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

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A time-varying electric field **E** produces an induced magnetic field **B** .
If the electron moves in a time-varying **E** , it is actually subject to two fields **E** and **B** simultaneously . In the previous article entitled " **Extended electron in constant electric field** " we have investigated the action of the constant electric field **E** on the electron . Now in this article , we will investigate the action of the induced magnetic field **B** on the electron which is moving through a time-varying electric field **E** .
The electron can move parallel (or anti-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 (or anti-parallel) to **E** .
The induced magnetic field **B** produces different magnetic forces on the electron due to these two components **V'** and **V"** of the velocity **V** :
1 / Magnetic forces **fs** produced by **V' (⊥ E)** cause the **electron to spin** ,
2 / Magnetic forces **fm** produced by **V" (// E)** cause **the electron to radiate** .

Introduction

The readers are recommended to read the article [1] : "**A new extended model for the electron "** to have a look on the *extended model* of the electron and the *assumptions for calculations* . All calculations in this 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) . It is a real particle , having *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 including its spin and radiation .

Let us recall that when the extended electron is subject to a constant electric field [2] **E** , two opposite forces **F** and **F'** are produced on it :

- **F** is the resultant of all electric forces $\mathbf{f_e}$ which are produced on *surface dipoles* of the electron ($\mathbf{F = \Sigma f_e}$) ; **F** directs in the direction of **E** ,
- and **F'** is the electric force produced on *the core* ($-q_0$) of the electron ; **F'** directs in the opposite direction to **E** .

The net electric force is thus **Fe = F + F' : Fe** directs in the opposite direction to **E ,** and the extended electron behaves like a negative particle .

In this article we will investigate the actions of the induced magnetic field **B** on two components : **V' (⊥ E)** and **V" (// E)** of the velocity of the electron when it moves in the time-varying electric field **E** .

1. Magnetic forces produced by the perpendicular component V' (⊥ E): Spinning Forces fs

Since we consider the electron as an extended particle , we view its spin as its rotation about its axis like a tiny top . In the discussion of spin , we will admit the following points related to the time-varying electric field **E** and the induced magnetic field **B** :
i / The direction of the time-varying electric field **E** is always kept upward ; only its intensity changes with time : d**E** / dt > 0 means **E** increases with time ; d**E** / dt < 0 means **E** decreases with time ; (i.e., **E** does not change its direction) .
ii **/** The time-varying electric field **E** produces an induced magnetic field **B** <u>outside</u> and <u>inside</u> the extended electron **;** its circular field lines have directions as shown in Figs. 1 & 2 . These directions comply with Maxwell's equation $\nabla\times \mathbf{H} = \partial\mathbf{D}/\partial t$ (where $\mathbf{B} = \mu\,\mathbf{H}$ and $\mathbf{D} = \varepsilon\,\mathbf{E}$) .
iii / Because of the spherical symmetry of the electron , all circular field lines are centered on the axis **OE** and the induced magnetic field vectors **B** are tangent to these circles .

In this section we are going to show that when the electron moves obliquely through a time-varying **E** , the induced magnetic field **B** acting on the perpendicular component **V'** gives rise to magnetic forces **fs** on all surface dipoles of the electron . These forces form couples of forces causing the electron to spin about the axis **OS** that is normal to the plane (**E,V**) , (Figs. 5 & 6)

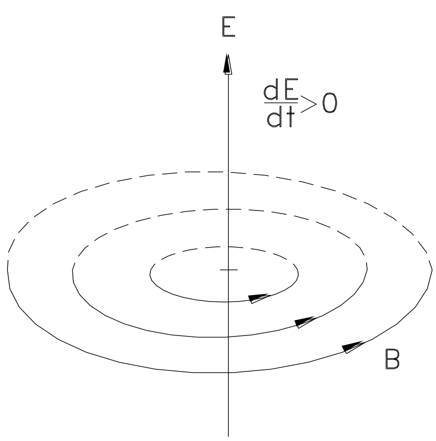


Fig.1 : Direction of the induced magnetic field **B** when d**E** / dt > 0 .

