

# Visualizing Spin & Radiation of the Extended Electron in Electric Field (Emission & Absorption of Photons)

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## Abstract

In this article the electron is conceived as an extended particle, consisting of a negatively charged core ( $-q_0$ ) which is surrounded by a cloud of electric dipoles ( $-q, +q$ ). The article presents the illustrations that show how and why the electron spins and radiates in an external electric field. In the appendices, Bremsstrahlung & Cerenkov radiations, and the processes of Emission & Absorption of photons will be discussed.

## Keywords

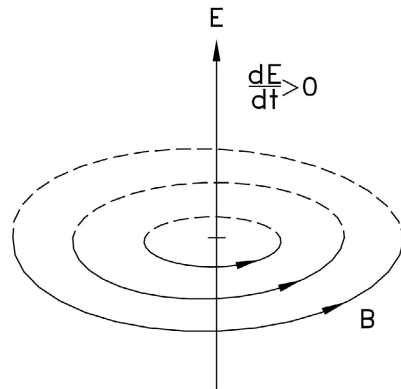
Spinning Forces ( $f_s$ ), Spin By Inertia, Radiating Forces ( $f_r$ ), Pulsating Forces ( $f_p$ ); Photons or Electric Dipoles, Spin-Orbit Coupling

## 1. Introduction

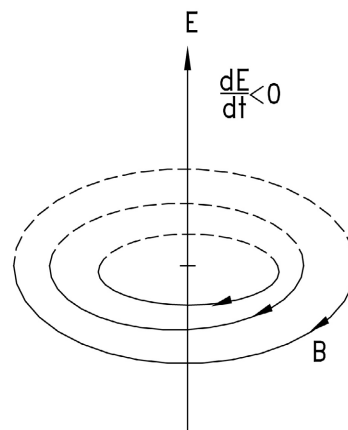
A time-varying electric field  $\mathbf{E}$  ( $d\mathbf{E}/dt > 0$  or  $d\mathbf{E}/dt < 0$ ) produces the rotational induced magnetic field  $\mathbf{B}$ . Maxwell's equation  $\nabla \times \mathbf{H} = \partial\mathbf{D}/\partial t$  (where  $\mathbf{B} = \mu\mathbf{H}$  and  $\mathbf{D} = \epsilon\mathbf{E}$ ) determines the direction and strength of the induced magnetic field  $\mathbf{B}$ : **Figure 1 & Figure 2.**

When the electron is subject to a time-varying electric field  $\mathbf{E}$ , it is actually subject to the main electric field  $\mathbf{E}$  and the induced magnetic field  $\mathbf{B}$ . In a previous article [1] we have examined the action of the electric field  $\mathbf{E}$  on the electron: it produces the electric force  $\mathbf{F}_e$  on the electron causing it to move through the induced magnetic field  $\mathbf{B}$  with the velocity  $V$ .

In this article, we focus on the action of the induced magnetic field  $\mathbf{B}$  on two components  $V'$  and  $V''$  of the velocity  $V$ :  $V'$  normal to  $\mathbf{E}$ : ( $V' \perp \mathbf{E}$ ) and  $V''$  parallel to  $\mathbf{E}$ : ( $V'' \parallel \mathbf{E}$ ). The induced magnetic field  $\mathbf{B}$  produces different magnetic forces by these two components:



**Figure 1.** Direction of the induced magnetic field  $B$  when  $dE/dt > 0$  ( $E$  increases with time).



**Figure 2.** Direction of the induced magnetic field  $B$  when  $dE/dt < 0$  ( $E$  decreases with time).

- component  $V' \perp E$  produces magnetic forces  $f_s$  causing the **electron to spin** (Section 2).
- component  $V'' \parallel E$  produces magnetic forces  $f_m$  causing **the electron to radiate** (Section 4).

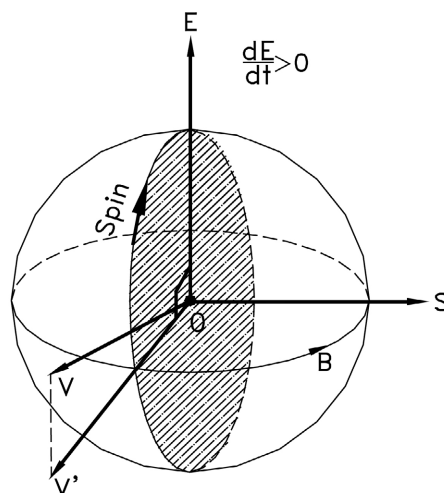
## 2. Visualizing the Spin of the Electron in Time-Varying Electric Field $E$

When the electron is subject to a time-varying electric field  $E$ , the induced magnetic field  $B$  (Figure 1 & Figure 2) acts on the normal component  $V' \perp E$  to cause it to spin as shown in two Figure 3 & Figure 4 for two cases  $dE/dt > 0$  and  $dE/dt < 0$ .

