Extended Electron in Time-Varying Magnetic Field : Spin & Radiation

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In this article we try to explain the mechanisms of spin and radiation of the extended electron by forces that are produced 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 **B** is subject to two fields **B** and **E** simultaneously .
Part I : The induced electric field **E** produces spinning forces **fs** which cause the **electron to spin** .
Part II : The spinning motion of the electron in the time-varying magnetic field **B** produces radial forces **fr** which cause the **electron to radiate** .
In the investigation of the radiation of the electron which moves *normally* to the magnetic field , we will consider **Synchrotron Radiation** (**SR**) and **Free Electron Laser** (**FEL**) .
Part III : We make speculation on the possibility of radiation of the electron which moves *parallel* to a time-varying magnetic field , and to a constant magnetic field .

Introduction

The readers are recommended to read the article [1] : "**A new extended model for the electron "** to have a view on the *extended model* of the electron and the *assumptions for calculations* . All calculations in the current article will be based on this model and the assumptions on the electric and magnetic boundary conditions .
In a nutshell , this extended model of the electron is a version of the image of the *screened electron by vacuum polarization* [1] : it is a spherical composite structure consisting of the point-charged core ($-q_0$) which is surrounded by countless electric dipoles (-q ,+q) ; a surface dipole is schematically shown in Figs.3 & 4 . It is a real particle , and has no virtual components in its structure . When it is subject to an external field , the actions of the field on these point charges ($-q_0$, -q , +q) generate various properties of the electron such as its spin and radiation among others .

Part I : Spin of the extended electron in time-varying magnetic field

According to Maxwell's electromagnetic theory , a time-varying magnetic field **B** produces a rotational induced electric field **E** ; the direction of its circular field line can be deduced from Maxwell's equation $\nabla\times\mathbf{E} = -\partial\mathbf{B}/\partial t$; it is shown in Figs.1 & 2 .
The induced field **E** is assumed to be produced not only *outside* but also *inside* the extended electron as shown by two field lines C_1 and C_2 in Figs.3 & 4 (See note below).
In this article , <u>the direction of the magnetic field **B** is always kept upward</u> , (i.e., in the z-direction of the Cartesian coordinates) ; only its magnitude changes with time : $d\mathbf{B}/dt > 0$ means **B** increases with time , and $d\mathbf{B}/dt < 0$ means **B** decreases with time , without changing the direction .
In this part I , while investigating the spin of the electron in the time-varying magnetic field , <u>we won't consider its orbital motion in the magnetic field</u> ; i.e., it is supposed to keep a fixed position in the magnetic field and spins (i.e., rotates on its axis) at this

position . The effects of its orbital motions (normal and parallel to **B**) will be explored in Part II .

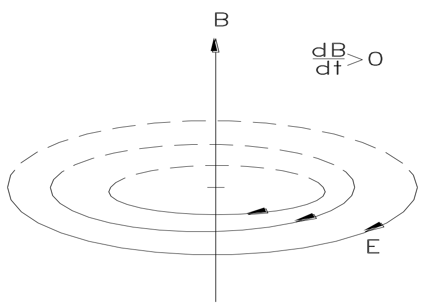


Fig.1 . Direction of the induced electric field **E** produced by the magnetic field **B** which increases with time : d**B**/dt > 0

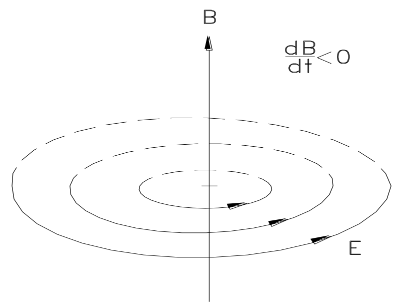


Fig. 2 . Direction of the induced electric field **E** produced by the magnetic field **B** which decreases with time : d**B**/dt < 0

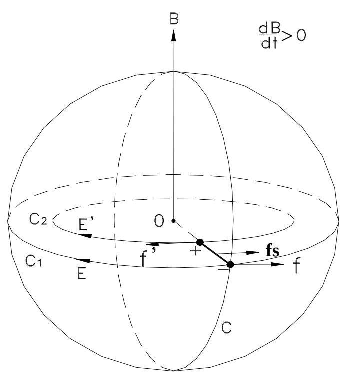


Fig.3 . C_1 and C_2 are circular field lines of the induced electric field **E** : C_1 lies on the surface of the electron , C_2 inside the electron. An arbitrary surface dipole (-q , +q) lies in the equatorial plane . Two electric forces **f** and **f'** are produced on two ends of the dipole . The resultant **fs = f + f'** acts on the dipole .

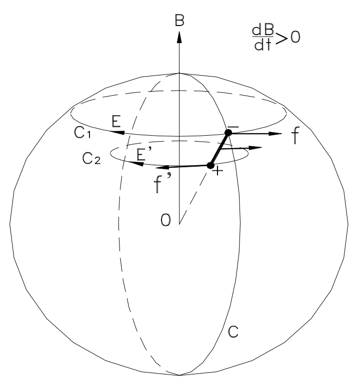


Fig.4 . An arbitrary surface dipole lies on the upper hemisphere : **f** is the electric force produced on the negative end -q by **E** : **f** = -q **E** ; **f'** is the electric force produced on the positive end +q by **E'** : **f'** = +q **E'.** The resultant **fs = f + f'** acts on the dipole .

Note on heuristic speculations [2] :
Two figures 1&2 which show the directions of the induced electric field lines **E** in a medium , can be found in a current textbook of electromagnetics , but two figures 3&4 showing field lines of **E** *inside* the extended electron are only heuristically speculative from two figures 1&2 because the electron is too small , nobody knows its structure . Hence we have to make heuristic speculations on its attributes if we wish to make a plausible progress in the research. Also , in the section I.2 below , we use Lenz 's law to determine the direction of spin **S** of the extended electron in a time-varying magnetic field . This is a heuristic reasoning because Lenz ' s law is applied to macroscopic current loops , not to microscopic current loops on the surface of the extended electron .
" We need heuristic reasoning when we construct a strict proof just as we need scaffolding when we erect a building " .
Owing to heuristic speculations we can explore the **mechanism of the processes of spin and radiation of the extended electron by forces which act on the electron .**

I. 1 Spinning forces fs

Now , let us consider the case when the magnetic field **B** increases with time ; i.e., d**B** / dt > 0 as an example . Fig.3 shows an arbitrary surface dipole (-q , +q) lying in the equatorial plane of the electron and in the great circle C : the negative end (-q) lies on C_1 (which is the equator) ; the positive end (+q) lies on C_2 inside the electron ; **f** and **f'** are two electric forces produced on these two ends :

$$\mathbf{f} = -q\,\mathbf{E} \qquad \text{and} \qquad \mathbf{f'} = +q\,\mathbf{E'}$$

Since **E** is produced on C_1 in free space (ε_0) , whereas **E'** is on C_2 in the material (ε') of the extended electron , so **E** ≠ **E'** in magnitude ; and hence **f** and **f'** have different magnitude and are opposite in direction ; their resultant is

$$\mathbf{fs} = \mathbf{f} + \mathbf{f'} = q\,(\,\mathbf{E'} - \mathbf{E}\,) \neq 0 \qquad (1)$$

Since **f** and **f'** are normal to the plane of the great circle C , so is the resultant **fs** that tends to rotate the electron about the axis **OB .** Since the dipole is very small, **fs** can be considered tangent to the spherical surface of the electron .
More generally , if we consider another arbitrary surface dipole lying in the great circle C (Fig.4) , we will obtain similar result : the resultant force **fs** is normal to the plane of the great circle C and tends to rotate the electron around the axis **OB .**
So , the induced electric field **E** produces electric forces **fs** on all surface dipoles ; they form couples of forces which cause the electron to spin about the magnetic axis **OB** .

