge for the *point electron* :
because the point electron has no surface dipoles : $F = 0$; $F' = Fm = -q_0 \ VB$ **(V ⊥B)**
i.e., the extended electron reduces to the point electron of charge $-q_0$.

Because the extended electron has $\mu > 1$, while for the point electron $\mu = 1$: this physically means that the extended electron can never be reduced to the point electron .
The point electron is only the result of a mathematical speculation , it has no physical meaning .
(**Lamb** pointed out in his Nobel lecture (1955) that *" the electron does not behave like a point charge as implied in Dirac's equation "*) .

C . Radiation of the extended electron moving normally to the magnetic field : cyclotron radiation

We have determined various magnetic forces produced on the extended electron when it moves parallel (A) and normally (B) to the external magnetic field **B** . As mentioned before , it is possible to show that the extended electron can <u>radiate by forces</u> which are produced on <u>its surface dipoles</u> by the applying field .

When the electron moves <u>parallel</u> to the magnetic field **B** , the magnetic forces **fm** which are produced on its surface dipoles are shown in Figs.7 & 8 : **fm** are tangent to the spherical surface of the electron , and thus <u>the radiation cannot occur</u> because the radiation occurs only when **fm** are in opposite direction and stronger than the cohesive forces **G** which are centripetal inside the electron .

When the electron moves <u>normally</u> to the magnetic field **B** , the magnetic forces **fm** which are produced on its surface dipoles are shown in Fig.9 : **fm** point to the right-hand side of the observer ; their magnitude and direction depend on their position on the surface of the electron ; their resultant **F** = Σ **fm** is shown in Fig.10 .

Fig.9 shows that on *the right hemisphere* , **fm** point outwards the electron , while the cohesive forces **G** are centripetal : so , <u>the radiation can occur</u> if **fm >** **G** in magnitude .

On the contrary , on *the left hemisphere* of Fig. 9 , **fm** point inwards the electron , i.e., in the same direction as the cohesive forces **G** : <u>the radiation cannot occur</u> .

Conclusion : The radiation of the electron moving normally to a constant magnetic field **B** is characterized by *a beam of radiation which emits in the direction of the right- hand side of the observer* . That is , the beam of radiation is in the same direction as the force **F** that points to the right- hand side of the observer as shown in Fig.13 .
This is the **cyclotron radiation** of the electron by the constant magnetic field in the **cyclotron** .

Note : In the **synchrotron** , electrons circulate normally to the magnetic field **B** of the bending magnets . The field **B** is not constant , but increases with time (d**B**/dt > 0) . Electrons emit a beam of radiation , called **synchrotron radiation** , which bends forwards on the orbit of the electron as shown in Fig.14 . The different patterns of cyclotron and synchrotron radiations as shown in two Figs.13 & 14 can be explained by magnetic forces produced on the surface dipoles of the electron . We will discuss the synchrotron radiation of the electron in the time-varying magnetic field in the next (also the last) article of the theory of the extended electron .

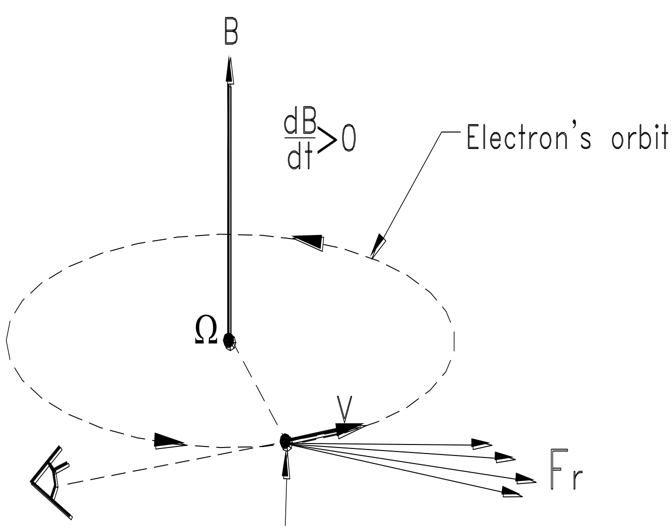


Fig.14 : The beam of Synchrotron Radiation **Fr** bends forwards on the orbit of the electron , forming a cone of radiation .