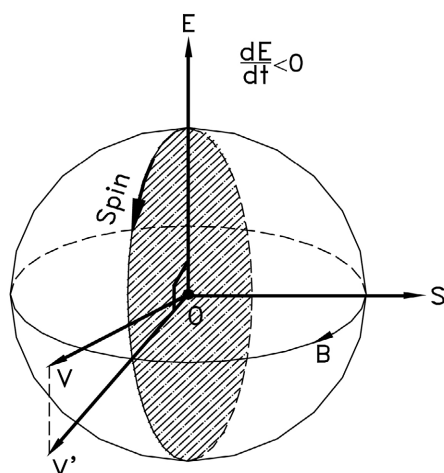
In a previous article [2] the magnitude of the spinning force  $f_s$  has been determined as

$$f_s = (\mu - 1)qV'B \sin \beta \tag{1}$$

where  $\mu > 1$  is the relative permeability of the electron to free space;  $q$ : the electric charge at the end of a dipole;  $V'$ : normal component of the velocity of the



**Figure 3.** The spin is caused by the component  $V' \perp E$ : The direction of spin of the electron is shown when  $dE/dt > 0$ . Spin axis  $OS$  is normal to the plane  $(E, V)$ .



**Figure 4.** The spin is caused by the component  $V' \perp E$ : The direction of spin of the electron is shown when  $dE/dt < 0$ . Spin axis  $OS$  is normal to the plane  $(E, V)$ .

electron;  $B$ : the induced magnetic field at the surface of the electron;  $\beta$  is the angle  $(V'IB)$  at the surface dipole  $I$ .

Equation (1) suggests the following consequences:

- If the electric field  $E$  is *constant in time*, the induced magnetic field  $B$  is not produced; and hence spinning forces  $f_s$  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  $E$ , the normal component  $V'$  is zero, hence spinning forces  $f_s = 0$  and thus the electron does not spin when it moves parallel or anti-parallel to  $E$ .

In two above cases ( $E$  is constant in time and the electron moves parallel to  $E$ ) since  $f_s = 0$  the electron may be *spinning by inertia; i.e., spin with no spinning forces*.

Therefore, the spinning force  $f_s$  in Equation (1) shows that the spin of the

electron depends on the component  $V'(\perp E)$  of its orbital velocity and on the induced magnetic field  $B$ ; (i.e., on  $E$  and the time rate of change  $dE/dt$  which cause the electron to spin). This is the **spin-orbit coupling** of the electron when it moves through electric field  $E$ . When the time rate  $dE/dt$  changes its signs from positive to negative and vice versa, spinning forces  $f_s$  reverse their directions and so does the spin direction (**Figure 3 & Figure 4**). Let's notice that the spin axis  $OS$  is normal to the plane  $(E, V)$ ; i.e., it is normal to the time-varying electric field  $E$ .

(By the way, let's notice that when the electron spins by a time-varying magnetic field, the spin axis is parallel to the magnetic field).

**A digression: Comment on the report of controlling the spin of the electron by electric field in Science Magazine and Physics World.**

A team of physicists in the Netherlands, led by L. Vandersypen [3], reported in the Science magazine (Nov. 2007) that they have experimentally controlled the spin of a single electron by using an oscillating electric field.

M. Banks [4] reviewed this work of **Vandersypen**, wrote in Physicsworld.com: *"It is possible to control the spin of a single electron by using an electric field rather than a magnetic field, as is usually the case"*.

The report did not demonstrate the mechanism that causes the electron to spin, and hence it could not elaborate the reason why the electron can reverse its spin direction by an oscillating electric field. Moreover, it viewed these two types of spin (by time-varying electric field and by time-varying magnetic field) as of the same type. Actually, they have different characteristics in their modes of spin: in the former case, the spinning forces  $f_s$  are magnetic forces [Equation (1)] and the spin-axis  $OS$  is normal to the electric field  $E$  as shown in **Figure 3 & Figure 4**; while in the latter case, spinning forces are electric forces and the spin-axis lines up with the magnetic field  $B$  or precesses around it [5].

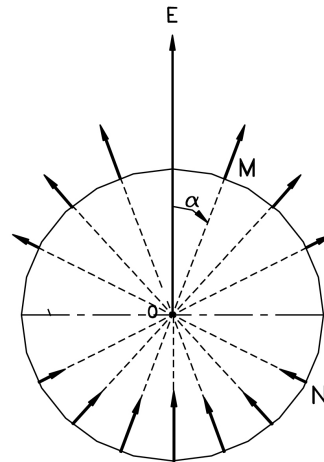
### 3. Visualization of Radiation of the Electron in Constant Electric Field $E$

The forces that cause the radiation of the extended electron come from two sources: From the external constant electric field  $E$  (which is considered in this Section 3); From the induced magnetic field  $B$  (Section 4).