<u>For an interior dipole which lies inside the electron</u> : since the dipole is very small , the electric field **E'** that exerts on its two ends -q and +q can be considered equal ; and hence two forces **f** and **f'** are equal and opposite , or **fs** = 0 . The resultant force Σ**fs** on all interior dipoles cancels out , hence it has no effect on the motion of the electron .

Therefore , the spin , which is the rotation of the extended electron about its own axis , is caused by couples of forces **fs** that develop on its surface dipoles , and hence **fs** **are called spinning forces .**

I. 2 Direction of spin (S) of the electron in the time-varying magnetic field B : spin-up and spin-down

To determine the direction (**S**) of spin of the electron about the magnetic axis **OB** we have to resort to **Lenz's law** which states that : " *a change in the magnetic flux through a current-carrying loop induces a current **I** in the loop ; the direction of the current **I** is such that the induced magnetic field **P** produced by **I** will oppose the change in the flux of the original magnetic field* ."

Since the extended electron carries negative charges on its surface, when it spins , these charges form closed current loops on the surface of the electron . So , a spinning electron can be regarded as equivalent to a loop carrying an induced current **I** that is produced by the time-varying magnetic field **B** . The current **I** produces an induced magnetic field **P** which opposes the change in the magnetic flux , according to Lenz's law ; that is :

- When **B** increases with time (d**B** / dt > 0) , the magnetic flux Φ through the electron increases with time ; in order to oppose this increase of Φ , the induced magnetic field **P** must oppose the increase of **B** ; i.e., **P** ↓↑ **B** .

- When **B** decreases with time (d**B** / dt < 0) , the magnetic flux Φ through the electron decreases with time ; in order to oppose this decrease of Φ , **P** must add to the decrease of **B** ; i.e., **P** ↑↑ **B** .

So, if the time rate of change of **B** (d**B** / dt) is known (either positive or negative), the direction of **P** is known and from which the direction of the current **I** can be deduced . The direction of spin (**S**) is then opposite to that of **I** because the superficial charge of the electron is negative .
Therefore , based on Lenz's law , the direction of spin (**S**) will be deduced from the directions of **P** and **I** as follows :

- when d**B** / dt > 0 (e.g., <u>when **B** is turned on</u> : **B** increases with time from zero to a certain value $\mathbf{B_0}$) ; **P** is in opposite direction to **B** (**P** ↓↑ **B**) , and the directions of **I** and **S** can be deduced as shown in Fig.5 .
  We notice that the direction of spin **S** is *opposite* to that of **E** .
- when d**B** / dt < 0 (e.g., <u>when **B** is turned off</u> : **B** decreases with time from $\mathbf{B_0}$ back to zero) ; **P** is in the same direction as **B** (**P** ↑↑ **B**), and the directions of **I** and **S** can be deduced as shown in Fig. 6 . We notice that **S** is *opposite* to **E .**

In short , from two figures 5 & 6 we can state that the direction of spin S of the electron by a time-varying magnetic field is *opposite* to that of the induced electric field **E** , the direction of which is defined by the Maxwell's equation $\nabla\times\mathbf{E} = -\partial\mathbf{B}/\partial t$.

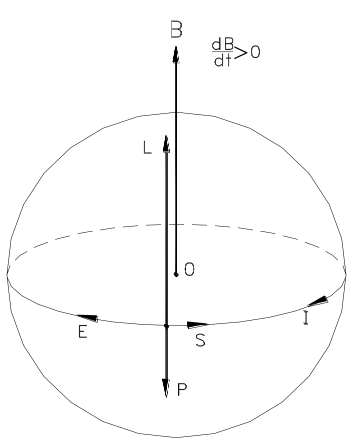


Fig. 5 . d**B** / dt > 0 : Lenz's law gives directions of **P , I , S** . The electron **spins up** : **L ↑↑ B** .
The spin magnetic moment **μs** is identified with **P :** **μs ≡ P**

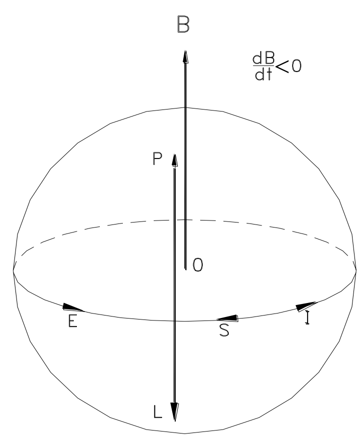


Fig. 6. d**B** / dt < 0 : Lenz 's law gives directions of **P , I , S** . The electron **spins down** : **L ↓↑ B;**
μs is identified with **P :** **μs ≡ P**

I . 3 Other attributes of the spinning electron : L and μs

1 . The spin of the electron is characterized by the **spin angular momentum L** . Because spinning forces **fs** lie in planes perpendicular to **B** and are symmetric around **B** (Figs.3 & 4) **, L** is collinear (i.e., parallel or anti-parallel) to **B** (Figs.5 & 6) .

2 . The relationship between the direction of **L** and the direction of spin **S** can be described with the aid of an imaginary observer standing at the center O of the electron , in the direction of **B ,** and looking at an arbitrary point A on the equator of the electron while it is spinning :

- if the point A rotates <u>from the right hand to the left hand</u> of the observer **:** the electron **spins up : L ↑↑ B ;** this is the case when d**B** / dt > 0 as shown in Fig. 5 .
- if the point A rotates <u>from the left hand to the right hand</u> of the observer **:** the electron **spins down** : **L ↓↑ B** ; this is the case when d**B** / dt < 0 as shown in Fig. 6 .

3. If the magnetic field **B** changes periodically in time (i.e., its magnitude increases and decreases periodically in time while its direction remains upward) , it will cause the electron to spin up (**L ↑↑ B**) and down (**L ↓↑ B**) alternatively .