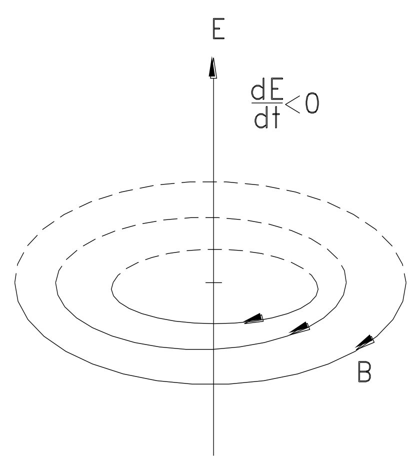
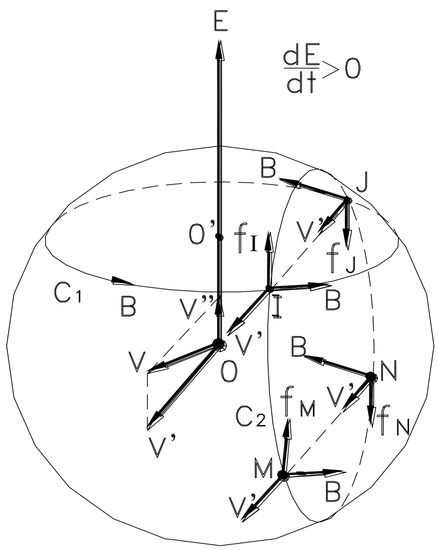


Fig.2 : Direction of the induced magnetic field **B** when d**E** / dt < 0 .



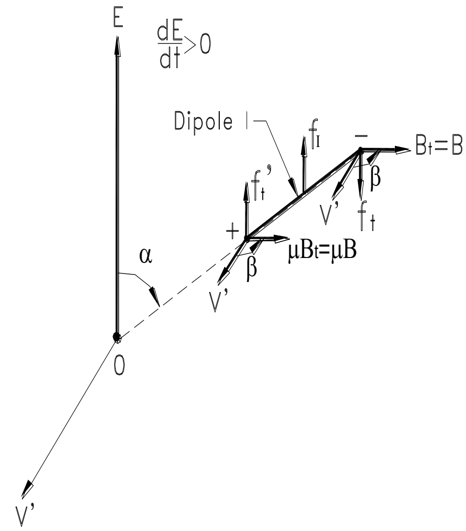


Fig.3 : Four surface dipoles I , J , M , N on circle C_2
- magnetic forces $\mathbf{f_I}$ and $\mathbf{f_M}$ point upwards ,
- magnetic forces $\mathbf{f_J}$ and $\mathbf{f_N}$ point downwards
The velocity **V** has two components **V'** and **V" :**
V' ⊥ E , V" // E .

Fig.4 : Magnetic forces $\mathbf{f_t}$ and $\mathbf{f_t'}$ are produced on two charges +q , -q of the dipole I ; their resultant $\mathbf{f_I}$ points upwards **.**

1.1 Determination of spinning forces fs

First of all let us consider two arbitrary circles C_1 and C_2 which are drawn on the surface of the electron as shown in Fig.3 . The plane of C_1 is normal to the axis **OE** ; the plane of C_2 is parallel to the plane (**E , V**) ; I and J are two points of intersection of these two circles ; the perpendicular component **V'** and the magnetic field **B** are shown at I and J .
First we calculate magnetic forces $\mathbf{f_I}$ produced on the surface dipole I by applying boundary conditions at I (Fig.4) :

$$\mathbf{B = Bn + Bt}$$
$$\mathbf{B' = Bn + \mu Bt}$$

Since vector **B** is tangent to C_1 at I , it is perpendicular to the normal at I , i.e., **Bn** = 0 and hence **B = Bt** and **B' = μBt = μB .** The normal and tangential components **fn , fn' , ft , ft'** of the magnetic force $\mathbf{f_I}$ are :
fn = fn' = 0 ; ft = q V' Bt sinβ = q V' B sinβ and ft' = μ q V' B sinβ .
Since **ft** and **ft'** are both perpendicular to the plane of C_1 or (**B , V'**) , so is the resultant $\mathbf{f_I}$ (= fn + fn' + ft + ft' = ft + ft') , i.e., $\mathbf{f_I}$ is parallel to the axis **OE** .

Since $\mu > 1$ for the extended electron in magnetic field [3] , ft' > ft , hence $\mathbf{f_I}$ points upwards and has magnitude

$$f_I = ft' - ft = (\mu - 1)\, q\, V'\, B \sin\beta \qquad (1)$$

To calculate the magnetic force $\mathbf{f_J}$ produced on the dipole J (Fig.3) we notice that two angles (**V'IB**) and (**V'JB**) are equal to β and hence $f_I = f_J$ in magnitude but $\mathbf{f_J}$ points downwards .
Now , if we calculate magnetic forces $\mathbf{f_M}$ and $\mathbf{f_N}$ acting on two surface dipoles M and N (lying on C_2 , symmetric to I and J over the equatorial plane of the electron) , we get $f_M = f_N$ in magnitude ; $\mathbf{f_M}$ points upwards and $\mathbf{f_N}$ downwards (Fig.3) .
Four magnetic forces $\mathbf{f_I}$, $\mathbf{f_J}$, $\mathbf{f_M}$, $\mathbf{f_N}$ form two couples of forces : **(** $\mathbf{f_I}$ **,** $\mathbf{f_N}$ **)** and **(** $\mathbf{f_M}$ **,** $\mathbf{f_J}$ **) ,** both of which tend to rotate the electron about the axis **OS** that is normal to the plane (**E ,V**) (Fig.5)

