A Framework for an Electromagnetic Field Theory approach to Atomic Orbitals and Energy Transitions

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Abstract- Texts on Quantum Mechanics all cover the electron's magnetic dipole, or spin. However, texts on Electromagnetic Field Theory never mention it, and electromagnetic machines such as electron microscopes are designed without any reference to a magnetic dipole. No experiment has ever shown the presence of a permanent magnetic dipole in free electrons. All we have is Pauli's assertion that blurring masks the experimental results. This paper, based on Field Theory, considers the alternative possibility, that free electrons have an induced rather than a permanent magnetic dipole, and demonstrates that the consequences of that alternative approach are to create a framework for an electromagnetic model of atomic behavior. This is a framework only. It identifies three separate pieces of work needed to create the full working model.

Keywords- *Magnetic Dipole, Electron Orbitals, Paramagnetic Resonance, Field Theory*

I. INTRODUCTION

The Stern-Gerlach demonstrates that a beam of silver atoms, when passed through a non-homogenous magnetic field, will split in two [1]. Silver atoms contain a permanent magnetic dipole and in passing through the magnetic fields some of the atomic dipoles will align with the field. This is the lowest-energy orientation and some must orient themselves in opposition (the highest energy orientation) to maintain the Conservation of Energy. The interesting fact is that only these two orientations appear.

Although this twinning of the beam is seen in many experiments, J. Van Huele and J. Stenson state that "Spin is a non-classical duplicity useful for classifying atomic states but not observable with free electrons" (a few textbooks do erroneously claim that this twinning can be observed with free electrons) [2]. This lack of experimental proof for free electrons led to Pauli's assertion that the interaction of the charge with the magnetic field causes an incompressible blurring of the trajectories from Lorentz forces, at least as great as the separation between the spin components.

However, modern technology can control a beam of electrons very precisely using electromagnetic focusing and scanning. This occurs in Cathode Ray Tube televisions and Scanning Electron Microscopes. The electron beam travels through these cycling fields at speed, adding induced fields to the mix. There are significant non-homogeneities in these fields, not only across the lenses but also in the scanning mechanism, yet a beam can be focused to a probe spot of nanometer size with no evidence of twinning or blurring beyond that generated by the electromagnetic lens' aberrations and diffraction. The Scanning Electron Microscope might be viewed as a variant of the Stern-Gerlach apparatus applied to electrons, and the controllability of the focus of the electron beam in these machines might appear to refute Pauli's assertion that blurring masks twinning of the electron beam.

If an electron does not have a permanent (or intrinsic) magnetic dipole, it must still have a dipole in certain situations, such as for Paramagnetic Resonance. Hence if it does not have a permanent dipole, it must then be able to enter a state where it has an induced dipole. In the scanning and focusing beams of a Scanning Electron Microscope an induced electron dipole would then charge and discharge in response to the local field fluctuations, and all electrons would behave identically. On the other hand, a permanent electron dipole, as mentioned above, will have a fixed dipole that randomly moves to either the stable aligned state or the metastable opposition state as it passes through the fluctuating fields, causing twinning of the electron beam and affecting the focusing ability of the that beam.

Electromagnetic Field Theory does not make any design consideration for a permanent electron dipole and it is rare to find any reference to one in a textbook on Field Theory, whilst it is important in Quantum Mechanics. This paper takes a Field Theory approach and considers what might result from the free electron's dipole being modelled as induced rather than permanent.

II. What can induce a dipole in a free electron?

If the electric field of an electron rotates it creates a dipole. Refer to Fig. 1. Here the center of the electron is shown as 'e' and its electric field lines are shown dashed. The electric fields of the electron are shown rotating with a velocity vector 'v' at the analysis points. The motion of the electric fields induces a magnetic field 'B' that points downwards in this example. It is clear that a rotating electron induces a magnetic dipole.