4. Since the electron is electrically charged , when spinning , it generates the **spin magnetic moment μs** which is collinear to **L .**
For the electron , **L** and **μs** are always in opposite directions .
(In Quantum Mechanics , **L** and **μs** have the relationship : **μs = -** g_s (e/2m) **L** where the dimensionless gyromagnetic ratio g_s = 2.0023).
Because **μs** and **P** are two induced magnetic vectors which are generated by the spinning motion of the electron , we identify **μs** with **P** ; that is **μs** ≡ **P .**

From this identification , we can state that under the action of the time-varying magnetic field **B** , the electron reacts by spinning about its own axis in order to create the spin magnetic moment **μs** that opposes the change of the original time-varying magnetic field . This means that :

- when d**B** / dt > 0 : **μs ↓↑ B** **,** Fig.5
- when d**B** / dt < 0 : **μs ↑↑ B** **,** Fig.6

Therefore , **μs** and **L** can help us determine the direction of spin **S** without resorting to Lenz's law .

5 . When **L** and **μs** are generated by the time-varying magnetic field **B** , they are collinear to **B** ; their magnitudes depend on the strength of **B** and the rate of change d**B** / dt , and hence they vary with time .

Comment :

It should be emphasized that the spin of the *extended electron* can be explained by forces because it is made up of electric dipoles . The spinning forces **fs** are produced on its surface dipoles by the induced electric field **E** . For *a point electron* , since it has no electric dipoles , no spinning force is produced on it , and thus the spin of a point electron cannot be explained by forces .
Because the electron is a particle that has mass , it cannot be conceived as a structureless point charge , or a wave packet ; it must be thought of as an extended particle , no matter how small it may be . And as a result , it can spin like a tiny top . From this spinning motion of the extended electron , the mechanism of radiation by forces can be deduced . This viewpoint is explored in this article .

Meanwhile , Quantum Mechanics considers electron as a point particle , its spin is conceived in this way : " *The electron is a quantum-mechanical point particle , and its spin arises from relativistic quantum effects in the wave field of the electron rather than from rigid – body rotation* ." Or in other words : " *Thus , in contrast to a common misconception , the electron spin does not arise from an internal structure of the electron, rather , it arises from the structure of the electron wave field .*" [3]
We don't believe in this concept simply because it is vague and counterintuitive .
It is an irony that although physicists always deny the idea of spin of the electron as its rotation about its own axis , but this picture – a spherical electron rotating about its axis – is always found in their accounts of research ! [4] The excuse for this is that :
" *The electron is not literally spinning , but the analogy with a spinning ball of charge is a useful one.* " [5]

I. 4 Spin by inertia of the electron in constant magnetic field and in free space

The preceding sections showed that the spin of electron is a consequence of a time-varying magnetic field **B**. So , if the magnetic field **B** is *constant in time* , then the induced electric field **E** is not generated , and hence the spinning forces **fs** do not exist **.**
This means that a *constant magnetic field cannot cause the electron to spin* .
Similarly , *free space* (where there is no field, and hence no force) cannot spin the electron . Therefore, only a time-varying magnetic field **B** can cause the electron to spin by its induced electric field **E** .
However, in a constant magnetic field and in free space the *electron can spin by inertia* , i.e., it can spin with no spinning forces at all . This standpoint can be proved by the following argument :

Let us consider an electron *which is spinning by a time-varying magnetic field* **B** , and hence **L** is collinear to **B** . Let **T** be the net torque of all spinning forces **fs** about the axis **OB** , we have

$$\mathbf{T} = d\,\mathbf{L}/dt \neq 0 \tag{2}$$

Now , if the time-varying magnetic field **B** is suddenly stopped at a fixed value $\mathbf{B_0}$ or removed (i.e., **B = 0**) , the electron is thus left in the constant magnetic field $\mathbf{B_0}$ or in free space , respectively . The result is : the induced electric field **E** and all spinning forces **fs** disappear at the same time , Eq.(2) becomes

$$\mathbf{T} = d\mathbf{L}/dt = 0 \qquad (3)$$

hence

$$\mathbf{L} = \text{constant} \qquad (4)$$

This means that after the magnetic field **B** is stabilized at $\mathbf{B_0}$ or removed , the electron continues to spin with constant angular momentum **L** : it spins with no spinning forces at all . This is **spin by inertia** of the electron in the constant magnetic field $\mathbf{B_0}$ (or in free space) and in this case **L** is collinear to $\mathbf{B_0}$ and has constant magnitude .

Let 's note that the electron must be spinning by spinning forces **fs** in the time-varying **B** first, this spin gives Eq.(2) ; then it spins by inertia in constant field $\mathbf{B_0}$, this gives Eq.(3) .
Therefore , the electron must spin by forces before it can spin by inertia .

I. 5 Precession of the electron in the constant magnetic field $\mathbf{B_0}$

Now , in the previous example , if we swiftly switch the time-varying magnetic field **B** to a constant magnetic field $\mathbf{B_0}$, <u>which makes an angle θ with **B**</u> , the electron continues to spin by inertia with spin angular momentum **L** which precesses around $\mathbf{B_0}$.
In Fig.7 , the field " **B** (constant)" is this constant field $\mathbf{B_0}$.
Since the linear velocity **Vs** of the surface dipole (due to the spinning motion) is not perpendicular to $\mathbf{B_0}$**,** the magnetic forces **fr** produced by $\mathbf{B_0}$ on the surface dipoles are not radial , hence their resultant Σ **fr** is different from zero . It is the resultant force $\Sigma\,\mathbf{fr} \neq 0$ that causes the electron to wobble and **L** precesses around the direction of $\mathbf{B_0}$**.**

We conclude that in addition to its orbital motion in the magnetic field **B** , the electron is always associated with a spinning motion :

1/ in a time-varying magnetic field **B** , the electron spins by spinning forces **fs** : **L** is collinear to **B** ;
2/ in a constant magnetic field $\mathbf{B_0}$, the electron spins by inertia : **L** precesses around $\mathbf{B_0}$ if the angle θ between **L** and $\mathbf{B_0}$ is different from zero .

The consequence of the spin of the electron (whether by forces or by inertia) in an external magnetic field is that it produces **radial forces fr** on the electron <u>which can cause the electron to radiate</u> .