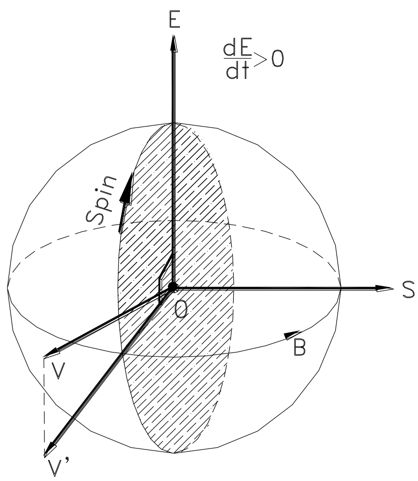


Fig.5 : Direction of spin of the electron in a time-varying **E** when d**E** /dt > 0 by the perpendicular component **V' .** Spin axis **OS** is normal to the plane (**E , V**)

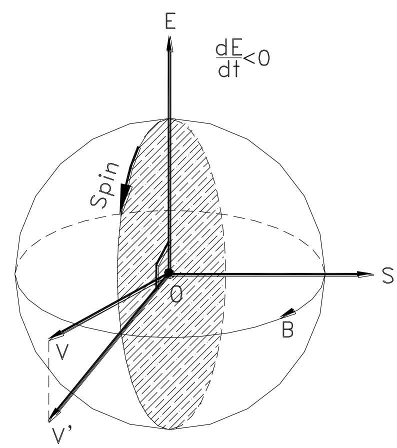


Fig.6 : Direction of spin of the electron in a time-varying **E** when d**E** /dt < 0 by the perpendicular component **V' .** Spin axis **OS** is normal to the plane (**E , V)**

1.2 Generalizing the spinning forces fs

Since two circles C_1 and C_2 are arbitrarily drawn on the surface of the electron , four points I , J , M , N are also arbitrary . If we suppose that we can move the circle C_1 vertically (parallel to itself) and the circle C_2 horizontally (parallel to itself) , four points of intersection I , J , M , N would cover the whole spherical surface of the electron .

Therefore , four magnetic forces $\mathbf{f_I}$, $\mathbf{f_J}$, $\mathbf{f_M}$, $\mathbf{f_N}$ calculated on four arbitrary dipoles I , J , M , N represent all magnetic forces **fs** which are produced on all surface dipoles of the electron ; and they tend to rotate the electron about the axis **OS** which is normal to the plane (**E , V**) . When d**E** / dt > 0 (as shown in Fig.3 and Fig.4) the electron spins as shown by Fig.5 . When d**E** / dt < 0 , the electron spins in reverse direction as shown by Fig.6 . And hence , in an oscillating electric field , the electron alternatively reverses its spin direction . In other words , the electron flips its spin direction because the time rate of change d**E** / dt changes its signs (positive or negative) .

In short , when an electron moves obliquely through a time-varying electric field **E**, the perpendicular component **V'** of its velocity **V** produces magnetic forces **fs** on all surface dipoles . These **spinning forces fs** form couples of forces which cause the electron to spin about the axis **OS** which is normal to the plane (**E , V**) .

We note that since the spin axis **OS** is perpendicular to direction of the electric field **E** , two terms <u>spin-up</u> and <u>spin-down</u> are *no longer appropriate* as in the case of spin in the magnetic field where the spin axis is collinear (parallel or anti-parallel) to the direction of the magnetic field .

From Eq.(1) the magnitude of **fs** is

$$fs = (\mu - 1) \, q \, V' B \sin \beta \qquad (2)$$

where $\mu > 1$ is the relative permeability of the electron to free space ; q : the electric charge at the end of a dipole ; V' : perpendicular component of the velocity of the electron ; B : the induced magnetic field at the surface of the electron ; β is the angle (**V'I B**) at the dipole I .

Eq.(2) suggests two immediate consequences :

- If the electric field **E** is *constant in time* , the induced magnetic field **B** is not produced ; and hence spinning forces **fs** are not produced either ; therefore , the electron does not spin in a constant electric field .
- If the electron is moving *parallel or anti-parallel* to the time-varying electric field, the perpendicular component **V'** is zero , hence spinning forces **fs** do not exist and thus the electron does not spin .

From Eq.(2) the magnitude of the spinning force $\mathbf{f_S}$ depends on **V'** and **B** , that is :
- on the orbital motion of the electron in the electric field **E** ; and
- on the time rate of change d**E** / dt of the time-varying electric field **E** (which gives rise to the induced magnetic field **B**) .