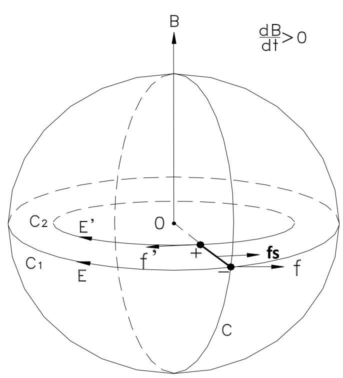
<u>Article 6</u> : Extended Electron in Time-Varying Magnetic Field : Spin & Radiation [15]

This is the last article of the theory of the extended electron . It discusses the mechanisms of the spin and radiation of the extended electron by a time-varying magnetic field .
A time-varying magnetic field **B** produces an induced electric field **E** ; and thus an electron moving in a time-varying magnetic field is subject to two fields : **E** and **B** simultaneously.
Part I **:** The induced electric field **E** produces spinning forces **fs** on the electron , causing it to spin .
Part II **:** The spinning motion of the electron in the magnetic field **B** produces radial forces **fr** which cause the electron to radiate .
Part III : When moving *normally* to the magnetic field , the electron emits **Synchrotron Radiation (** SR **)** and **Free Electron Laser (** FEL **) .**
Part IV : Finally , we consider the possibility of radiating of the electron when it moves *parallel* to the magnetic field .

Part I : Spin by induced electric forces fs

The purpose of this part is to show that the extended electron spins by induced electric forces **fs** that are produced by the induced electric field **E** (of a time-varying magnetic field **B) .**

Readers are invited to read the article **6** (Ref.**15**) , in which the electric forces **fs** are shown acting on the surface dipoles of the electron ; these forces form torques which tend to rotate the electron about the magnetic axis **OB** (Fig.15) . And hence , we call them "spinning forces" **fs** .



f = -q **E** and **f’** = +q **E’**

fs = **f** + **f’** = q (**E’** – **E**) ≠ 0 since **E’** ≠ **E**

fs is normal to the plane of the great circle C ;

it tends to rotate the electron about the axis **OB** .

Fig.15 : Two electric forces **f** and **f '** are produced on two ends (+ , -) of the surface dipole . The resultant **fs = f + f '** acts on the dipole . The induced electric field **E** produces electric forces **fs** on all surface dipoles : they form torques that cause the electron to spin about the magnetic axis **OB** .

The direction of spin (or rotation) **S** of the electron can be determined in aid of Lentz 's law or Maxwell ' s equation $\nabla\times\mathbf{E} = - \partial\mathbf{B} / \partial t$, which gives the direction of **E** . The results are shown in Figs.16 & 17 : **S** is always in opposite direction to **E** in both cases .

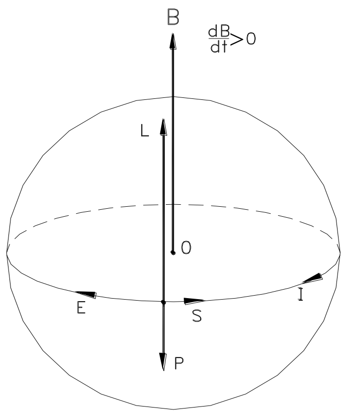


Fig. 16 : In an increasing magnetic field **B** (d**B**/dt > 0) : **S** is in opposite direction to **E** . The angular momentum **L** is in the same direction as **B** : the electron spins up .

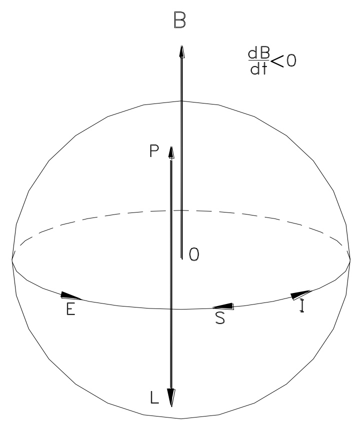


Fig. 17 : In a decreasing magnetic field **B** (d**B**/dt < 0) : **S** is in opposite direction to **E** . The angular momentum **L** is in opposite direction to **B** : the electron spins down .

