A New Extended Model for the Electron

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Since the time when J.J. Thomson discovered the electrons as free particles (1897) , various models for the electron have been proposed .
Because the electron is experimentally too small (radius ≈ 10^{-20} cm) , many physicists considered it as a point particle , but many others thought of it as an extended particle . In order to be able to explain some properties or behaviors of the electron (e.g., the variability of its electric charge , its spin and radiation in external fields) , the electron should be thought of as an extended particle rather than a single point charge . This preliminary article introduces an extended model of the electron which will be used to investigate these properties of the electron . The investigation will be presented in a series of subsequent articles which will appear later .
Keywords : Screened electron , central core ($-q_0$) of the electron , static electric dipole (-q,+q) , attractive (cohesive) forces G , electric & magnetic boundary conditions.
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1. A brief history of the theory of the electron [1, 2, 3]

" Truth could be grasped in many ways ; in the robust imagery of a model or in the pale abstractions of mathematical equations , and neither was inferior to the other ."
James Clark Maxwell (1831-1879)

In 1902 **Abraham** proposed an extended model with charges uniformly distributed over the surface of a rigid sphere that maintained its shape in motion .
In 1904 **Bucherer** proposed his spherical model which , once set in motion , deformed to become an ellipsoid, but its volume remained unchanged .
In 1904 **Lorentz** proposed his model of electron as a uniform spherical surface charge . When it moved, its transverse dimensions remained unchanged, but its length in the direction of motion contracted and its mass increased with velocity as

$$m = m_0 \left(1- v^2/c^2 \right)^{-1/2} \tag{1}$$

All extended models of electron faced the problem of stability because the Coulomb's repulsive forces between the same charges on the surface of the electron would break it apart .
In 1906 **Poincaré** proposed a solution to the stability of the electron by postulating non-electromagnetic forces existing inside the electron that compensated Coulomb's repulsive forces , and thus kept the electron stable. Thereby, he introduced a spherically symmetric model with a flexible surface that was held together by a uniform mechanical pressure on its surface (called the Poincaré stress) .

To avoid the stability problem and the Poincaré stress , many physicists (**Dirac , Pearle, Rohrlich** …) turned to the *point electron* , despite its infinite self-energy . In 1938 , by modifying the equation of motion of the point electron of Lorentz , Dirac came to a relativistic equation which is now called the Lorentz-Dirac equation of the point electron

$$m\, \dot{v}^{\mu} = \mathbf{F}^{\mu}_{ext} + \mathbf{\Gamma}^{\mu} \tag{1a}$$

where m is the observed (or experimental) mass of the electron and $\mathbf{\Gamma}^{\mu}$ is the Abraham 4-vector of the radiation reaction .
This equation presents two unrealistic behaviors :

i / Runaway : the acceleration of the electron increases indefinitely with time , and even when there is no external field , the electron can exert a force on itself which accelerates it to infinite velocity .
ii / Pre-acceleration : the electron is accelerated before the external field is turned on .
So , this equation (1a) failed to represent a suitable model for the electron because it did not behave like a real electron .

Besides these "*robust*" * physical models , there were two "*pale*" * mathematical models for the electron : **Schrodinger**'s wave equation for non-relativistic electron (1925) and **Dirac**'s equation for relativistic quantum mechanics (1928) . Dirac's equation , in spite of its remarkable results in explaining energy levels in hydrogen atom , it could not reveal the splitting between two small energy levels of the hydrogen atom , called Lamb shift (1947). **Lamb** pointed out in his Nobel lecture (1955) that " *the electron does not behave like a point charge as implied in Dirac's equation "* .

Now, since all the models cited above are problematic , we look for another extended model which contains both charges (+ and -) in its volume . The idea comes from the configuration of the "**screened electron**" in the phenomenon of vacuum polarization . In this phenomenon , the electron's field polarizes the vacuum by producing virtual electron-positron pairs which surround the real electron .