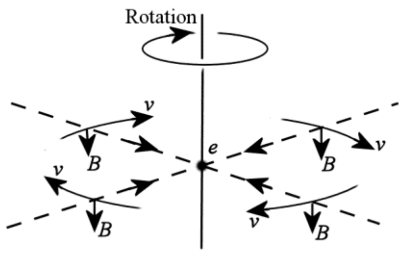

Figure 1. A rotating electron creates a magnetic dipole

The next question is, what might cause the electron's fields to rotate, since this rotation is required to induce the dipole? Consider what happens when an electron enters an electric field aligned transversely across (i.e. normal to) its path, as shown in Fig. 2.

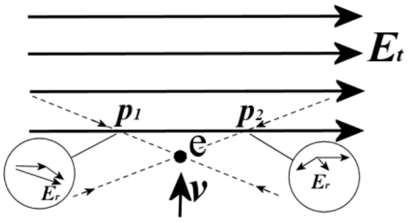

Figure 2. Electron entering a transverse electric field.

Such a situation will occur when the electron is entering a magnet – the induced electric field will be normal to its path and to the magnetic field. It also happens progressively as an electron spirals into an atomic orbit. For this analysis we ignore the transverse forces on the electron. In Fig. 2 the electron 'e' is moving at velocity '$\boldsymbol{v}$' up the page into a transverse electric field $\mathbf{E_t}$. The boundary of the transverse field is the lowest transverse vector drawn. Insets at p_1 and p_2 show the resultant field at these points as the electron's field moves into the transverse field.

At p_1 the transverse electric field $\mathbf{E_t}$ and the electron's field $\mathbf{E_e}$ interact to give the energy density dW/(dx dy dz)

$$\frac{dW}{dx\,dy\,dz} = \frac{\varepsilon(|E_t + E_e|)^2}{2}$$

$$= \frac{\varepsilon E_t \bullet E_t}{2} + \varepsilon E_t \bullet E_e + \frac{\varepsilon E_e \bullet E_e}{2}$$

The first term is the transverse electric field's energy density, and the third term is the electron's electric field energy density, whilst the second term is the energy density of the interaction when the electron's field is inside the transverse field – the potential energy density. If this second term is positive the energy density rises as the electron's field moves into the transverse field and repulsive forces arise. If it is negative the energy density falls and there are attractive forces. At point p_1 in Fig. 2 the electric fields lie in similar directions and the energy density rises leading to repulsive forces on the left of the electron. At point p_2 the fields tend to oppose and cancel each other out reducing the energy density and leading to attractive forces on the right of the electron. This combination of forces causes the electron's field to rotate anticlockwise in Fig. 2 as it enters the transverse field but as there is no net change in energy, the kinetic energy of the electron drops as the rotational energy increases.

The electron's electric field is now rotating, generating a magnetic dipole which contains energy. On exiting the far end of the transverse electric field, the rotation will be reversed to zero and the original kinetic energy will be restored. If, however, the rotational energy is discharged inside the transverse field then on exiting that field a reverse rotation will be created that extracts yet more energy from the kinetic energy, reducing the velocity a second time rather than restoring the electron's original velocity.

Where the transverse field comes form the positive nucleus of an atom, the electron's rotation is prograde to its orbit.

III. Atomic orbitals

When an electron enters an atom, and starts spiraling in towards the nucleus, it picks up rotational energy from the transverse field it encounters, as described in Section II. Both the rotational energy and the orbital kinetic energy are provided by the potential energy of the electron falling towards the nucleus. So how much energy goes into kinetic energy, and how much into rotational energy? The formal equations for this part of the framework need to be developed, but the experimental evidence is very clear.

The electron is known to wander freely in and out from the atomic nucleus, implying that the kinetic energy is sufficient at all orbits to maintain a stable orbit. The orbit is stable when the electrostatic force between the electron charge q_e and the nuclear charge q_n is exactly matched by the centripetal force on the electron mass m, from its orbital motion. So

$$F = \frac{mv^2}{r} = \frac{q_e q_n}{4\pi\varepsilon r^2}$$

$$mv^2 = \frac{q_e q_n}{4\pi\varepsilon r}$$

Now the total potential energy between an electron charge q_e and the neutron charge q_n, U at an orbital radius 'r' is

$$U = \frac{q_e q_n}{4\pi\varepsilon r}$$

As can be seen, the orbit is stable when the kinetic energy $mv^2/2$ of the orbit is equal to half the potential energy

$$\frac{mv^2}{2} = \frac{\left(\frac{q_e q_n}{4\pi\varepsilon r}\right)}{2}$$

The other half goes into rotational energy. Since only half of the potential energy is consumed by orbital kinetic energy, the electron is stable at all orbits, so is free to wander in and out from orbit to orbit. As it wanders in towards the nucleus, it picks up rotation and its magnetic dipole becomes stronger and creates stronger magnetic effects. It loses its rotation again as it wanders out, returning the energies of rotation and of kinetics back to potential energy.