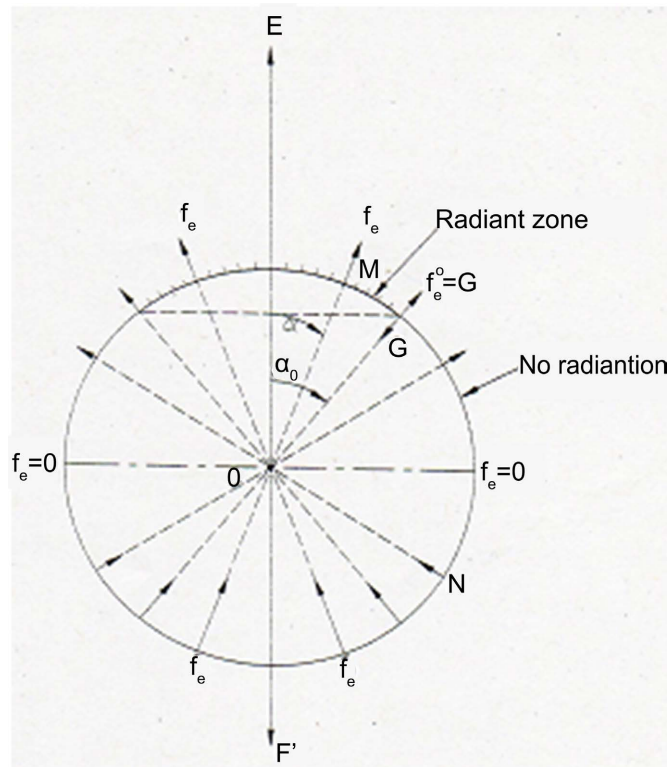
In the previous article [1] we have come to two **Figure 5 & Figure 6** which visualize the radiation of the electron in the constant electric field  $E$ .

Let us examine two **Figure 5 & Figure 6** which are drawn for the case  $\varepsilon < 1$  (when the particle behaves like an electron). **Figure 5** shows electric forces  $f_e$  developed on all surface dipoles of the electron:  $f_e$  are centrifugal on the upper hemisphere and centripetal on the lower hemisphere. **Figure 6** shows, in addition to the electric forces  $f_e$ , the cohesive forces  $G$  which attract all surface dipoles to the core and the force  $F'$  (produced on the core) which accelerates the electron downwards.

On the upper hemisphere, while  $f_e$  are centrifugal, cohesive forces  $G$  are centripetal; when the magnitude of  $f_e$  is greater than that of  $G$  ( $f_e > G$ ), these surface



**Figure 5.** (For  $\epsilon < 1$ ) shows electric forces  $f_e$  acting on all surface dipoles of the electron: - on the upper hemisphere:  $f_e$  are centrifugal; - on the lower hemisphere:  $f_e$  are centripetal. The magnitude of  $f_e$  is  $f_e = (1/\epsilon - 1)qE\cos\alpha$ ,  $\alpha$  is the angular position of the surface dipole M.



**Figure 6.** Shows electric forces  $f_e$ , cohesive forces  $G$  and the electric force  $F'$  that is produced on the core ( $-q_0$ ) of the electron. The magnitude of  $G$  is  $G = (1/\epsilon - 1)qE_0$ , where  $E_0$  is the self field of the electron. At the angle  $\alpha_0$ :  $f_e^0 = G$  (in magnitude).

dipoles can be emitted from the surface of the electron; that is, the electron radiates these photons outwards while it is moving downwards by the force  $F'$ . So, the condition for the electron to radiate is that the force  $f_e$  that acts on this dipole is greater than the cohesive force  $G$ .

$$f_e > G \text{ (in magnitude)} \tag{2}$$

Meanwhile, on the lower hemisphere, since both  $f_e$  and  $G$  are centripetal, these surface dipoles cannot break free from the surface of the electron; *i.e.*, there is no radiation from the lower hemisphere.

**Figure 6** shows the radiant zone, which does not cover the entire upper hemisphere of the electron, but only a limited zone around the north pole, defined by the angle  $\alpha_0$  where

$$f_e^0 = G \text{ (in magnitude)} \tag{3}$$

Now let's try to determine this angle  $\alpha_0$ . Let us recall that the magnitude of  $f_e$  produced on a surface dipole M of the upper hemisphere has been calculated as:

$$f_e = \left(\frac{1}{\varepsilon} - 1\right) qE \cos \alpha, \text{ where } \varepsilon < 1 \text{ and } 0 < \alpha < \pi/2 \tag{4}$$

$f_e$  is centrifugal and depends on the angular position  $\alpha$  of the surface dipole M.