The Fig.13.1 below is scanned from the text book **"Nuclear and Particle Physics"** by W.S.C. Williams , showing the screening effect on the electron that causes the effective electric charge . We notice from this figure and its caption that the effective charge was not calculated but estimated by conjecture . This is because the virtual pairs (e^- , e^+) emerge and disappear at undetermined times .

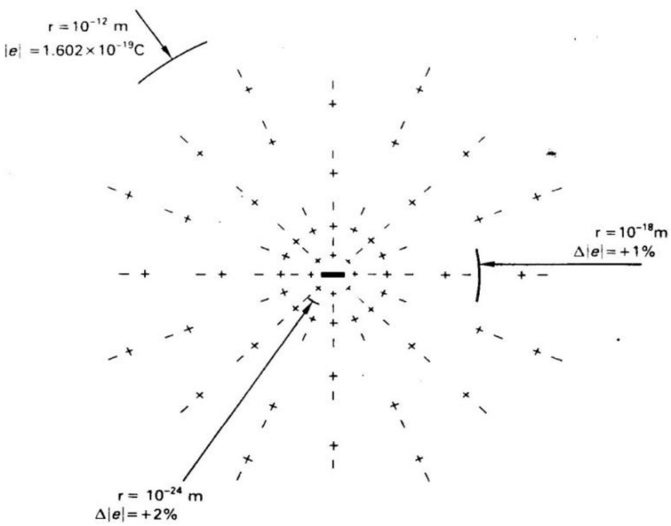

Fig.13 .1: (From " Nuclear and Particle Physics" by W.S.C. Williams)

Probing the charge on the electron at smaller and smaller distances. The bare electron charge polarises the vacuum by the production of virtual electron-positron pairs . The positron is , on the average , closer to the bare electron so that at any radius the sphere concentric with the electron encloses the bare electron charge plus a positive excess of polarization charge which screens the former . The effect is to reduce the field due to the electron from its value in the absence of polarization . As the distance of approach decreases the screening decreases and the apparent charge on the electron increases . The number on the figure are meant to show the slow rate of increase and are not correct in the sense that they have been estimated assuming , incorrectly , that only electron-positron pairs contribute to the screening .

We come to the idea that a point electron surrounded by a cloud of pairs of charges (+ , -) is equivalent to an extended electron which contains permanent pairs (+ , -) of electric charges .

From this image , I would like to introduce the following extended and structured model for the electron , which will be used to calculate the effective electric charge and also enable us to explore the mechanisms of spin and radiation of the electron in an external field .

* These two adjectives "robust" and "pale" are taken from the above quotation from Maxwell .

2. A proposed extended and structured model for the electron

The physical extended and structured model of the electron has a spherical composite structure consisting of a *central core* ($-q_0$) surrounded by an assembly of *static electric dipoles* (+q , -q) (Fig.4) .
The core is a point charge carrying an inherent negative charge ($-q_0$) which produces a radial electric field $\mathbf{E_0}$ around it as shown in Fig.1 .
Now let us assume that in the surrounding space there exist countless of these tiny static electric dipoles , each having the form of a needle , carrying on its ends two point charges +q and –q separated by a very short distance as shown by Fig.2 . We note that the magnitude of the charge q_0 of the core is different from q on the electric dipole : $q_0 \neq q$.
Because a great deal of these electric dipoles always exist in space , if they happen to fall into the non-uniform electric field $\mathbf{E_0}$ of a core , they will be attracted to the core as shown in Fig.3 since a non-uniform electric field pulls electric dipoles into the region of stronger field .
And thus , a great deal of these dipoles eventually gather around the core , orienting in the direction of the field $\mathbf{E_0}$ to form the outer part of the electron as shown in Fig.4. (This figure shows a sketch of a sector of the model electron which is assumed to be a spherical particle).