IV. Radiation from Accelerating Charges

It is important to realize that electron atomic orbitals never lose energy from centripetal acceleration, and in fact no accelerating charges radiate electromagnetic energy in an energy-conserving universe.

We can summarize all such theories by the following generic "thought experiments". Let us analyze a simple case. An electron is accelerated by some arbitrary means out of an Observer's rest frame. In being accelerated it purportedly radiates energy. This is more easily grasped if, after we accelerate the electron for a while, we decelerate it back into the Observer's rest frame as shown in Fig. 3. The acceleration and deceleration speeds are assumed constant, and equal but opposite in the electron's frame of reference. The velocity with respect to the Observer, and the acceleration, are show graphically.

The electron starts from rest in the Observer's reference frame at point 'a', on the left of Fig. 3. It accelerates to the right, coast for a period, and then decelerates back to rest in the Observer's rest frame on the right at point 'b'. The electron perceives acceleration, then nothing as it coasts, then an identical acceleration but in the opposite direction. The electron, in its local frame of reference, cannot perceive deceleration any differently to acceleration. Hence in both periods of electron acceleration it must behave identically, putatively emitting electromagnetic radiation. Any reactive forces arising from this radiation are mirrored, so if they were to the left (say) in the acceleration they are to the right in the deceleration. From the symmetry in Fig. 3 it is clear that whatever forces were required during acceleration must be returned in full during deceleration. Since the energy associated with these forces is $W = \int \mathbf{F}\, d\mathbf{L}$, where W is the work done, F is the force, and L is the acceleration distance, it follows that any energy expended in accelerating the electron to radiate this energy must be returned to the Observer's rest frame during deceleration, and there is therefore no net expenditure of energy to provide the acceleration and deceleration forces. However, two photon bursts have also been emitted so there is a net increase in the total energy of the system, by the sum of the energies in these two bursts. Hence the Principle of Conservation of Energy is violated. It follows that accelerating electrons do not radiate.

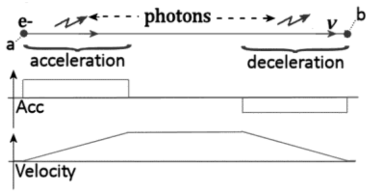

Figure 3. And electron accelerated from rest then brought back to rest.

If we consider the cyclotron in the light of this model, there is radiation from electrons following a curved path through a magnetic field. However, it cannot be the acceleration that induces the radiation, but a discharge of rotational energy. As the total electron velocity around the cyclotron increases, the induced electric field in the magnet increases in proportion, creating incremental rotation of the electron. When the electron enters the steering magnet, the induced transverse electric field causes it to pick up rotation and – from the Principle of Conservation of Energy – lose kinetic energy. This rotation is converted to radiant energy, just as in an atomic orbital energy discharge. On exiting the magnetic field, the lost rotational energy means that the original kinetic energy cannot be restored. We can therefore think of cyclotronic radiation as atomic-style energy transitions which we would experience between the far outer shells of atoms with ultra-massive atomic numbers.

Because accelerating charges do not radiate as a result of that acceleration, electromagnetic models of atomic orbitals are perfectly stable and do not have the electron taking a decaying path into the nucleus.

V. Atomic Energy Transitions

At certain very specific combinations of orbit radius and velocity, the electron's rotation can be discharged by precession of its induced dipole. The mechanism is not clear but appears related to the effect seen in the Power Ball Gyroscope Wrist Exerciser, where a forced procession on one axis can be used to spin up a gyroscope spin axis. Essentially, that gyroscope operates with two simultaneous spin axes. This defines the second equation that will be needed to fill in this framework.