Since  $\alpha_0$  is assumed to be the value of the angle  $\alpha$  at which  $f_e^0 = G$  (in magnitude) then the condition for the radiation to occur  $f_e > G$  (in magnitude) is rewritten as

$$f_e > f_e^0 \text{ (in magnitude) or } \left(\frac{1}{\varepsilon} - 1\right) qE \cos \alpha > \left(\frac{1}{\varepsilon} - 1\right) qE \cos \alpha_0 \tag{5}$$

$$\text{or } \cos \alpha > \cos \alpha_0 \tag{6}$$

$$\text{or } \alpha < \alpha_0 \tag{7}$$

**Figure 6** shows *the radiant zone* on the upper hemisphere, restricted in a zone around the north pole of the electron, limited by the angle  $\alpha_0$  which is defined by the relation (3).

All radiating rays emitted from the radiant zone are contained inside a radiation cone of solid angle  $2\alpha_0$  at the vertex O. So, the existence of the angle  $\alpha_0$  means the existence of the radiation cone. Now let us determine the condition for the existence of the angle  $\alpha_0$ . From (3) we have

$$\left(\frac{1}{\varepsilon} - 1\right) qE \cos \alpha_0 = G \tag{8}$$

In the article “**A new extended model for the electron**” [6], the magnitude of  $G$  has been calculated to be equal to

$$G = \left(\frac{1}{\varepsilon} - 1\right) qE_0, \text{ where } E_0 \text{ is the self field of the electron} \tag{9}$$

$$\text{Hence } \left(\frac{1}{\varepsilon} - 1\right) qE \cos \alpha_0 = \left(\frac{1}{\varepsilon} - 1\right) qE_0 \text{ or } \boxed{\cos \alpha_0 = E_0/E < 1} \tag{10}$$

$$\text{The condition for the radiation to occur is thus } \boxed{E > E_0} \tag{11}$$

Therefore: **1)** if  $E < E_0$ ,  $\cos \alpha_0 > 1$ ;  $\alpha_0$  does not exist: no radiation emits from the electron while it is accelerated in  $E$ ; this also implies that in free space ( $E = 0$ ) the electron cannot radiate.

**2)** if  $E = E_0$ ,  $\cos \alpha_0 = 1$ ,  $\alpha_0 = 0$ : the radiation cone reduces to a beam of light

emitted from the north pole of the electron. In other words, the electron can radiate only at its north pole ( $\alpha_0 = 0$ ).

3) if  $E > E_0$ ,  $\cos\alpha_0 < 1$ ,  $0 < \alpha_0 < \pi/2$ : radiation occurs around the north pole of the electron and expands towards the equator as the magnitude of  $\mathbf{E}$  increases: the radiation cone emitted in the direction of the electric field  $\mathbf{E}$  as shown in **Figure 6**.

4) if  $E \rightarrow \infty$ ,  $\cos\alpha_0 \rightarrow 0$ ,  $\alpha_0 \rightarrow \pi/2$ : the radiant zone expands to cover entirely the upper hemisphere (this case is only theoretical because  $\mathbf{E}$  cannot tend to infinity).

**Conclusion:** the condition for the existence of the angle  $\alpha_0$  (which is also the condition for the emission of radiation) is thus  $E > E_0$ . So, while it is accelerated in  $\mathbf{E}$ , the extended electron whether or not radiates depending on the strength of the applying field  $\mathbf{E}$  compared to that of the self field  $\mathbf{E}_0$ , regardless of its motion in the field  $\mathbf{E}$ . In other words, the radiation of the extended electron in *constant electric field* depends on the strength of the centrifugal electric forces  $\mathbf{f}_e$  which are showed in two **Figure 5 & Figure 6**.

But if the electric field  $\mathbf{E}$  is a *time-varying electric field*, then additional forces  $\mathbf{f}_m$  will emerge to reinforce or restrain these centrifugal forces  $\mathbf{f}_e$  and change conditions for the radiation, as we will discuss in the next section.

#### 4. Visualizing the Radiation of the Electron in the Time-Varying Electric Field

When an electron moves obliquely through a time-varying electric field  $\mathbf{E}$ , its velocity  $\mathbf{V}$  has two components:  $\mathbf{V}'$  perpendicular to  $\mathbf{E}$  and  $\mathbf{V}''$  parallel (or anti-parallel) to  $\mathbf{E}$ . In the previous section, we investigated the action of the induced magnetic field  $\mathbf{B}$  on the perpendicular component  $\mathbf{V}'$ : 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  $\mathbf{B}$  on the component  $\mathbf{V}''$  parallel (or anti-parallel) to  $\mathbf{E}$ .