1.3 Comment on the report of controlling the spin of the electron by electric field

A team of physicists in the Netherlands , led by **L . Vandersypen** [4] , 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* .

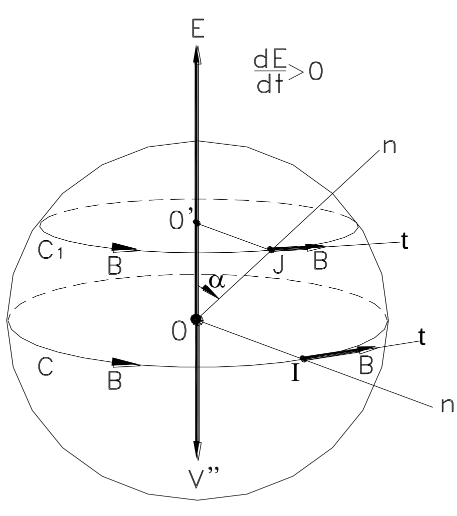
M . Banks [5] reported this work of Vandersypen et al., in Physicsworld.com ; he wrote : *" It is possible to control the spin of a single electron by using an electric field rather than an magnetic field , as is usually the case ".*

In both reports these physicists did not explain the mechanism that causes the electron to spin and hence they could not elaborate on the reason why the electron can reverse (flip) its spin by an oscillating electric field .

The analysis in this section shows that if we consider the electron as an extended particle, we can demonstrate the production of spinning forces **fs** which help explain the spin and the flipping of the electron in an oscillating electric field . In this spin , spinning forces **fs** are magnetic forces and the spin axis (**OS**) is normal to the plane (**E , V**) ; that is , it is perpendicular to the direction of **E** (Figs.5 & 6) . While the spin of the electron in the magnetic field is caused by electric forces and the spin axis is collinear to the magnetic field [6]. So , they are two different types of spin which have different characteristics .

2. Magnetic forces produced by parallel component V" : Pulsating Forces fm

When an electron moves obliquely through an external time-varying electric field **E**, its velocity **V** has two components : **V'** perpendicular to **E** and **V"** parallel (or anti-parallel) to **E** . In the previous section we investigated the action of the induced magnetic field **B** (produced by the time-varying electric field **E)** on the perpendicular component **V'** : the spinning forces $\mathbf{f_S}$ are produced and spin the electron .
Now , in this section we will consider the action of the induced magnetic field **B** on the component **V"** parallel (or anti- parallel) to **E** . When the electron moves parallel (or anti-parallel) to **E** , **V'** = 0 and the component **V"** is the velocity **V** of the electron as shown in Figs. 7 , 8 , … , 16 , 17 which we consider in this section .



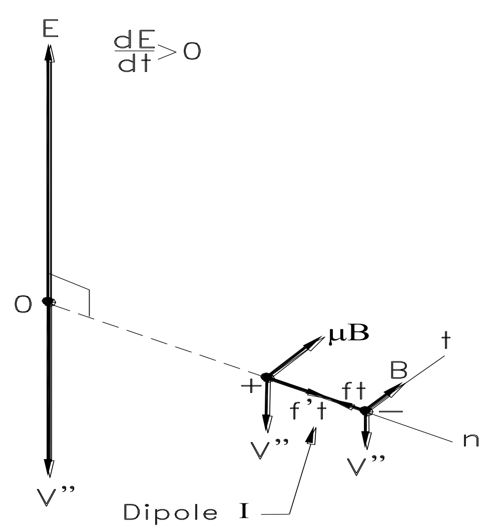


Fig.7 : Two arbitrary surface dipoles I and J ; I on the equatorial circle C , J on C_1 . **B** lies on the tangent **t** and perpendicular to the normal **n** ; $\mathbf{B_t} = \mathbf{B}$ and $\mathbf{B_n} = 0$.

Fig. 8 : Two tangential components $\mathbf{f_t}$, **ft'** acting on two ends –q and +q of dipole I . Normal components $\mathbf{f_N} = \mathbf{f_N'} = 0$ because $\mathbf{B_n} = 0$.