Conclusion : Whenever the electron is subject to a time-varying magnetic field **B ,** it spins about the magnetic axis **OB** by the induced electric forces **fs** . The spin angular momentum **L** and the spin magnetic moment **P** (or μ_s) are two characteristics associated to the spin of the electron . For the electron , **L** and **P** are always in opposite direction .

Note : In a constant magnetic field the **electron spins by inertia** if it spins beforehand by spinning forces **fs** . Readers are invited to read the article **6 (Ref.15)** for the explanations of the spin by inertia and the precession of the electron in constant magnetic field .

Part II : The magnetic radial forces fr produced by the spinning motion .

Let us consider an extended electron which is spinning under the action of the time-varying magnetic field **B** . The spinning motion of two point charges –q and +q of a surface dipole in the magnetic field **B** produces *radial magnetic force* **fr** :

- **fr** is centrifugal when d**B**/dt > 0 (Fig.18)
- **fr** is centripetal when d**B**/dt < 0 (Fig.19)

The magnitude of the force **fr** which exerts on a surface dipole of the electron is
fr = $(\mu-1)\, q\, Vs\, B \sin\alpha$, where $\mu > 1$, $0 \le \alpha \le \pi$, Vs is the linear velocity of the dipole due to the spinning motion of the electron about the axis OB .

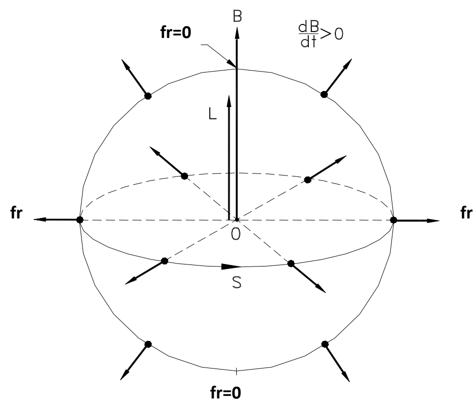


Fig.18 . d**B** / dt > 0 : magnetic forces **fr** produced on all surface dipoles are centrifugal .
If **fr > G** **:** the electron can radiate by forces **fr** .

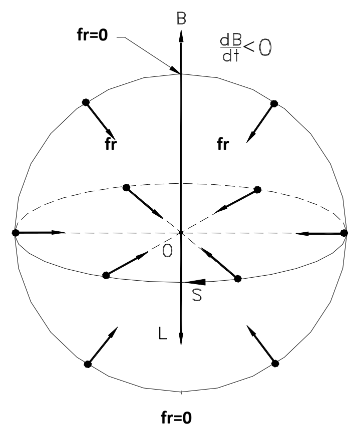


Fig.19 . d**B** / dt < 0 : magnetic forces **fr** produced on all surface dipoles are centripetal :
the electron cannot radiate .

Fig.18 illustrates the case when the electron can radiate if **fr > G** (in magnitude) on some surface dipoles : they will break away from the surface of the electron ; that is , the electron emits (or radiates) these dipoles into surrounding space .

Up to this point , we have seen two different forces : **fs** and **fr** which are produced on the surface dipoles of the electron when it is subject to the external time-varying magnetic field **B** .
- **fs** are the electric forces produced by the induced electric field **E** : they form torques that spin the electron about the magnetic axis .
- **fr** are magnetic forces produced by the time-varying magnetic field **B** on the spinning motion of the surface dipoles : they are centrifugal when d**B** / dt > 0 , and centripetal when d**B** / dt < 0 .

But associated with this spinning motion , the electron must have an orbital motion **,** which can be either normal or parallel to the direction of **B** . These orbital motions give rise to magnetic forces **fm** on the surface dipoles . Three forces **fs , fr , fm** together act on the surface dipoles and cause the electron to radiate .

Conclusion : In the time-varying magnetic field **B** , it is the radial forces **fr** that cause the electron to radiate ; but two forces **fs** and **fm** , together with **fr** , also contribute to the production of two specific radiations , called **synchrotron radiation** (**SR**) and **free electron laser** (**FEL**) . In the following part , we will briefly present the mechanism of the emission of these two kinds of radiation by forces .

Part III. Electrons moving *normally* to the magnetic field emit Synchrotron Radiation (SR) and Free Electron Laser (FEL) .