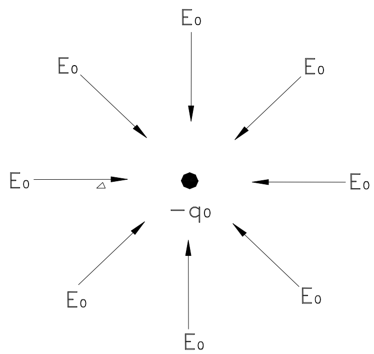

Fig.1 : The core ($-q_0$) of the electron and its radial electric field $\mathbf{E_0}$.

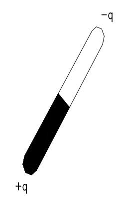

Fig.2 : A static electric dipole carries two point charges +q , -q on its two ends .

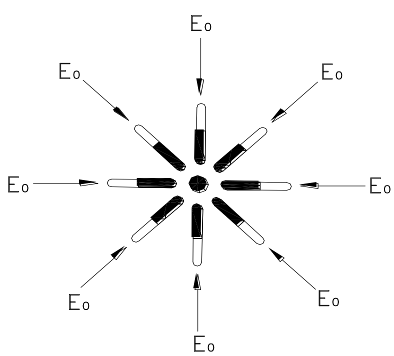

Fig.3 : The core and some electric dipoles attached to the core , orienting in the direction of $\mathbf{E_0}$.

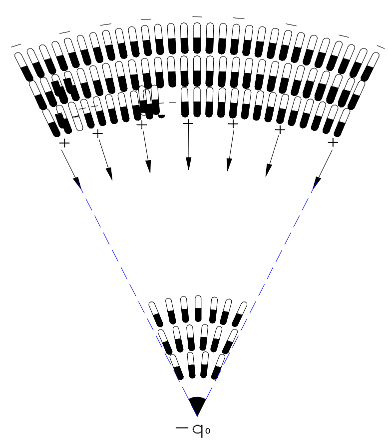

Fig.4 : This is a sector of the extended model of the electron . Countless electric dipoles (+q , -q) gather around the core ($-q_0$) . Cohesive forces **G** (represented by the arrows) attract all dipoles to the core , ensuring the electron's stability .

In Fig.4 the *attractive forces* **G's** represent the cohesive forces that keep all dipoles attracted to the core and stabilize the electron . All dipoles are aligned in the radial direction of the electric field $\mathbf{E_0}$. All negative ends (-q) of *surface dipoles* form the spherical surface of the electron .

Following are some attributes of the model electron which will be used in the calculations on the electron . Fig.5 shows an arbitrary surface dipole P with its two point charges –q and +q ; the negative charge (-q) lies on the surface of the electron ; the positive charge (+q) lies inside the electron.
Fig.6 shows the vector **E** (or **B**) drawn from the center O of the sphere to represent the *direction* of the external electric (or magnetic) field which exerts on the electron . In all situations , the external field **E** (or **B)** is always arranged to keep upward direction . If the external field is time-varying , only its intensity varies with time, but its direction is always kept upward . Two imaginary circles (c) and (c') drawn on the spherical surface of the electron will be used in the calculation of forces produced on the model electron .

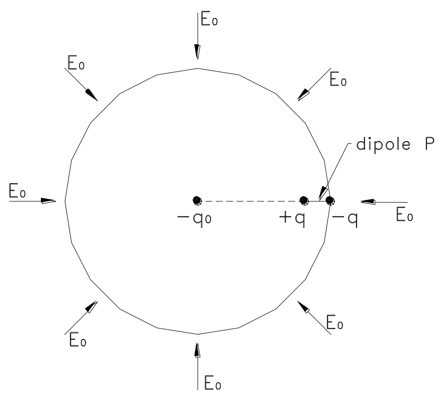

Fig.5 shows a surface dipole (P) :
its negative end (-q) lies on the surface of the electron ; its positive end (+q) lies inside the electron , just below the surface .