2.1 Determination of magnetic forces fm produced by V" (↓↑ E) .

Let's consider two arbitrary surface dipoles I and J in Fig.7 : I on the equatorial circle C and J on an arbitrary circle C_1 parallel to C . By applying boundary conditions for the magnetic field **B** on the surface dipole I we get

$$\mathbf{B} = \mathbf{Bn} + \mathbf{Bt}$$
$$\mathbf{B'} = \mathbf{Bn} + \mu\mathbf{Bt}$$

we will determine magnetic forces **fm** produced on dipoles I and J by the induced magnetic field **B** acting on **V" (↓↑E).**
First , we calculate **fm** produced on surface dipole I (Fig.8) . Since **B** is tangent to C at I (Fig.7) , it is perpendicular to the normal at I , hence **Bn** = 0 , **B = Bt** , **B'** = μ **Bt** = μ **B** . Since **Bn** = 0 , **fn** = **fn'** = 0 .
On the negative charge -q of the dipole I : ft = q V"B (**V"⊥ B**) , **ft** is <u>centripetal</u> ;
On the positive charge +q of the dipole I : ft' = μ q V"B , **ft'** is <u>centrifugal</u> ;
where **B** is the induced magnetic field along the equatorial circle C .
Since μ > 1 , ft' > ft , the resultant force **fm** acting on dipole I has magnitude
fm = ft' - ft = (μ - 1) q V"B ; **fm** is <u>radial</u> from the center O of the electron (Fig.9)

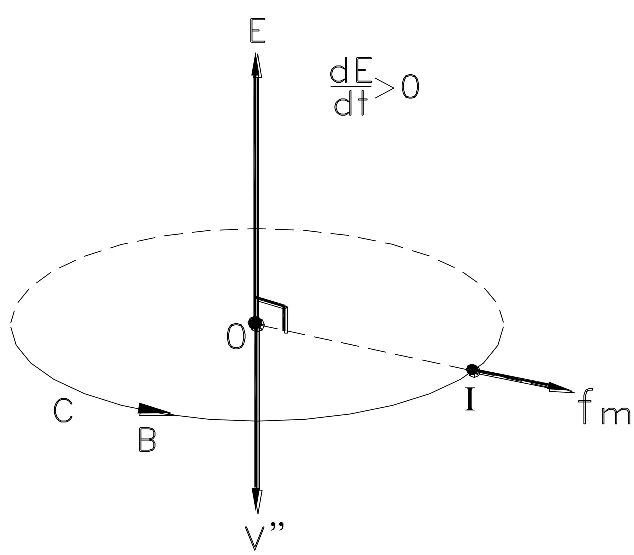


Fig. 9 : The resultant force $\mathbf{F_m}$ acting on dipole I is radial from the centre O of the circle C.

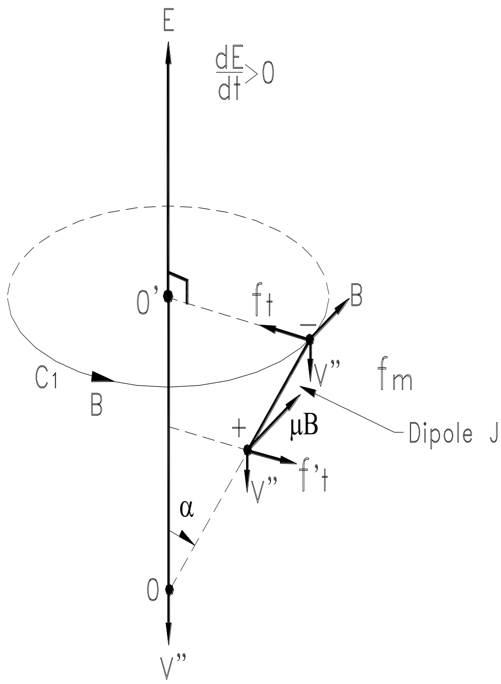


Fig. 10 : Two tangential components f_t , ft' acting on two charges –q and +q of dipole J . Normal components $f_N = f_N' = 0$ because $B_n = 0$.

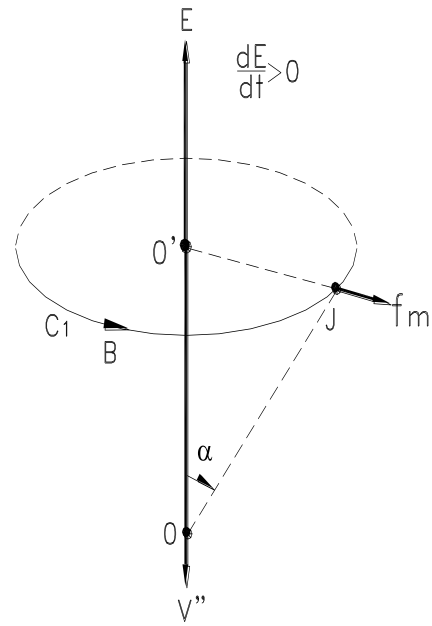


Fig. 11 : Because the dipole is extremely small , the resultant force F_m acting on dipole J is radial from the centre O' of circle C_1 .