Synchrotron Radiation (SR)

In the synchrotron , the bending magnets generate a time-varying magnetic field **B** which increases with time (d**B** / dt > 0) . The electron curves its trajectory when travelling normally to **B** . Three forces **fs , fr** and **fm** are produced on the surface dipoles of the electron causing it to radiate : this is synchrotron radiation (SR) . The mechanism of emission of this radiation can be described briefly in three steps : 1/ The time-varying magnetic field **B** produces spinning forces **fs** which cause the electron to spin . 2/ The magnetic field **B** acting on the spinning motion of the electron produces radial forces **fr** which cause it to radiate .
3/ The orbital motion of the electron , normal to the magnetic field **B** of the bending magnets, generates magnetic forces **fm** which point to right-hand side of the observer (Fig.9) .

If the magnetic field **B** is constant in time , then the beam of radiation points to the right-hand side of the observer (it is the direction of the force **F** shown in Fig.13) : this is **cyclotron radiation** . But because **B** in the bending magnets is time-varying , spinning forces **fs** are generated and bend the beam forwards on the orbit of the electron as shown in Fig.14 : this is synchrotron radiation .

Free Electron Laser (FEL)

In the undulator (or wiggler) a static and spatially periodic magnetic field is generated by an array of permanent magnets . When a beam of relativistic electrons is injected normally through this field , a specific radiation is produced : this is free electron laser (FEL) .
The mechanism of emission of FEL is similar to that of synchrotron radiation : it can be explained by three steps :
1/ When the electron moves through the static and spatially periodic magnetic field of the undulator , it cuts magnetic field lines at different intensities and directions ; and hence the *cutting flux through the electron changes periodically with time* ; i.e., the time rate of change d**B**/dt through the electron changes its magnitude and sign periodically with time **.**
2/ This change produces an induced electric field **E** which causes the electron to spin up when d**B**/dt > 0 , and down when d**B**/dt < 0 , as shown in Figs. 16 & 17 .
3/ As a consequence of the spinning motion , radial forces **fr** are produced on the electron :
- when d**B**/dt > 0 , **fr** are centrifugal : the electron can radiate , as shown in Fig.18 .
- when d**B**/dt < 0 , **fr** are centripetal : the electron cannot radiate , as shown in Fig.19 .

Since d**B**/dt changes its sign periodically with time while the electron travelling through the undulator , the electron radiates ***in pulses*** along its trajectory through the undulator .

Conclusion : The above analyses show that the mechanisms of the emissions of **SR** and **FEL** can be explained ***by forces*** which are produced on surface dipoles of the extended electron when it moves ***normally*** to the magnetic field .

Part IV. The possibility of radiating of the electron when it moves *parallel* to the magnetic field

First , let us consider the case when the electron moves parallel to a time-varying magnetic field. The induced electric field **E** produces spinning forces **fs** which spin the electron . Then the magnetic field acts on the spinning motion of the electron to produce radial forces **fr** which cause the electron to radiate . That is what we have already known from previous parts .
Now , since the electron moves parallel to the magnetic field , the magnetic forces **fm** produced on the surface dipoles are tangent to the surface of the electron as shown in Fig.8 . The radiation depends on the magnitude of the radial force **fr** which depends on the angular position α of the dipole

$$fr = (\mu - 1)\, q\, Vs\, B \sin\alpha$$

A simple calculation defines the radiant zone on the surface of the electron alongside its equator as shown in Figs.20 & 21 . Unlike **the cyclotron radiation and SR** which direct to the right-hand side of the observer (Figs. 13 & 14) , this kind of radiation directs in all directions around the electron as shown in Figs.20 & 21 .

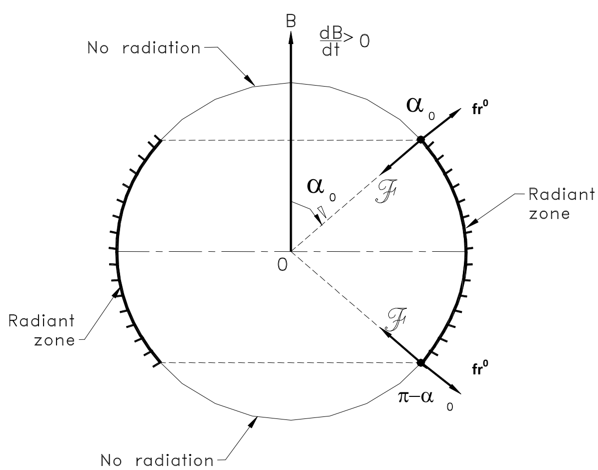


Fig. 20. The radiant zone on the surface of the electron :