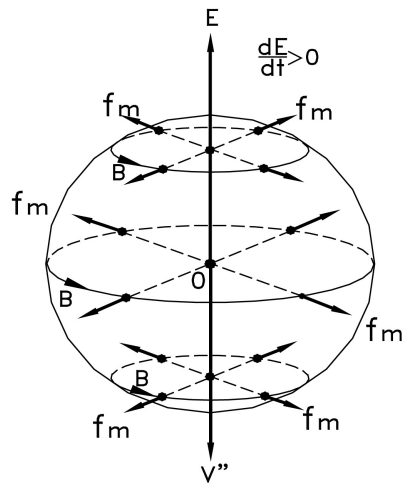
The result is: the induced magnetic field  $\mathbf{B}$  acting on  $\mathbf{V}''$  gives rise to magnetic forces  $\mathbf{f}_m$  which are radial from centers lying on the axis  $\mathbf{OE}$ , as shown in **Figure 7**.

$$\text{The magnitude of } \mathbf{f}_m \text{ is } f_m = (\mu - 1)qV''B \quad (12)$$

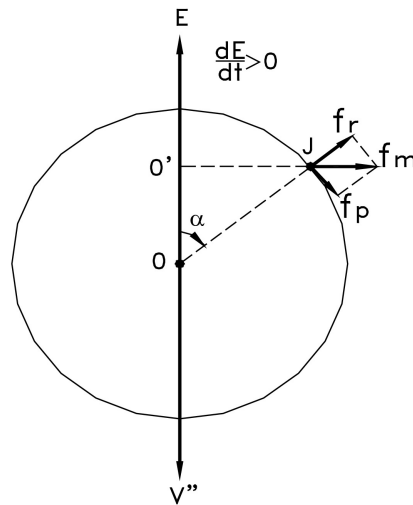
The magnetic force  $\mathbf{f}_m$  can be decomposed into two components  $\mathbf{f}_r$  and  $\mathbf{f}_p$  with  $\mathbf{f}_r$  radial from the core O and  $\mathbf{f}_p$  tangent to the spherical surface of the electron as shown in **Figure 8**.

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

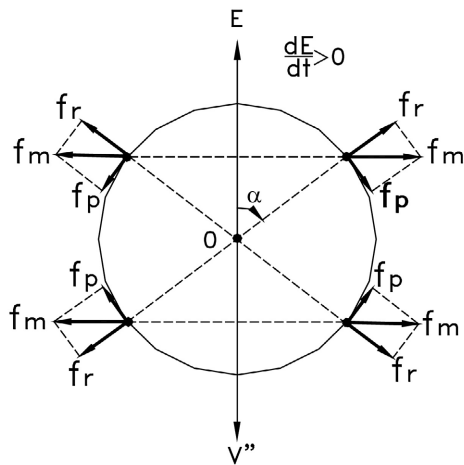
- 1)  $\mathbf{V}'' \downarrow \uparrow \mathbf{E}$ ,  $d\mathbf{E}/dt > 0$ : electron is accelerated by an increased  $\mathbf{E}$ : **Figure 9**
- 2)  $\mathbf{V}'' \downarrow \uparrow \mathbf{E}$ ,  $d\mathbf{E}/dt < 0$ : electron is accelerated by a decreased  $\mathbf{E}$ : **Figure 10**
- 3)  $\mathbf{V}'' \uparrow \uparrow \mathbf{E}$ ,  $d\mathbf{E}/dt > 0$ : electron is decelerated by an increased  $\mathbf{E}$ : **Figure 11**



**Figure 7.** The magnetic forces  $f_m$  produced on all surface dipoles are radial from centers lying along the axis  $OE$ .

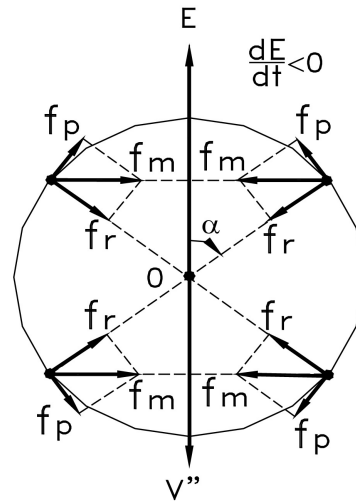


**Figure 8.** The force  $f_m$  can be decomposed into two components:  $f_r$  and  $f_p$ ;  $f_r$  is radial from  $O$ ;  $f_p$  is tangent to the surface of the electron.