Now , let's calculate **fm** acting on the surface dipole J on the circle C_1 (Fig.10) .
Since **B** is tangent to C_1 at J , it is perpendicular to the normal at J , hence **Bn** = 0 , **B** = **Bt** and **B'** = μ **Bt** = μ **B** . Since Bn = 0 , fn = fn' = 0 ;
On the negative charge –q of the dipole J : ft = q V''B (**V''⊥ B**) ; **ft** passes the center O' of the circle C_1 . On the positive charge +q of the dipole J : ft' = μ q V''B where **B** is the induced magnetic field along the circle C_1 .
Since μ > 1 , ft' > ft , the resultant force fm = ft' –ft = (μ - 1) q V''B .
Because the dipole is extremely small , the resultant force **fm** acting on the dipole J is radial from the center O' of the circle C_1 (Fig.11) .
Generally , the magnetic force **fm** produced on all surface dipoles are radial from centers lying on the axis **OE** as shown in Fig.12 .

In summary , the induced magnetic field **B** acting on **V''** gives rise to magnetic forces **fm** which are radial from centers lying on the axis **OE** , as shown in Fig.12 .
The magnitude of **fm** is

$$fm = (\mu - 1) q V''B \qquad (3)$$

The magnetic force **fm** can be decomposed into two components **fr** and **fp :** **fr** is radial from O and **fp** tangent to the spherical surface of the electron as shown in Fig.13. Their magnitudes are

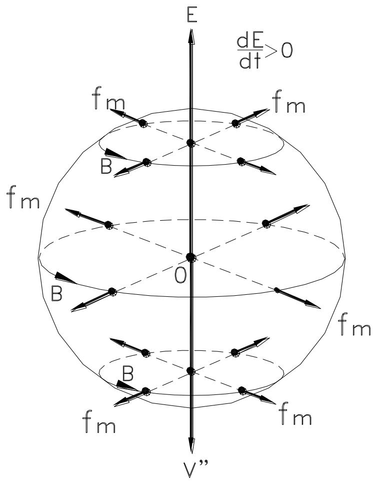


Fig. 12 : Magnetic forces **fm** acting on all surface dipoles are radial from centers lying on the axis **OE .**

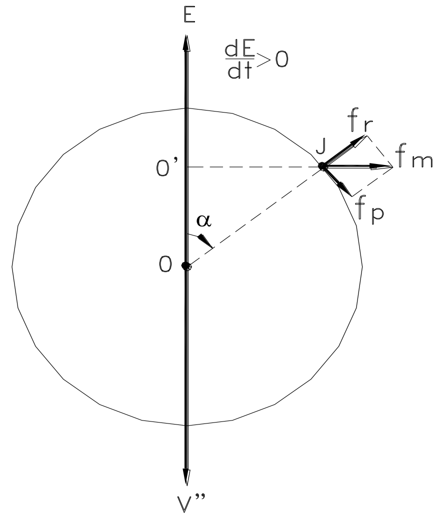


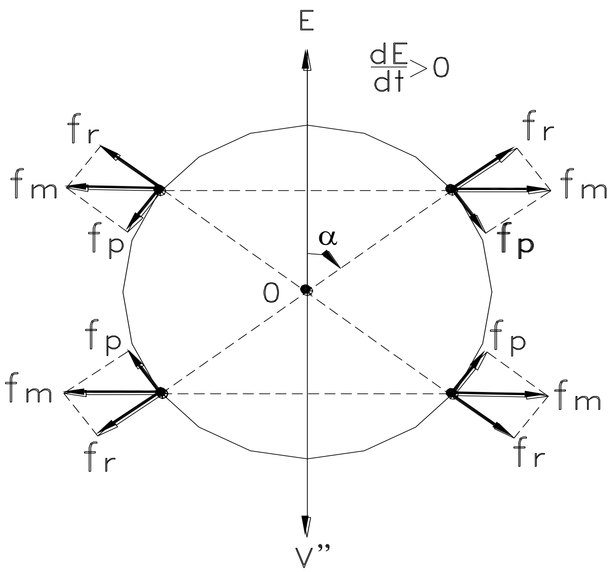
Fig.13 : **fm** acting on dipole J can be decomposed into two components **fr** and **fp** : **fr** is radial from O , **fp** is tangent to the surface of the electron .

$$fr = fm \sin\alpha = (\mu - 1)\, q\, V''B \sin\alpha \qquad (4)$$
$$fp = fm \cos\alpha = (\mu - 1)\, q\, V''B \cos\alpha \qquad (5)$$

The direction of **fm** depends on the directions of **V''** and **B** , where **V''** can be parallel or anti-parallel to **E** , while the direction of **B** (see Figs. 1 & 2) depends on the time rate of change (d**E** / dt) of **E** , which can be positive or negative . We therefore have four different situations :