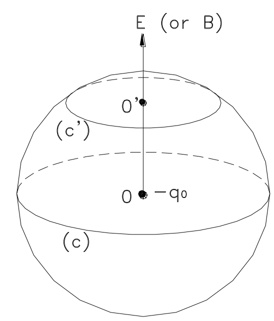

Fig.6 : The model electron is schematically drawn as a sphere ; the vector **E** (or **B**) represents the direction of the external field ; (c) and (c') are imaginary circles drawn on the surface of the electron , they will be used in the calculation of forces produced on the electron.

Three specific notes for this extended model :

i) Let's us notice the similarity between the structure of this extended model containing electric dipoles (Fig.4) and the structure of the **screened electron** containing virtual pairs (+, -) (Fig.13.1) .
The difference is that the outer part of the extended model electron consists of the electric dipoles (+q ,-q) which are **real components** , there is **no virtual components** in its structure . This extended electron is thus a **real particle** , consisting of a central core $(-q_0)$ surrounded by an assembly of electric dipoles (+q , -q) which the core collects from surrounding space to form its outer part . So , the extended model of the electron is a modification (a version) of the image of the screened electron such that calculations can be performed on it .

ii) The idea that " *a photon being a neutral particle , having the form of a needle carrying two opposite charges* (+ , -) *on its two ends* " (Fig.2) comes from the following observation in a book of physics (I forgot its title and author 's name) :
" *Due to the phenomenon of polarization of light , if photon is a particle , then it is not a tiny sphere, but a tiny needle*".

From this idea , the **static electric dipoles** (+q , -q) which constitute the extended model of the electron are assimilable to **photons** ; the electron collects them from the surrounding space to form its outer part around the core ($-q_0$) as schematically shown by Fig.4 .

iii) The **wave nature** of the electron and photon is **not** considered in this article . The extended model of electron and its electric dipoles (i.e., photons) are treated as **real particles .** The wave concepts of the quantum mechanics will not be used in this article and subsequent ones .
Feynman strongly confirmed in his Lectures of Physics that : *" I want to emphasize that light comes in this form – particles . It is very important to know that light behaves like particles , especially for those of you who have gone to school , where you were probably told something about light behaving like waves . I'm telling you the way it does behave – like particles . "* (Optics , E . Hecht , p.138)

3. Assumptions for calculations

Now we already have a model for the electron and we want to investigate its properties when it interacts with an external field . As all other theories, some assumptions are needed to help perform calculations . In this article, to determine electric or magnetic forces produced on the model electron , we will have to accept the following assumptions : **the electric and magnetic boundary conditions will be applicable to the spherical surface of the model electron which is considered as the boundary between the dielectric material of the electron and the surrounding free space** .
The application of these assumptions implies that the material of the extended electron is assumed to be linear , homogeneous and isotropic with respect to the external field .
These assumptions will allow us to calculate electric and magnetic forces produced on the electron and hence help investigating the interactions of the model electron with an external field .
These assumptions will be justified in subsequent articles .

3.1 Boundary conditions for electric field E [4]

Let **E** and **E'** be the electric fields on two sides of the boundary (interface) which is the spherical surface of the electron (Fig.7) :

$$\mathbf{E} = \mathbf{E}_n + \mathbf{E}_t \qquad (2)$$

$$\mathbf{E'} = \mathbf{E'}_n + \mathbf{E'}_t \qquad (3)$$

Boundary conditions for the electric field state that

$\mathbf{E'}_t = \mathbf{E}_t$: the tangential component $\mathbf{E}_t$ is continuous (i.e., $\mathbf{E}_t$ undergoes no change on the boundary) , (4)

$\mathbf{E'}_n = \dfrac{1}{\varepsilon}\mathbf{E}_n$: the normal component $\mathbf{E}_n$ is discontinuous on the boundary . (5)