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

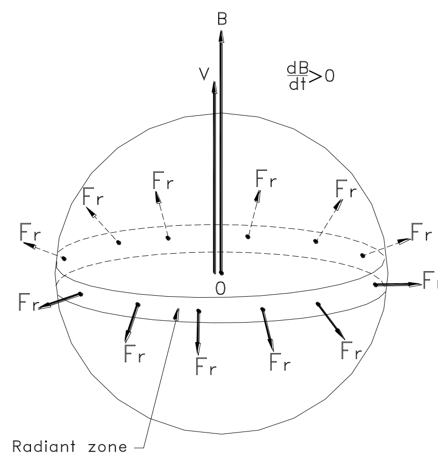


Fig. 21. **v // B** , d**B**/dt > 0 : Radiant zone on the surface of the electron (which moves parallel to **B)** is restricted alongside the equator of the electron . **Fr** is the resultant force acting on a surface dipole : **Fr = G + fm + fs + fr**

Now , let us consider the case when the electron moves parallel to a constant magnetic field . In the note at the end of page 16 , we mentioned that the electron can **spin by inertia** in a constant magnetic field if it previously spun by spinning forces **fs** prior to entering the constant magnetic field . So , a constant magnetic field can produce radiating forces **fr** on an electron which is spinning by inertia , and hence the electron can radiate if **fr** are stronger than the cohesive forces **G** in magnitude .

Readers are invited to read the *thought experiment* at the end of the article **6** (Ref.15) , which uses two *solenoids* aligned on the same horizontal axis to test the radiation of electrons that move parallel to magnetic field . It is described briefly as follows :
1/ In the first solenoid , a time-varying magnetic field is generated by a time-varying electric current . Electrons moving parallel to this time-varying magnetic field radiate by spinning forces **fs** which are produced by the induced electric field **E** .
2/ In the second solenoid , a constant magnetic field is generated by a constant electric current . Electrons , which are radiating from the first solenoid , continue to radiate in the constant magnetic field due to their spin by inertia .

Conclusion : I don't know if physicists have observed these radiations experimentally, (which are emitted from electrons moving parallel to a time-varying or constant magnetic field) , but if these radiations exist , they prove that the radiation of the electron is associated with its spin , but not with its acceleration (because the electron is not accelerated when travelling parallel to the magnetic field) .

CONCLUSION

Now it' s time to conclude the theory of the extended electron which is a version of the screened electron . All calculations of forces produced on the electron are based on the assumption that the electric and magnetic boundary conditions be applied on the surface of the extended electron. Among other findings , the theory focuses on three novel concepts :

1/ The variability of the effective electric charge

The electric charge of the extended electron is an effective one ; it changes with the velocity and when it is " hit " by an external electric or magnetic field , its permittivity ε or its permeability μ varies , causing its electric charge to change accordingly . The concept of varying charge can replace the concept of varying mass if the mass of a particle is considered as a fundamental constant.

2/ The mechanism of the process of spin

Since the electron is an extended particle , it can spin like a tiny top when it is subject to a time-varying electric or magnetic field . The (induced) electric or magnetic forces developed on the surface dipoles of the electron form torques that cause the electron to spin about its own axis while it moves on its orbital trajectory . From this mechanism , the idea of spin - orbit coupling can be understood and the concept of spin by inertia can be explained .

3/ The mechanism of the process of radiation

Inside the electron , the centripetal cohesive forces **G** attract all electric dipoles toward the core of the electron . The applying electric or magnetic field can produce radial forces **fr** on the surface dipoles of the electron ; whenever these radiating forces are stronger than the cohesive forces G , a number of surface dipoles can break free from the electron ; i.e., the electron radiates its dipoles (i.e., photons) into the surrounding space .

Therefore , using the extended electron we can illustrate the mechanisms of the process of spin and radiation by forces which are produced on the surface dipoles of the electron .
In other words, the theory demonstrates the physical reasons that cause the electron to spin and radiate ; it did not attempt to recall the properties of these radiations (SR , FEL ...) after they left the electron .

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