1. **V''** ↓↑ **E** , d**E** / dt > 0 : electron is accelerated by an increasing **E** **:** Fig.14
2. **V''** ↓↑ **E** , d**E** / dt < 0 : electron is accelerated by a decreasing **E** : Fig.15
3. **V''** ↑↑ **E** , d**E** / dt > 0 : electron is decelerated by an increasing **E** : Fig.16
4. **V''** ↑↑ **E** , d**E** / dt < 0 : electron is decelerated by a decreasing **E** : Fig.17

The magnetic forces **fm** and the radial forces **fr** in these four situations create <u>compressive /</u> <u>expansive effects</u> on the electron ; they can be called <u>pulsating forces</u> . We notice that in two Figs. 14 & 17 the components **fr** are centrifugal , they enhance the radiation process of the electron in the electric field . On the other hand , in two Figs.15 & 16 , since the components **fr** are centripetal , they reduce the radiating capacity of the electron in the electric field (as we discuss below) .



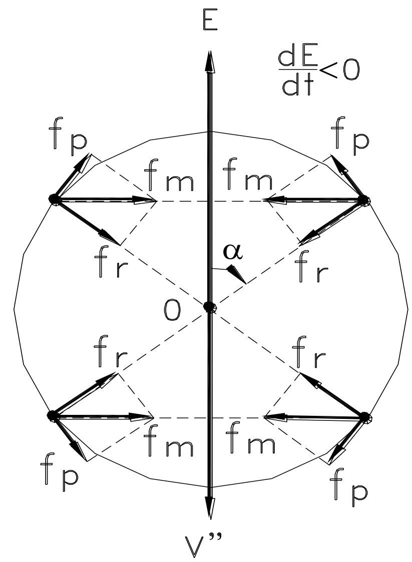
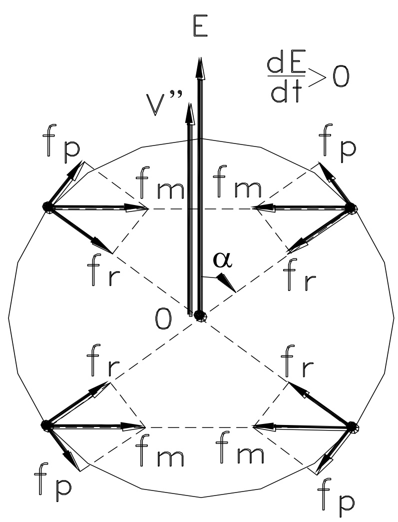


Fig.14 : When **V”** ↓↑ **E** , and d**E** / dt > 0 :
all components **fr** are centrifugal ,
creating an expansive effect on the electron.

Fig.15 : When **V”** ↓↑ **E** , and d**E** / dt < 0 :
all components **fr** are centripetal ,
creating a compressive effect on the electron .



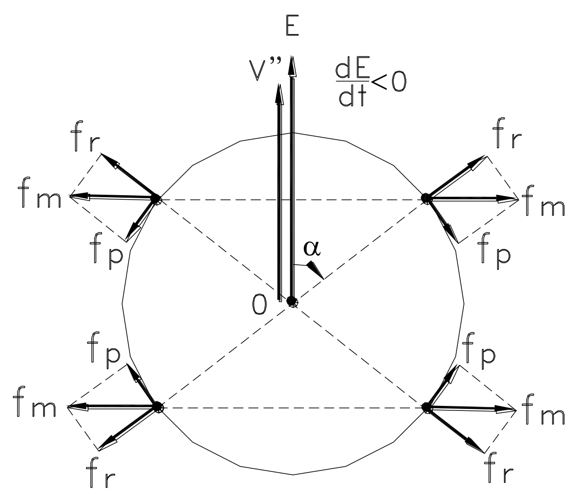
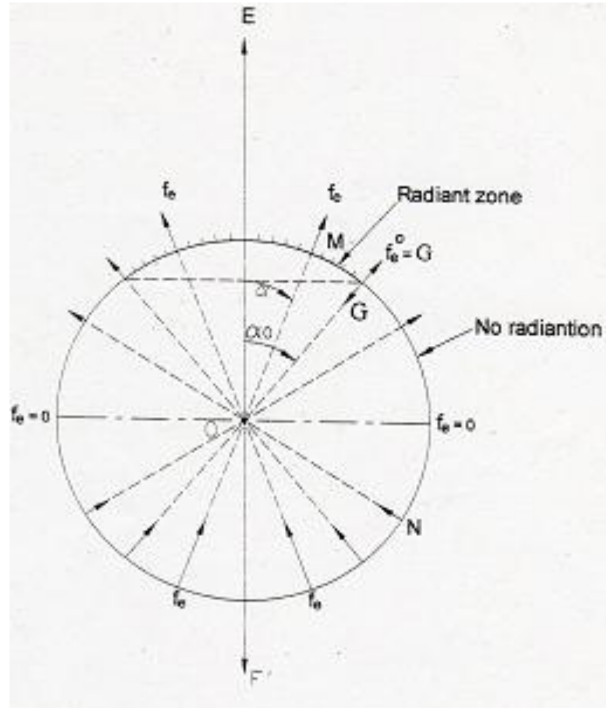


Fig. 16 : When **V”** ↑↑ **E** , and d**E** / dt > 0 :
all components **fr** are centripetal ,
creating a compressive effect on the electron .