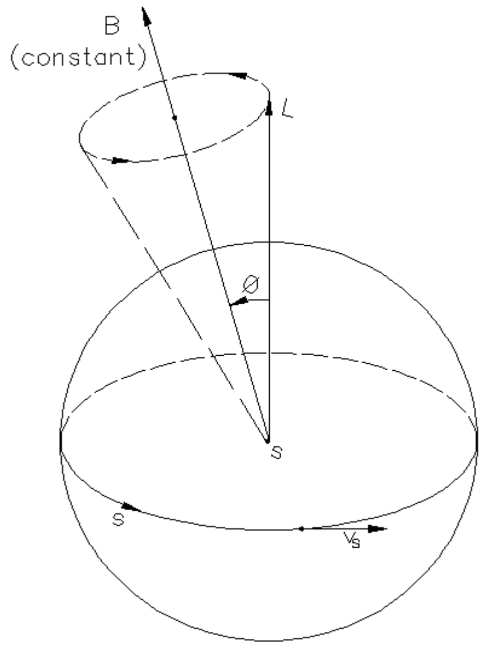


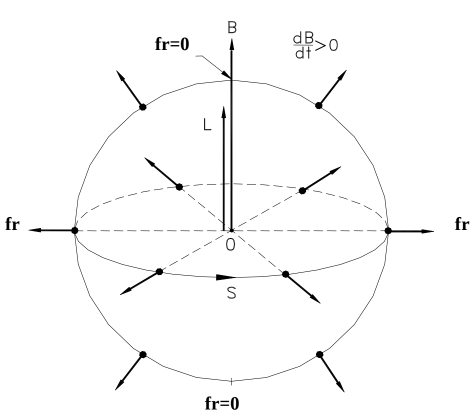
Fig.7. **B** (constant) showed in this figure is the constant field $\mathbf{B_0}$, which makes the angle θ with the time-varying magnetic field **B** . Because **Vs** is not perpendicular to $\mathbf{B_0}$**,** the magnetic force **fr** produced by $\mathbf{B_0}$ is not radial, hence the resultant $\mathbf{\Sigma\, fr} \neq 0$ causes **L** to precess around $\mathbf{B_0}$.

I. 6 Action of the time-varying magnetic field B on the spinning electron : radial forces fr which can cause the electron to radiate

Let us consider an extended electron which is spinning under the action of the time-varying magnetic field **B** . In addition to spinning forces **fs** which are produced by the induced electric field **E** , what other forces are produced on the electron when it spins in the time-varying magnetic field **B** ?
The answer is : the spinning motion of two point charges –q and +q of a surface dipole about the axis **OB** produces *radial magnetic force* **fr** :

- **fr** is centrifugal when d**B**/dt > 0 (Fig.8) (5)
- **fr** is centripetal when d**B**/dt < 0 (Fig.9) (6)

In the following , let us explain the production of the radial magnetic force **fr** and determine its magnitude on an arbitrary surface dipole of the electron .
From the previous article we knew that the extended electron behaves like an electron when its relative permittivity μ varies in the interval $1 < \mu < b / (b\text{-}1)$; so, in the following calculations we always consider the case $\mu > 1$.



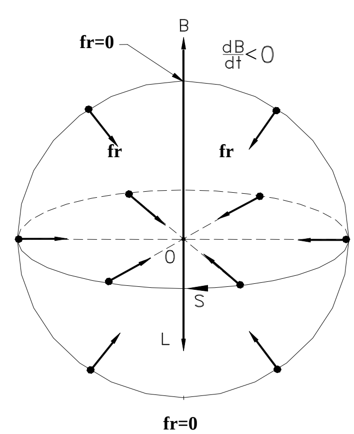


Fig.8 . $d\mathbf{B} / dt > 0$, magnetic forces **fr** produced on all surface dipoles are centrifugal and the electron spins up : **L** ↑↑ **B** .

Fig.9 . $d\mathbf{B} / dt < 0$, magnetic forces **fr** produced on all surface dipoles are centripetal and the electron spins down : **L** ↓↑ **B** .

Let's consider an arbitrary surface dipole M lying on the upper hemisphere ($\alpha < \pi/2$) of the electron which spins in the direction (**S**) as shown in Fig.10 . Let's consider the case $d\mathbf{B} / dt > 0$ first . When the electron spins , the surface dipole M rotates about the axis **OB** with linear velocity **Vs** ⊕ : i.e., **Vs** is perpendicular to **B** and pointing down from the page . Since the dipole is extremely small , we assume that its two ends (-q and +q) of the dipole M have the same linear velocity **Vs .**

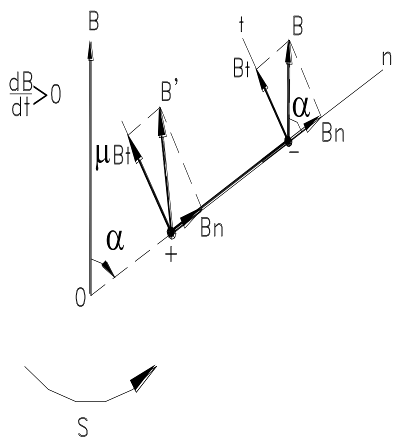


Fig.10 . Components of magnetic fields **B** and **B'** acting on two ends of dipole M : $Bn = B \cos\alpha$, $Bt = B \sin\alpha$, $B't = \mu\, Bt$.

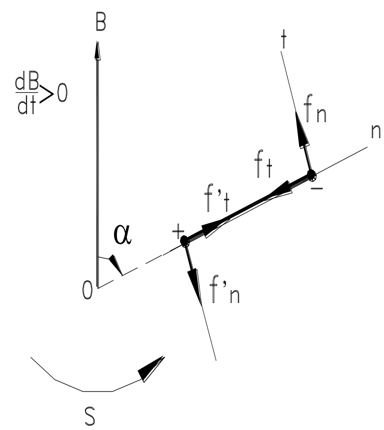


Fig.11 . Normal and tangential components of magnetic force **fr** acting on two ends of dipole M : **fr = fn + f'n + ft + f't = ft + f't** since **fn + f'n =** 0

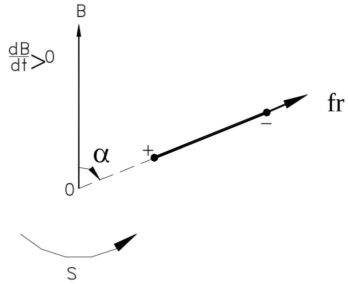


Fig.12 . The resultant force **fr** acting on dipole M is centrifugal (radial) .

Components of the magnetic field **B** at two ends of the surface dipole M are
B = Bn + Bt and **B' = B'n + B't** where Bn = B cosα and Bt = B sinα
Boundary conditions applied to dipole M give
B'n = Bn , and **B't** = μ**Bt** (Fig.10)
Normal components of force : fn = f'n = q Vs Bn = q Vs B cosα (**Vs** $\perp$ **Bn**) (7)
fn points upward , **f'n** points downward (Fig.11)
Tangential components of force :
ft = q Vs Bt = q Vs B sinα (**Vs** $\perp$ **Bt**) : **ft** is centripetal ; (8)
f't = q Vs B't = μ q Vs B sinα : **f't** is centrifugal . (9)
The resultant force **fr** acting on dipole M is
fr = fn + f'n + ft + f't = ft + f't because **fn + f'n =** 0 (10)
Since $\mu > 1$, f't > ft , the magnitude of the resultant **fr** is
fr = f't - ft = (μ-1) q Vs B sinα : **fr** is centrifugal (Fig.12) . (11)

If we calculate **fr** on a surface dipole lying on the lower hemisphere of the electron , ($\alpha > \pi/2$) we get the same result ; i.e., **fr** is centrifugal .
So, if d**B**/dt > 0 : **fr** acting on all surface dipoles of the electron are *centrifugal* (Fig.8)