And hence , Eq.(3) can be rewritten as $\mathbf{E'} = \dfrac{1}{\varepsilon}\mathbf{E}_n + \mathbf{E}_t$ (6)

where ε is *the relative permittivity* of the extended electron to free space (ε_0) ; i.e., $\varepsilon = \varepsilon'/\varepsilon_0$

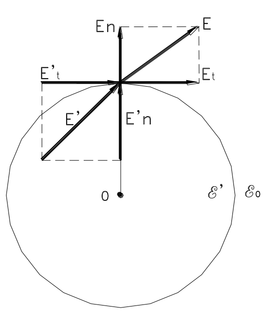

Fig. 7 : The spherical surface of the electron is the boundary (or the interface) between two media ε_0 and ε'.

Therefore , Eq.(6) allows us to determine the electric field **E'** inside the electron by two components $\mathbf{E_n}$ and $\mathbf{E_t}$ of the electric field **E** on the surface of the electron (which is known) .

3.2 Boundary conditions for magnetic field B [4]

Let **B** and **B'** be the magnetic fields on two sides of the boundary of the electron (Fig.8) :

$$\mathbf{B} = \mathbf{B_n} + \mathbf{B_t} \tag{7}$$

$$\mathbf{B'} = \mathbf{B'_n} + \mathbf{B'_t} \tag{8}$$

Boundary conditions for the magnetic field state that

$\mathbf{B'_n} = \mathbf{B_n}$: that is, the normal component $\mathbf{B_n}$ is continuous on the boundary , (9)

$\mathbf{B'_t} = \mu\, \mathbf{B_t}$: that is, the tangential component $\mathbf{B_t}$ is discontinuous on the boundary (10)

where μ is *the relative permeability* of the electron to free space (μ_0) ; i.e., $\mu = \mu' / \mu_0$.

And hence , Eq.(8) can be rewritten as $\mathbf{B'} = \mathbf{B_n} + \mu\, \mathbf{B_t}$ (11)

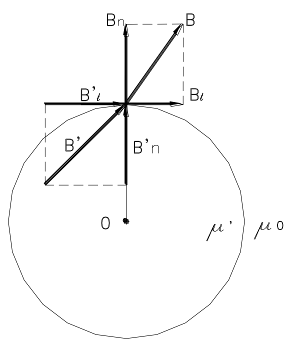

Fig. 8 : The spherical surface of the electron is the boundary between two media μ_0 and μ'.

Therefore , Eq. (11) allows us to determine the magnetic field **B'** inside the electron by two components $\mathbf{B_n}$ and $\mathbf{B_t}$ of the magnetic field **B** on the surface of the electron (which is known) .

3.3 Some remarks on the determination of electric and magnetic forces produced on the model electron .

i) When applying the boundary conditions we consider the electron in free space . And hence, in the above equations of boundary conditions we have substituted the absolute permittivity ε' and permeability μ' of the electron by ($\varepsilon_0\, \varepsilon$) and ($\mu_0\, \mu$) respectively , where ε and μ are the relative permittivity and permeability of the electron . Therefore , only ε or μ remains in the calculations .

ii) The boundary conditions remain valid for ***time-varying*** electric and magnetic fields [4]

iii) When the electron is subject to a time-varying field (e.g., a time-varying electric field **E**) it is actually subject to two fields at the same time : the applying electric field **E** and the induced magnetic field **B** . In this case ***the principle of superposition of fields*** allows us to determine the action of each field separately.

iv) We should note that the *self- field* $\mathbf{E_0}$ of the electron generates the *cohesive forces* **G's** which always exist inside the electron to represent the self -field $\mathbf{E_0}$. And hence **,** in the determination of forces produced on the electron by the external field , there is no need to consider again the action of the self -field $\mathbf{E_0}$. All cohesive forces **G's** are centripetal ; they cancel out , and thus they have no effect on the orbital and rotational motion of the electron in the external field . But as we will see later , they are an influential factor in shaping the *radiation pattern* when the electron radiates .