Fig.17 : When **V”** ↑↑ **E** , and d**E** / dt < 0
all components **fr** are centrifugal ,
creating an expansive effect on the electron.

Fig.18 : Electric field **E** generates electric forces **fe** on all surface dipoles ; **fe** are centrifugal on the upper hemisphere and centripetal on the lower one . Electric forces **fe** on the upper hemisphere cause the electron to radiate in a restricted zone limited by the angle α_0 where $\mathbf{fe^o} = \mathbf{G}$.



2.2 Radiation of the electron by electric field .

In the article entitled " **Extended electron in constant electric field** [2] " we have seen that the electric forces **fe** produced on surface dipoles are centrifugal on the upper hemisphere and centripetal on the lower hemisphere as shown in Fig.18
When **fe > G** in magnitude , **fe** cause the electron to radiate from a restricted zone around the north pole as shown in Fig.18 and there is no radiation on the lower hemisphere .
Now , if the electric field is time-varying , in two cases of Figs.14 & 17 , the centrifugal forces **fr** reinforce **fe** on the upper hemisphere, and hence enhance the radiating ability : the radiant zone expands .
Conversely, in two cases of Figs.15&16 , the centripetal forces **fr** oppose and weaken **fe** on the upper hemisphere , and hence reduce the radiating ability of the electron .
Therefore , in a time-varying electric field **E** , both electric forces **fe** and magnetic pulsating forces **fr** take part in the radiation process of the electron .

2.3 Spin-orbit interaction

When the electron moves parallel (or anti-parallel) to the time-varying **E** , the electric force **fe** and the pulsating force **fm** are produced on a surface dipole ; their resultant force **Fr** acting on the dipole is

$$\mathbf{Fr} = \mathbf{G} + \mathbf{fe} + \mathbf{fm} \qquad (6)$$

where **G's** represent the cohesive forces which always exist inside the electron .
If the electron moves obliquely to the time-varying **E** , the spinning forces **fs** are produced due to the perpendicular component **V'** , causing the electron to spin ; **fs** is added to the resultant force **Fr** ; Eq.(6) becomes

$$\mathbf{Fr} = \mathbf{G} + \mathbf{fe} + \mathbf{fm} + \mathbf{fs} \tag{7}$$

The resultant force **Fr** in Eq.(7) which acts on a surface dipole of the electron determines the direction and energy of the emitted dipole (photon) when the electron radiates . The presence of the spinning force **fs** (due to **V'**) and the pulsating force **fm** (due to **V"**) in the resultant force **Fr** proves that the direction and energy of the emitted photon depend on both the spin and the orbital motion of the electron in the time-varying electric field : this is spin-orbit interaction .

3. Summary & Conclusion

When an extended electron moves through a time-varying electric field **E ,** it is subject to the electric field **E** and the induced magnetic field **B** at the same time .

* From the previous article [2] , we knew that the electric field **E** produces two opposite electric forces **F** and **F'** on the electron . The force $\mathbf{F} = \sum \mathbf{fe}$ directing in the direction of **E** is the resultant of all the electric forces **fe** which are produced on all surface dipoles , causing the electron to radiate in the direction of **E** . The force **F'** produced on the core ($-q_0$) of the electron directs in the opposite direction to **E** . The net force **Fe** = **F + F'** pointing in the opposite direction to **E** accelerates the electron in the opposite direction to **E** when $\varepsilon < 1$.

* The induced magnetic field **B** gives rise to **spinning forces fs** (due to the perpendicular component **V'**) and **pulsating forces fm** (due to the parallel component **V"** of the velocity **V**) . The pulsating forces **fm** create compressive / expansive effects on the electron , contribute to the radiation process and determine the radiation pattern when the electron radiates .

The findings of forces (**fe , fs , fm**) that cause the extended electron to spin and radiate , demonstrate that we can explain the *mechanisms of spin and radiation by forces,* a procedure that the mainstream physics has not considered so far . We need to look at the mechanisms of spin and radiation differently to change the traditional point of view of the mainstream physics to boost the advancement of physics .

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