Now , if d**B** / dt < 0 , the electron reverses its direction of spin (**S**) and so does **Vs** ; and hence **fr** becomes *centripetal* on all surface dipoles of the electron (Fig.9)

The magnitude of **fr** exerting on a surface dipole of the electron is shown in Eq.(11)

$$\boxed{\text{fr} = (\mu-1)\, q\, \text{Vs}\, B \sin\alpha} \quad \text{where } \mu > 1,\ 0 \le \alpha \le \pi,\ \mathbf{Vs} \perp \mathbf{B} \qquad (12)$$

Therefore , when the electron moves in a time-varying magnetic field **B** , in addition to the magnetic forces **fm** which are produced by the orbital motion , spinning forces **fs** and radial forces **fr** are also produced on surface dipoles of the spinning electron .
The resultant force **Fr** that exerts on the surface dipole is thus

$$\boxed{\mathbf{Fr} = \mathbf{G} + \mathbf{fm} + \mathbf{fs} + \mathbf{fr}} \qquad (13)$$

where G are the cohesive forces that attract all the dipoles toward the core of the electron.
Since the **radial forces fr can cause the electron to radiate** , they can also be called **radiating forces .**

Summary

1/ When an electron is subject to a time-varying magnetic field **B** , the induced electric field **E** produces *spinning forces* **fs** (Fig.3 & 4) which cause the electron to spin ; meanwhile the magnetic field **B** produces *radial magnetic forces* **fr** on surface dipoles of the spinning electron (Figs.8 & 9) .

2 / When the electron spins up or down by a time-varying magnetic field **B ,** since **Vs** is perpendicular to **B** , **fr** are radial , and hence Σ **fr =** 0 ; **L** and **B** are collinear .

But when the electron spins by inertia in a constant magnetic field **B_0** , since **Vs** is generally not perpendicular to **B_0 ,** magnetic forces **fr** are no longer radial , their resultant Σ **fr** $\neq 0$ causes the electron to wobble and **L** precesses about **B_0** (Fig.7).

The spin of the extended electron in a time-varying magnetic field **B** and its consequences can be summarized in the following diagram :

B $\rightarrow$ E $\rightarrow$ spinning forces fs (spin) $\rightarrow$ radial forces fr (radiation)
(Figs.3 & 4) (Fig.8) (14)

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 creates radial forces **fr** which cause the electron to radiate (discussed in Part II below).
The spin angular momentum **L** and the spin magnetic moment **μs** are two physical factors that characterize the spin of the electron .

Part II : Radiation of extended electron in time-varying magnetic field

Introduction

In this part , we try to explain the mechanism of radiation of the extended electron by forces which are produced on the electron by a time-varying magnetic field .
We maintain so far that the radiation of the electron implies that the electron emits its surface dipoles into space and this process occurs whenever its surface dipoles are subject to external forces that overcome the cohesive forces **G** inside the electron .

To illustrate the process of radiation by forces , let us compare it to this ordinary example : all objects on the surface of the Earth are pulled down by the force of gravity ; now , if an object (e.g., a rocket) can produce on itself an upward force , stronger than the pull down of the gravity , then this object can break free and leave the surface of the Earth . Similarly , Fig.8 shows the surface dipoles of the electron which are subject to the radial forces **fr.** It suggests that if **fr > G** (in magnitude) , some surface dipoles are able to break away and detach from the surface of the electron ; that is , the electron emits (or radiates) these dipoles into space . (The emitted electric dipoles have been identified with photons in the article "**A new extended model for the electron** "[1]).

The findings of forces **fm , fs , fr** produced on surface dipoles of the electron lead to various aspects of radiation of the electron in a time-varying magnetic field .
In this part , we will investigate the radiation of the electron when it moves *normally* to the time-varying magnetic field : these are **Synchrotron Radiation** (**SR**) and **Free Electron Laser** (**FEL**) .

In part III , we will speculate on the possibility of radiating of the electron when it moves *parallel* to a time-varying magnetic field and a constant one .

II. 1 Radiation of the electron moving normally to the time-varying magnetic field : Synchrotron Radiation (SR)

In the synchrotron , electrons circulate normally to the magnetic field **B** which increases with time (d**B**/dt > 0) in the bending magnets : SR is emitted in a cone pattern (Fig.15). The actions of three forces **fm** , **fr** and **fs** on surface dipoles of the electron help explain the mechanism of emission of SR as follows :

First , the normal motion of the electron to **B** (**V ⊥ B**) produces magnetic forces **fm** which direct to the right hand of the observer **:** **fm** on the right hemisphere pull surface dipoles *out of the electron* ; **fm** on the left hemisphere push surface dipoles *into the electron* (See Fig.29 in the article : **" Extended electron in constant magnetic field "**[6])

Secondly , the time-varying magnetic field **B** produces the induced electric field **E** which gives rise to spinning forces **fs** that spin the electron . The spinning motion of the electron in **B** gives rise to radial forces **fr** which are centrifugal when d**B**/dt > 0 (Fig.8)

So, on the right hemisphere , **fr** reinforces **fm** (Fig. 13) . If their resultant (**fm + fr**) overcomes **G** **:** surface dipoles break free from the surface of the electron ; i.e., the electron radiates its surface dipoles (photons) into space .
Meanwhile , on the left hemisphere , **fr** opposes **fm** (Fig.13) and hence their resultant may be weaker than the cohesive force **G :** surface dipoles cannot leave the electron .
Therefore , the electron radiates only from the right hemisphere and there is no radiation from the left hemisphere of the electron (Fig. 14) .

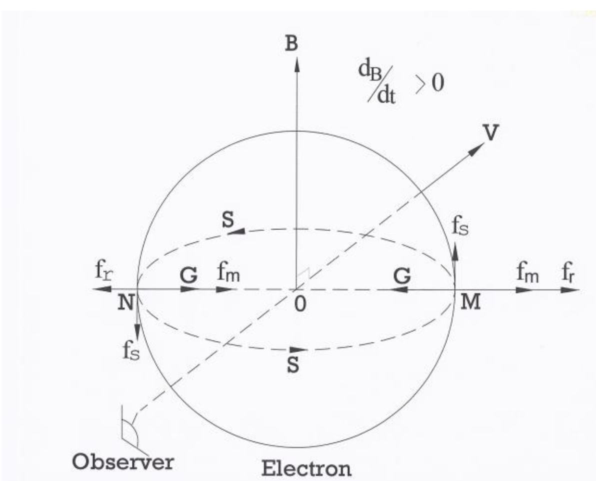


Fig.13. On the right hemisphere : **fr** reinforces **fm** , if **fr + fm > G** , the surface dipole M breaks free from the electron . On the left hemisphere : **fr** opposes **fm** , the dipole N cannot leave the electron .
Fr = G + fm + fs + fr is the resultant force acting on surface dipoles such as M and N .