4. Calculation of the cohesive forces G's (Fig.9)

Now let's begin applying the boundary conditions to determine the electric forces produced on the electron. Let's consider an extended electron <u>in free space</u> (where there is no external field). Its self- field $\mathbf{E_0}$ is radial ; i.e., $\mathbf{E_0}$ is normal to its spherical surface .

At the surface we have :
$$\mathbf{E_0} = \mathbf{E_0^n} + \mathbf{E_0^t} \qquad (12)$$

Boundary conditions [Eq.(6)] give
$$\mathbf{E_0}' = \frac{1}{\varepsilon}\,\mathbf{E_0^n} + \mathbf{E_0^t} \qquad (13)$$

where $\mathbf{E_0}'$ is the self- field inside the electron ; $\mathbf{E_0^n}$ and $\mathbf{E_0^t}$ are normal and tangential components of $\mathbf{E_0}$ **;** and ε is the relative permittivity of the electron : $\varepsilon = \varepsilon' / \varepsilon_0$.
Since $\mathbf{E_0}$ is normal to the surface of the electron , $\mathbf{E_0^t} = 0$; hence , Eqs.(12) and (13) become :

$$\mathbf{E_0} = \mathbf{E_0^n} \qquad (14)$$
$$\mathbf{E_0}' = \frac{1}{\varepsilon}\,\mathbf{E_0^n} = \frac{1}{\varepsilon}\,\mathbf{E_0} \qquad (15)$$

Hence $\mathbf{E_0}'$ is parallel to $\mathbf{E_0}$ and its magnitude depends on the value of ε .

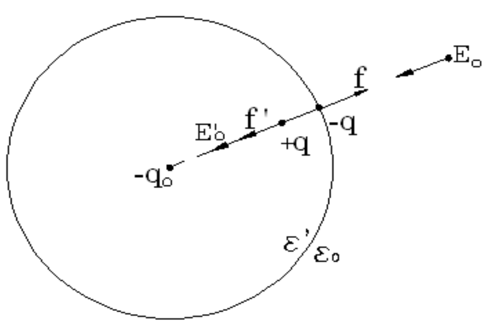

Fig. 9 : $-q_0$: the negative core of the electron ; $(+q - q)$: an arbitrary surface dipole ;
$\mathbf{E_0}$: self- field of the electron ; $\mathbf{E_0}'$: self- field inside the electron ;
f : electric force produced by $\mathbf{E_0}$ on the charge $-q$, **f** is centrifugal ;
f': electric force produced by $\mathbf{E_0}'$ on the charge $+q$, **f'** is centripetal**.**

And thus the field $\mathbf{E_0}'$ inside the electron is radial (like $\mathbf{E_0}$ on the surface of the electron) .
Since $\mathbf{E_0}'$ is radial , the resultant field at the central core ($-q_0$) is zero .

(If the field at the core were different from zero, it would produce a force on the core ($-q_0$) and accelerate the electron in free space . But actually, in free space , the electron is not accelerated , it travels in a uniform and rectilinear motion) .

Now let's calculate the electric forces **f** and **f '** which are produced on a surface dipole (-q , +q) as shown in Fig.9 . (The same calculations are applied to all other surface dipoles on the surface of the electron) .
The field $\mathbf{E_0}$ produces the force **f** on the external end –q of the dipole : $\mathbf{f} = -q\,\mathbf{E_0}$ (**f** is centrifugal)
The field $\mathbf{E_0}$**'** produces the force **f '** on the internal end + q of the dipole : $\mathbf{f'} = q\,\mathbf{E_0'} = \frac{1}{\varepsilon}\,q\,\mathbf{E_0}$ (**f '** is centripetal)

The resultant force is $\mathbf{G} = \mathbf{f} + \mathbf{f'} = [(1/\varepsilon) - 1]\,q\,\mathbf{E_0}$ (16)