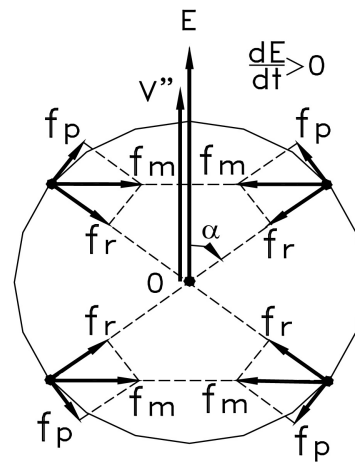


**Figure 9.** When  $V'' \uparrow E$ , and  $dE/dt > 0$ : all components  $f_r$  are centrifugal.





**Figure 10.** When  $V'' \downarrow \uparrow E$ , and  $dE/dt < 0$ : all components  $f_r$  are centripetal.



**Figure 11.** When  $V'' \uparrow \uparrow E$ , and  $dE/dt > 0$ : all components  $f_r$  are centripetal.

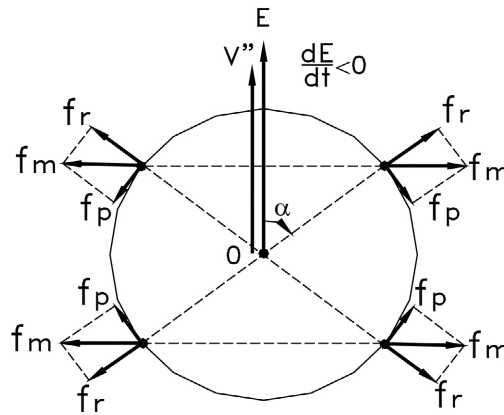
4)  $V'' \uparrow \uparrow E$ ,  $dE/dt < 0$ : electron is decelerated by a decreased  $E$ : **Figure 12**

The radial forces  $f_r$  in these four situations create contractive/expansive effects on the electron, we call them **pulsating forces**.

We notice that in two **Figure 9** and **Figure 12** the magnetic forces  $f_m$  point out of the electron, and the radial components  $f_r$  are centrifugal, they thus enhance the radiation process of the electron in the electric field. On the other hand, in two **Figure 10** and **Figure 11**, since the radial components  $f_r$  are centripetal, they restrain the radiating capability of the electron in the electric field as we see below.

In the Section 3 we have seen that the electric forces  $f_e$  produced on surface dipoles are centrifugal on the upper hemisphere and centripetal on the lower hemisphere as shown in **Figure 5** & **Figure 6**.

When  $f_e > G$  in magnitude,  $f_e$  cause the electron to radiate from a restricted zone around the north pole as shown in **Figure 6** and there is no radiation on the lower hemisphere.



**Figure 12.** When  $V'' \uparrow \uparrow E$ , and  $dE/dt < 0$ : all components  $f_r$  are centrifugal.

Now, if the electric field  $E$  is time-varying, in two cases of **Figure 9** & **Figure 12**, the centrifugal forces  $f_r$  reinforce  $f_e$  on the upper hemisphere, and enhance the radiating ability, hence the radiant zone expands.

On the other hand, in two cases of **Figure 10** & **Figure 11**, the centripetal forces  $f_r$  oppose and weaken  $f_e$  on the upper hemisphere, and hence reduce the radiating ability of the electron.

Therefore, in a time-varying electric field  $E$ , both electric forces  $f_e$  and magnetic pulsating forces  $f_r$  contribute to the radiation process of the electron.

### 5. Conclusions

Electric field can affect the electron by two different ways:

The external electric field  $E$  produces the electric forces  $f_e$  which are the main forces that cause the electron to radiate in the direction of the field  $E$ , no matter how the electron moves in the field<sup>1</sup>. In the meantime, if the electric field is a time-varying field, it produces the induced magnetic field  $B$  which gives rise to **spinning forces**  $f_s$  due to the normal component  $V'(\perp E)$  and **pulsating forces**  $f_r$  due to the parallel component  $V''(\parallel E)$  of the velocity  $V$ . The pulsating forces  $f_r$  create contracting or expansive effects on the electron, contributing to the radiation process and determining the radiation pattern when the electron radiates. All illustrations in this article help us visualize these features of the electron in an electric field.

### Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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<sup>1</sup>According to the Lorentz's forces equation  $F_L = q(E + V \times B)$ : the electric force  $F_e = qE$  is independent of the velocity, while the magnetic force  $F_m = qV \times B$  depends on  $V$ .

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## Appendix

We are going to discuss two topics:

### 1) Mechanisms of Bremsstrahlung and Cerenkov Radiation

#### 2) Emission & Absorption of photons

##### Discussion 1: Mechanisms of Bremsstrahlung and Cerenkov Radiation.

The visualizations of radiation of the electron by the electric field can be used to explain the mechanism of Bremsstrahlung and Cerenkov Radiation.