The discharge is complete, leaving no rotational energy, and it traps the electron. It cannot wander further out from the nucleus because the rotational energy is lost and cannot be returned to potential energy. Its magnetic dipole is lost. The electron can however continue to wander in and then back out within that limiting radius, picking up speed and rotation as it wanders in toward the nucleus and rebuilding its magnetic dipole, but not to the same strength as it would have been had it not discharged rotational energy.

The electron can, at these same very specific orbits, absorb energy from an electromagnetic wave to restore its rotational energy, allowing it to wander out from the atomic nucleus once again.

VI. PARAMAGNETIC RESONANCE

The magnetic dipole moment μ_e is proportional to the product of the electron's rate of rotation ω and the magnitude of its electric field strength E_e.

$$\mu_e = k_1 \omega |E_e|$$

Moving electric fields also have momentum proportional to the square of their field strength, and the rotation gives the fields angular momentum α that is proportional to the square of the field strength times the rate of rotation.

$$\alpha = k_2 \omega |E_e|^2$$

The rate of precession ρ of the rotating fields in an external magnetic field **B** is then the product of **B** times the magnetic dipole moment, divided by the angular momentum.

$$\rho = \frac{\boldsymbol{B}\mu_e}{\alpha}$$

$$= \frac{k_1}{k_2} \frac{B\omega|E_e|}{\omega|E_e|^2}$$

$$= \frac{k_1}{k_2} \frac{B}{|E_e|}$$

The precession frequency is therefore proportional to $\mathbf{B}/q_e$, where q_e is the unit charge on the electron. It is independent of the actual rate of rotation of the electron's fields.

The full formal derivation of this equation is the third part of this framework. In do so, it is important to realize that if the electron rotated as a solid object it would have infinite angular momentum, preventing it rotating at all. In fact, in this model the electron must rotate, but each and all radii of the charged particle's electric field must be free to rotate independently of other radii. There is no energy cost in such a slip-style rotation.

We can use the above formula to determine the unit charge of the neutron. The electron has a unit charge of q_e=1.602x10^{-19} coulombs and precesses at 2.8025x10^{10} Hz in a one Tesla field, so the unit charge of a neutron q_n, precessing at 1.91667x10^7 Hz in the same magnetic field, is...

$$q_n = q_e \frac{2.8025x10^{10}}{1.91667x10^7}$$

$$= 2.3424x10^{-16} \text{ coulombs}$$

This is nearly three orders stronger than the electron's field, leading to neutron-neutron forces that are nearly six orders stronger than they would be if the neutron's unit charge were that of the electron.

The calculation for the proton shows it has a similar strong field at its heart. The proton precesses at 4.25781 x10^7 Hertz in a one Tesla field giving a proton unit charge q_p of

$$q_p = q_e \frac{2.8025x10^{10}}{4.25781x10^7}$$

$$= 1.0544x10^{-16} \text{ coulombs}$$

This reinforces a model where the proton has a strong core field at its heart surrounded by a lower positron-strength field [3]. However, this in turn requires that a proton has a separate resonance for each part of its field, one for the core as described above, and another for its positron-like field, which will be at the same frequency as the electron. This latter resonance has not been reported, so either it does not exist (invalidating this model), or no-one is looking for it, or it is too difficult to devise an experiment which eliminates electron resonances when measuring proton resonances for this to be determined.

VII. CONCLUSION

An intrinsic electron dipole is never mentioned in Electromagnetic Field Theory. Although it is perhaps contentious in Quantum Mechanics to suggest that the electron's dipole is not intrinsic, the fact that modern technology can get by with ignoring its existence makes it interesting to at least consider this approach within Electromagnetic Field Theory. This paper has attempted to do just that and the fact that it permits in turn a calculation of the field strength of the neutron, and an explanation of atomic orbital behavior, warrants at least a consideration of the approach. It may of course be that this approach works only for Field Theory models of electron behavior, but in that case the approach can still be used to develop yet more detailed Field Theory models of electron behavior both inside and outside the atom.

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