The direction of **G** thus depends on the value of ε :

- if $\varepsilon < 1$: $(1/\varepsilon) - 1 > 0$, **G** is attractive (centripetal) force (same direction as $\mathbf{E_0}$) : the surface dipole is attracted to the core : the extended electron is stable .
- if $\varepsilon > 1$: $(1/\varepsilon) - 1 < 0$, **G** is repulsive (centrifugal) force (in opposite direction to $\mathbf{E_0}$) : the surface dipole is repulsive : the extended electron is unstable .
- if $\varepsilon = 1$: $\mathbf{G} = 0$ **:** the attractive force is equal to the repulsive force on the surface dipole : this is the case of the *point electron* , it has no dipoles at all around its core .

Since the electron is assumed to be stable in free space , **G's** must be **attractive** (**cohesive) forces** which attract all surface dipoles toward the core . Since the relative dielectric $\varepsilon = \varepsilon' / \varepsilon_0$, $\varepsilon < 1$ means $\varepsilon' < \varepsilon_0$, that is , the absolute permittivity ε' of the extended electron is less than ε_0 of the free space .
Also , since $\varepsilon < 1$, Eq.(15) gives $\mathbf{E_0'} > \mathbf{E_0}$ **.**
The result $\boldsymbol{\varepsilon < 1}$ for the extended electron will be justified in the next article .

Therefore , the self - field $\mathbf{E_0}$ of the electron produces cohesive forces **G's** which always exist inside the electron to secure the stability of the electron . We will no longer consider the action of the self - field $\mathbf{E_0}$ on the electron when we investigate the actions of an external field on the electron .

<u>Special note</u> : we should note that all ordinary materials like air , wood , quartz , mica , glass , paper , water ... all have relative permittivity ε (also called dielectric constant ε) greater than unity $(\boldsymbol{\varepsilon > 1})$:
(air : $\varepsilon = 1$; wood : 2.5 - 8.0 ; quartz : 5 ; mica : 6 ; glass : 5 - 10 ; paper : 7 ; distilled water : 81) [4]
For the material of the extended electron we came to $\boldsymbol{\varepsilon < 1}$, this is because it composes solely of electric dipoles ; while those ordinary materials compose of atoms and molecules .

5. Conclusion

In May 2011 a team of physicists at the Imperial College London (UK) reported in Nature magazine their experiment to measure the **electric dipole moment** of the electron [5, 6]. If their research confirms the existence of the electric dipole moment for the electron , their finding would provide an evidence that the *electron is an extended particle , containing both types of charges (+ and -)* , because a point electron with only negative charge cannot have an electric dipole moment .

So , the model of the electron should be an extended one . But whatever shape it may have , either a sphere or a cube , a pyramid or even a string (?) … , it is only a creation of the human mind to explain one or some (but not all) observed properties of the real electron . Since we absolutely have no hope of obtaining a perfect model which can explain everything , we should be content with a simple model which , despite its shortcomings, enables us to *explain an existing property* of the real electron and at the same time it can *provide new predictions* which are experimentally testable .

This proposed extended model , like other models which had been proposed so far , can not avoid drawbacks in the configuration and nature of its structure . The same situation had happened to two well-known models of modern physics : the Bohr's model of atom and the Standard Model of particle physics . Despite their imperfections in many situations , these two models did provide impressive insights into the physical world and made important advancement in the history of physics .
From this idea , I hope the readers will focus their assessment on the **explanatory capacity** of this extended model rather than on the unavoidable shortcomings of its structure , since *it is only a heuristic model , serving to explore some properties of the electron* ; it is not intended to reveal the structure or the nature of the real electron .

Using this proposed extended and structured model , we will be able to calculate **the effective electric charge** of the electron and demonstrate **its mechanisms of spin and radiation** in an external electric or magnetic field .
These topics will be presented in the coming articles .

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