In the literature, Bremsstrahlung (or braking radiation) is described as radiation due to the deceleration of a charged particle when it is deflected in the electric field of an atomic nucleus. And Cerenkov radiation is emitted when a charged particle (e.g., electron) passes through a dielectric medium at a speed greater than the phase velocity of light in that medium. (Wikipedia)

By these descriptions, physicists only tell us WHEN these radiations occur, not WHY they happen. They cannot elaborate the physical reasons that cause the electron to radiate because they view the electron as a point charged particle and thus they cannot figure out **why** it can emit radiation (photons).

Now if we view the electron as an extended particle with a structured configuration, composed of a core ( $-q_0$ ) surrounded by a cloud of electric dipoles ( $-q, +q$ ) (photons), then we can visualize the physical reason (the mechanism) for the radiation of the electron in external electric field.

**In Bremsstrahlung:** the electron is first decelerated in the (primary) electric field  $\mathbf{E}$ , thus it radiates by electric forces  $\mathbf{f}_e$  as shown in **Figure 5 & Figure 6** (regardless of its orbital motion). Secondly, since it moves through an inhomogeneous (non-uniform) electric field: this is equivalent to a time-varying electric field, hence it is also subject to a (secondary) induced magnetic field  $\mathbf{B}$  which creates radial forces  $\mathbf{f}_r$  that reinforce or restrained the radiation capability of the electron as shown in four **Figures 9-12**. In short, Bremsstrahlung is caused by the main electric forces  $\mathbf{f}_e$  which are reinforced (or restrained) by radial forces  $\mathbf{f}_r$ .

**In Cerenkov radiation:** the electron is forced to traverse a medium like water (or heavy water in a nuclear reactor): it glows a bluish light while accelerating or decelerating through the electric fields of atoms of the medium. Like in Bremsstrahlung, the main forces that cause the Cerenkov radiation is the electric forces  $\mathbf{f}_e$  which are reinforced (or restrained) by radial forces  $\mathbf{f}_r$  while the electron moves through the medium. Four **Figures 9-12** delineate four possible situations of the electron when it is accelerated or decelerated through the varying electric field of the medium.

##### Discussion 2: Emission & Absorption of photons.

In this discussion we will use mathematical expressions, which have been derived from the extended electron, to demonstrate two following statements (assertions) of the mainstream physics's theory of radiation:

- **when an electron emits (radiates) photons: it loses (kinetic) energy and slows down,** (13)
- **when an electron absorbs photons (by irradiation): it gains energy and**

**speeds up.** (14)

The reasoning will go through two steps:

1) First, we prove that the **emission and absorption** of photons of the electron are linked to the **physical factor “a”**, which represents the *physical structure of the extended electron*.

2) Next, we prove that this **factor “a”** has mathematical relation with the **velocity** of the electron. And as a result, we come to a full agreement with two statements (13) and (14).

First, let us recall the results we have obtained from calculations on the extended electron when it is subject to an external electric field  $\mathbf{E}$  [1]: Two electric forces  $\mathbf{F}$  and  $\mathbf{F}'$  are produced on the electron:

-  $\mathbf{F} = \sum \mathbf{f}_e = \left(\frac{1}{\varepsilon} - 1\right) q\mathbf{E} \sum_i^n \cos^2 \alpha_i$  is the resultant force of all forces  $\mathbf{f}_e$  developed on  $n$  surface dipoles of the electron;  $\varepsilon$  is the relative permittivity of the extended electron:  $\varepsilon < 1$

-  $\mathbf{F}' = -\frac{1}{\varepsilon} q_0 \mathbf{E}$  is the electric force developed on the core  $-q_0$  of the electron.

Hence, the net force developed on the electron is  $\mathbf{F}_e = \mathbf{F} + \mathbf{F}'$

$$\mathbf{F}_e = \left(\frac{1}{\varepsilon} - 1\right) q\mathbf{E} \sum_i^n \cos^2 \alpha_i - \frac{1}{\varepsilon} q_0 \mathbf{E}$$

by factoring, we get

$$\mathbf{F}_e = \left[ \left(\frac{1}{\varepsilon} - 1\right) (q/q_0) \sum_i^n \cos^2 \alpha_i - \frac{1}{\varepsilon} \right] q_0 \mathbf{E}$$

Let's set

$$a \equiv (q/q_0) \sum_i^n \cos^2 \alpha_i \tag{15}$$

we get

$$\mathbf{F}_e = \left(\frac{a-1}{\varepsilon} - a\right) q_0 \mathbf{E} \tag{16}$$

“ $a$ ” is a dimensionless positive number since  $q$ ,  $q_0$  and  $\sum_i^n \cos^2 \alpha_i$  are positive numbers; it represents the *physical structure of the extended electron* and depends on the number  $n$  of surface dipoles.