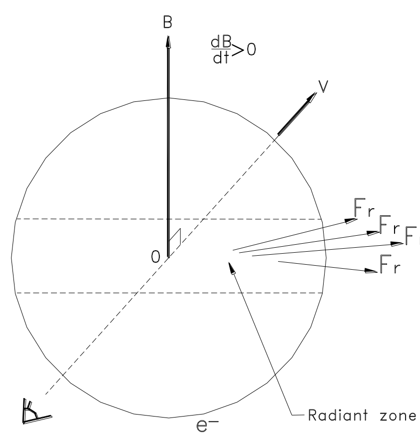


Fig.14. SR is emitted from the right hemisphere ; there is no radiation from the left hemisphere . The radiant zone is restricted to a region alongside the equator of the electron .
Fr = G + fm + fs + fr

Third , the spinning forces **fs** that are tangent to the surface of the electron , bend the radiation beam in the direction of spin **S** of the electron (Fig 15) .

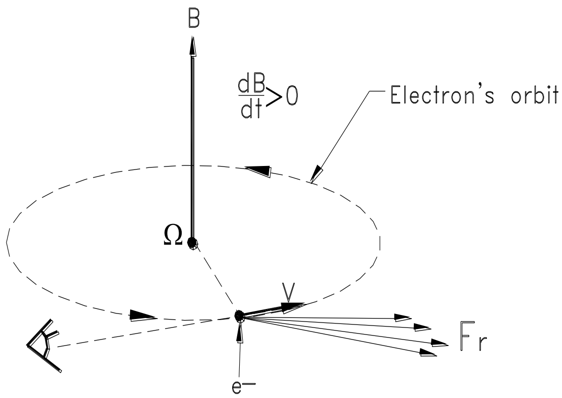


Fig.15 . SR : the beam of radiation is not emitted straight outwards as in the cyclotron radiation ; SR bends around the orbit of the electron due to spinning forces **fs** and forms a cone of radiation . **Fr = G + fm + fs + fr**

The resultant force **Fr** acting on a surface dipole is given by Eq.(15) :

$$\mathbf{Fr} = \mathbf{G} + \mathbf{fm} + \mathbf{fs} + \mathbf{fr} \tag{15}$$

In Eq.(15) **fm** is produced by the orbital motion of the electron in **B** . In the bending magnets of the synchrotron , the magnetic field **B** increases with time : $d\mathbf{B}/dt > 0$, it spins the electron (by spinning forces **fs)** and creates radial forces **fr .**

In this explanation of the production of SR , the bending magnets in the synchrotron perform two different tasks simultaneously :

i/ bending the orbit of the beam of electrons by the magnetic field **B** , this produces the radial acceleration on the electron . But this radial acceleration is not the real physical factor that causes the electron to radiate* (See note on next page) .

ii/ creating a time- varying magnetic field **B** ($d\mathbf{B}/dt > 0$) which produces spinning forces **fs** and radial forces **fr** that cause the electron to radiate .

Comment :

In current literatures on the synchrotron radiation (SR) , the radial acceleration created by the bending of the beam of the electrons in the bending magnets is regarded as the mechanism of the emission of SR . The Encyclopedia Wikipedia introduces SR as follows : " *The electromagnetic radiation emitted when charged particles are accelerated radially* (**a** ⊥**v**) *is called synchrotron radiation* " .
And under the headline " **Emission mechanism** " of SR we can read : " *When high-energy particles are in rapid motion , including electrons forced to travel in a curved path by a magnetic field , synchrotron radiation is produced* " .

These quotations do not actually explain the **mechanism of the emission of SR** ; they merely tell us **when** SR is produced , but do not explain **why** SR is emitted .
Scientists of Wikipedia only provided the answer to the question **when** , not **why !**
This indicates that scientists did not figure out the real mechanism of the emission of SR .
The reason for this is that , so far , scientists considered the electron as a point charge (or a wave packet) , rather than an extended particle . They ignored the effect of the time-varying of the magnetic field (d**B**/dt > 0) that causes the electron to spin , and as a result , the radial forces **fr** are generated and cause the electron to radiate .
For them , the magnetic field **B** of the bending magnets in the synchrotrons has only one function : it bends the trajectory of the electrons radially , and the radial acceleration causes the electron to radiate . But the radiation is not clearly related to the acceleration* of the electron as being pointed out by **Feynman , Jackson** and **Pearle** .

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* - **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

Conclusion :

The synchrotron radiation (SR) of extended electrons is essentially produced *by the radial forces* **fr** that are generated by their spin **,** *not by the radial acceleration* when they move through the bending magnets in the synchrotron . The radiation of the electron is associated with its spin , not with its acceleration .

II. 2 Radiation of the electron moving normally to a static , spatially periodic magnetic field : Free Electron Laser (FEL)

To produce FEL , a beam of relativistic electrons is passed normally through the static , spatially periodic magnetic field of the undulator (or wiggler) , " *it forces the electrons in the beam to follow a sinusoidal path . The acceleration of the electrons along this path results in the release of photons (synchrotron radiation)* " (from Wikipedia : FEL) .
This is the explanation of the emission of FEL by the contemporary physics : it is the *acceleration* of the electrons that produces FEL (as well as SR) . But as we maintained that the acceleration is not the actual cause of the radiation , we will explain the mechanism of emission of FEL *by forces* that exert on surface dipoles of the electron .

According to the diagram (14) of the production of radiating forces on page 10 , there must be a time-vary magnetic field **B** first , which produces the induced electric field **E** that spins the electron ; then the spin of the electron generates the radiating forces **fr** by the magnetic field **B** .
In the undulator , the magnetic field is static and periodic in space ; this field can give rise to the same induced electric field **E** on the electron as a time-varying magnetic field.

To confirm this statement , let us refer to the Faraday 's experiments (1831) .
In the Faraday ' s experiments to prove the law of induction there are two possibilities :
(i) the magnet moves to and fro while the coil stands still : that is , the magnetic field through the coil is time-varying ;
(ii) the magnet stands still while the coil moves around : that is , the magnetic field is static but the cutting flux through the coil is time-varying .
Two cases give the same result : an emf (or an induced current) appears in the coil .

The second case (ii) helps explain the production of the induced electric field **E** :
When the electron moves through the static , spatially periodic magnetic field of the undulator , it cuts magnetic field lines at different intensities and directions ; hence the *cutting flux through the electron changes periodically with time* ; i.e., the time rate of change d**B**/dt (or dΦ/dt) through the electron changes its magnitude and sign periodically with time **.**
As we have seen in the previous section that the time rate of change d**B**/dt of the magnetic field through the electron produces the induced electric field **E** that causes it to spin and as a consequence , radial forces **fr** are produced . These radial forces initiate the radiation from the electron as shown in Fig.8
Since the magnetic field is spatially periodic along the trajectory of the electron , the sign of d**B**/dt changes periodically : when d**B**/dt > 0 , **fr** are centrifugal , the electron can radiate (Fig.8) ; but when d**B**/dt < 0 , **fr** are centripetal : the electron cannot radiate (Fig.9). This is the reason why the electron emits *pulses of radiation* while travelling through the static , spatially periodic magnetic field of the undulator ; the pulses depend on the periodicity of the magnetic field of the undulator .

Beside the radial forces **fr** , two forces **fm** and **fs** are produced and participate in the process of the radiation of FEL :
- **fm** are produced by the normal motion of the electron to **B** . They point to the right hand of the observer (Fig.13) ; and hence when d**B**/dt > 0 : **fm** reinforce **fr** on the right hemisphere and oppose **fr** on the left hemisphere (Fig.13); so the radiation occurs only on the right hemisphere and there is no radiation on the left hemisphere .
When d**B**/dt < 0 : **fr** are centripetal , the electron cannot radiate .
- spinning forces **fs** are produced by the induced electric field **E** which appears on the electron **:** **fs** bend the emitted beam in the direction of spin of the electron .

Conclusion :

The above analysis shows that the mechanism 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 .
As for the acceleration , although it is always associated with the motion of the electron in **SR** and **FEL** , it is **not** the actual physical cause of the emission of these radiations .

While the mechanism of emission of **SR** and **FEL** can be explained by forces which act on the electron , the contemporary physics ignores the mechanism , it just examines the properties of these radiations after they have left the electron .

Part III : Radiation of extended electron moving parallel to a time-varying magnetic field and a constant magnetic field .

In this part , we discuss the possibility of radiation of the electron when it moves ***parallel*** to (1) a time-varying magnetic field and (2) to a constant magnetic field .
In these two cases , the electron is **not** subject to any acceleration because there is no net (magnetic) force produced on the electron .

III. 1 Radiation of the extended electron moving parallel to a time-varying magnetic field

When the electron moves parallel to the time-varying magnetic field **B** , three different forces **fm , fs , fr** are developed on surface dipoles of the electron .

- Magnetic forces **fm** are produced on all surface dipoles : **fm** are tangent to the spherical surface of the electron and form opposite torques on the upper and the lower hemispheres of the electron (See Fig.6 in the article : **" Extended electron in constant magnetic field "** [6]) .
- Spinning forces **fs** are produced by the induced electric field **E** which is generated by the time-varying magnetic field **B** (Figs.3 & 4) : **fs** are tangent to the surface of the electron , causing the electron to spin .
- Radial forces **fr** are produced by the magnetic field **B** on the spinning motion of the electron : - **fr** are centrifugal when d**B**/dt > 0 (Fig.8)
  - **fr** are centripetal when d**B**/dt < 0 (Fig.9)

In the case when **fr** are centrifugal , if **fr > G** on a group of surface dipoles , these dipoles break free from the surface of the electron ; i.e., the electron emits radiation into space .

From Eq.(12) , the magnitude of **fr** is $fr = (\mu - 1)\, q\, Vs\, B \sin\alpha$
The magnitude of **fr** can thus be controlled by adjusting **B** and the linear velocity **Vs** which depends on the induced electric fields **E** and **E'** ; i.e., on **B** and d**B** / dt .
So , the larger **B** and d**B** / dt , the stronger the radial forces **fr** are , and thus the radiation has more chance to occur .
But the magnitude of **fr** also depends on sinα ; i.e., on the angular position α of the surface dipole . This dependence restricts the extent of the radiant zone on the surface of the electron which will be determined below (Figs. 16 , 17 , 18) .

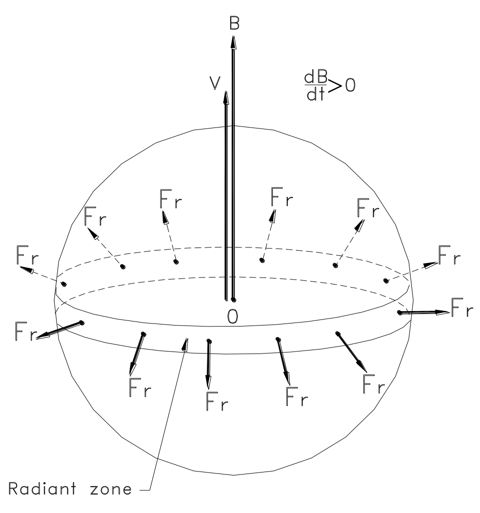

Fig. 16. d**B**/dt > 0 : Radiant zone on the electron which moves parallel to **B** is restricted alongside the equator of the electron .
Fr is the resultant force acting on a surface dipole : **Fr = G + fm + fs + fr**

Determination of the extent of the radiant zone on the surface of the electron :

We are going to show that the electron does not radiate from the entire spherical surface , but only from a limited zone alongside its equatorial line as shown in Fig.16 .
From Eq.(12) the magnitude of **fr** is equal to zero at two poles of the electron ($\alpha = 0$ and $\alpha = \pi$) and becomes maximum on the equator ($\alpha = \pi/2$) . Vs is the linear velocity of a surface dipole due to the spinning motion of the electron ; so , Vs is maximum on the equator . That is , on the upper hemisphere , the magnitude of **fr** increases from the north pole to the equator . Let's suppose that we can find an angle α_0 between 0 and $\pi/2$ such that **fr** at the angle α_0 is equal and opposite to **G** , i.e.,

$$fr^0 = G \quad \text{(in magnitude)} \qquad \text{(Fig. 17)} \tag{16}$$

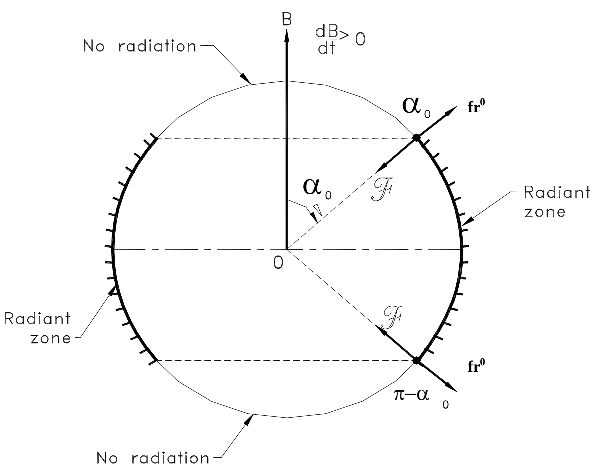

Fig. 17. The radiant zone on the surface of the electron :
- at two angles α_0 and $\pi - \alpha_0$, $fr^0 = G$
- inside the radiant zone (from α_0 to $\pi - \alpha_0$) : fr > G
- outside the radiant zone (no radiation) : fr < G

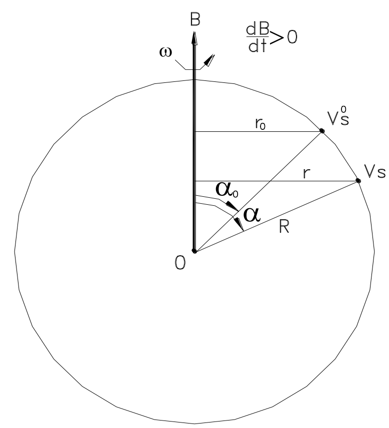

Fig.18 . ω is the angular velocity of the spinning electron . At the angle α_0 : the linear velocity of the dipole is Vs^0 ; at the angle α : it is Vs .