From Equation (15) we get the following relationship between **emission & absorption** and “ $a$ ”:

When the electron radiates, it loses its surface dipoles; *i.e.*,  $n$  decreases and hence “ $a$ ” decreases accordingly, because  $\sum_i^n \cos^2 \alpha_i$  is the sum of  $n$  positive terms  $\cos^2 \alpha_i$ . Therefore, “ $a$ ” **decreases in the emission of photons.** (17)

Conversely, when the electron absorbs photons, it gains more surface dipoles; *i.e.*,  $n$  increases and hence “ $a$ ” increases accordingly.

Therefore, “ $a$ ” **increases in the absorption of photons.** (18)

This is the first step of reasoning: we linked the physical factor “a” to the

**emission and absorption of photons of the electron.**

Now, in the second step we relate the factor “ $a$ ” to the velocity of the electron.

From Equation (16) we can deduce the effective electric charge  $Q$  of the electron (since  $F_e = QE$ ):

$$Q = \left( \frac{a-1}{\epsilon} - a \right) q_0 \quad \text{where } a > 1, \epsilon < 1 \tag{19}$$

Let us recall that in a previous article, entitled “**A fundamental problem in physics: Mass vs Electric charge**” [7] we have obtained the general expression for the effective electric charge of the electron when it is subject to an external field:

$$Q = -\left(1 - v^2/c^2\right)^{N/2} q_0 \tag{20}$$

where  $N \geq 0$  is a real number representing the applying field, and the minus sign on the right side indicates the negative charge  $Q$  of the electron.

From (19) and (20) we get

$$\frac{a-1}{\epsilon} - a = -\left(1 - v^2/c^2\right)^{N/2} \tag{21}$$

Now, let us extract  $(v^2/c^2)$  from Equation (21):

$$v^2/c^2 = 1 - \left[ a - (a-1)/\epsilon \right]^{2/N} \tag{22}$$

In the expression (22),  $v^2/c^2$  is a function of “ $a$ ” while  $\epsilon$  and  $N$  remain unchanged in the emission and absorption of photons.

**Note:** From the discussion in a previous article, we knew that  $\epsilon$  varies in a very narrow interval  $(1 - 1/a, 1)$ . Since “ $a$ ” is assumed to be a large number; so this interval becomes  $(1-, 1)$ , or  $\epsilon \approx 1 -$  (infinitesimally less than 1); so it is approximately constant. The real number  $N \geq 0$  represents the applying field, it is supposed to be constant. So, approximately speaking,  $\epsilon$  and  $N$  remain unchanged in the emission and absorption of photons.

Therefore, from Equation (22) we can take derivative of  $(v^2/c^2)$  with respect to “ $a$ ”, we get

$$d(v^2/c^2)/da = (2/N)(1/\epsilon - 1) \left[ a - (a-1)/\epsilon \right]^{(2/N)-1} \tag{23}$$

Since  $N > 0$ ,  $a > 1$  and  $\epsilon \approx 1 -$  we have

$$2/N > 0, \quad 1/\epsilon - 1 > 0 \quad \text{and} \quad \left[ a - (a-1)/\epsilon \right]^{(2/N)-1} > 0^2 \tag{24}$$

hence from Equation (23) we get

$$d(v^2/c^2)/da > 0 \tag{25}$$

<sup>2</sup>From Equation (16): since the electric force  $F_e$  is a negative force, (it points in the opposite direction to the electric field  $E$ ), the factor  $(\frac{a-1}{\epsilon} - a)$  is negative, and hence in (24)  $[a - (a-1)/\epsilon]$  is positive and  $[a - (a-1)/\epsilon]^{(2/N)-1} > 0$  for all values of the exponent  $(2/N) - 1$ .

Expression (25) allows us to conclude that  $(v^2/c^2)$  is **monotonic increasing with respect to the factor “ $a$ ”** which represents the physical structure of the extended electron.

This is the result of the second step of reasoning. Now by combining these two steps, we get:

- When the electron **emits photons**: “ $a$ ” decreases (first step), hence  $(v^2/c^2)$  also decreases (second step); that is, the electron slows down, or it loses its (kinetic) energy.
- When the electron **absorbs photons**: “ $a$ ” increases (first step), hence  $(v^2/c^2)$  increases as well (second step); that is, the electron speeds up, or it gains energy.

Therefore, by using expressions from (15) to (25), which belong to the extended electron, we can demonstrate two established statements (13) and (14) of the mainstream physics. This proves that the extended model of the electron is eligible for the explanation of the emission and absorption of photons of the electron.