By symmetry , on the lower hemisphere , fr is equal to G at the angle ($\pi - \alpha_0$) .
So , inside the interval from α_0 to ($\pi - \alpha_0$) , fr > G : radiation occurs ;
outside this interval **:** fr < G : there is no radiation .
Its extent is determined by Eq.(16) , which can be rewritten as

$$fr^0 = (\mu-1)\, q\, Vs^0\, B \sin\alpha_0 = G \tag{17}$$

where Vs^0 is the linear velocity of the surface dipole at the angle α_0 .

Now let's determine the extent of the radiant zone on the surface of the electron .
The condition for the radiation to occur is

$$fr > G$$

or $$fr > fr^0 \quad , \quad \text{since } fr^0 = G \quad [\text{ Eq.(16) }]$$

or $$(\mu\text{-}1)\, q\, Vs\, B \sin\alpha > (\mu\text{-}1)\, q\, Vs^0\, B \sin\alpha_0 \tag{18}$$

or $$Vs \sin\alpha > Vs^0 \sin\alpha_0 \tag{19}$$

From Fig.18 $$Vs = R \sin\alpha \,.\, \omega \quad \text{and} \quad Vs^0 = R \sin\alpha_0 \,.\, \omega \tag{20}$$
where R is the radius of the electron ; ω is the angular velocity of the electron due to the spinning motion of the electron about the axis **OB** . Expression (19) becomes

$$R \sin^2\alpha \,.\, \omega > R \sin^2\alpha_0 \,.\, \omega \tag{21}$$
or $$\sin^2\alpha > \sin^2\alpha_0 \tag{22}$$

Expression (22) gives $\alpha_0 \leq \alpha \leq \pi/2$ for surface dipoles on the upper hemisphere ,
and $\pi/2 \leq \alpha \leq \pi - \alpha_0$ for surface dipoles on the lower hemisphere .

The radiant zone on the surface of the electron is illustrated in Figs. 16 &17 .
We note that the radiation of this kind (**V** // **B**) occurs alongside the equator , around the electron ; i.e., it is undirectional , while the beam of SR and FEL are directional .
Since the radiation occurs only when fr > G , we have to strengthen **fr** by intensifying **B** and d**B**/dt to increase **Vs** (or ω) **.**
The radiant zone starts on the equator first (where **fr** is maximum) , then gradually expands towards the north and south poles of the electron as **B** increases with time .

If the radiation of the electron moving parallel to a time-varying magnetic field (**V** // **B**) is experimentally detected , it proves that the radiation of the electron is not related to its acceleration , but to its spin , because the electron is not accelerated while travelling parallel to the magnetic field .

III. 2 Radiation of the extended electron moving parallel to a constant magnetic field

From the preceding sections we know that in order for the electron to be able to radiate , there must be the radiating forces **fr ,** which are produced by the magnetic field **B** on the spinning electron .
In the previous section (III.1) , electrons spin by the time-varying **B** .
But we know (from section I. 4 on page 6) that the electron can <u>spin by inertia in a constant magnetic field **B**</u> if it already spun before being injected into 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 G in magnitude .

Now let's consider the following *thought experiment* which intends to show that the electron can radiate while travelling parallel to a constant magnetic field .

Two solenoids : 1 (on the left) and 2 (on the right) are arranged such that their axis lies on the same horizontal line .
The solenoid 1 carries an electric current which increases with time ; and hence it creates a time-increasing magnetic field $\mathbf{B_1}$ along its axis .
The solenoid 2 carries a constant electric current ; so it creates a constant magnetic field $\mathbf{B_2}$ along its axis .
Now , we inject a thin beam of electron through these two solenoids , from the left to the right hand side , along their horizontal axis . While passing through the solenoid 1 , the electrons spin and radiate by the time-varying magnetic field $\mathbf{B_1}$ (if the condition $\mathbf{fr} > \mathbf{G}$ is met) .
After leaving the solenoid 1 , the electrons enter the solenoid 2 , where they spin by inertia in the constant magnetic field $\mathbf{B_2}$, and the radiating forces **fr** are produced by $\mathbf{B_2}$ which causes the electron to radiate (if the condition $\mathbf{fr} > \mathbf{G}$ is satisfied) .

If this thought experiment gives the expected result , it shows that electrons can radiate while travelling parallel to a constant magnetic field . This result also proves that the radiation of electrons is actually related to their spin , but not to their acceleration , because electrons are not accelerated while travelling parallel to the magnetic field .

Summary & Conclusion

All results obtained in this article come from the *extended model of the electron* that was proposed in the article : " **A new extended model for the electron** "[1] when we apply classical electrodynamics 's laws on its surface dipoles .

Physicists have figured out the *screened electron*[1] (by vacuum polarization) to explain the changing of its electric charge . A version of this picture introduces an extended model for the electron which can be used to explore the mechanism of the processes of spin and radiation of the electron .

When the electron is subject to a time-varying magnetic field **B** , the induced electric field **E** produces spinning forces **fs** on its surface dipoles and causes it to spin like a tiny top.

Once the electron spins in the magnetic field **B** , this field acts on its surface dipoles , producing radial forces **fr** that cause the electron to radiate (if the condition $\mathbf{fr} > \mathbf{G}$ is met) .

The findings of these two forces **fs** and **fr** that cause the electron to spin and radiate lead to the concepts of <u>spin and radiation by forces</u> , which mainstream physics does not take into consideration . The synopsis (14) on page 10 shows the production of these two forces from the time-varying magnetic field **B** .

Synchrotron radiation (**SR**) and free electron laser (**FEL**) can be explained as the radiation of the electron by two successive steps : first , it spins by spinning forces **fs** , and then radiates by radial forces **fr** when it travels normally to the time-varying magnetic field and the static , spatially periodic one, respectively .

Because the electron can spin by inertia in a constant magnetic field , it can radiate in this field . The thought experiment presented on the preceding page intends to prove that the electron can radiate when travelling parallel to the magnetic field . If this radiation is experimentally detected , it proves that the radiation of the electron is actually associated with its spin , not with its acceleration .

Physics has no frontier , and thus it has no final truth . So , we are free to guess the truth as we can figure out , provided that the findings are compatible with observed phenomena and able to provide predictions for the advancement of physics .

Finally, let us recall the message from the French physicist , **Louis de Broglie**, that we should frequently and profoundly re-examine those physical principles which we have considered as definitively established * .

* **Louis de Broglie** (Nobel Laureat in physics , 1929) : “ L’ histoire des sciences montre que les progrès de la science ont constamment été entravés par l’influence tyranique de certaines conceptions que l’on avait fini par considérer comme des dogmes . Pour cette raison , il convient de soumettre periodiquement à un examen très approfondi les principes que l’on a fini par admettre sans plus les discuter .”

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