The Free Electron's Magnetic Dipole

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Date: 1st May 2017
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Abstract

To quote J. Van Huele and J. Stenson, in their paper "Stern-Gerlach experiments: past, present, and future" (J. Utah Academy of Sciences, Arts & Letters, 2004, 81, 206-212) "Spin is a non-classical duplicity useful for classifying atomic states but not observable with free electrons". So why is it not observable? Pauli claimed that the interaction of the charged particle with the magnetic field causes an incompressible blurring of the trajectories at least as great as the separation between the spin components. However, free electrons twist and turn in the focussing and directing electromagnetic fields of electron microscopes to give precise focussing to a single dot of less than 22nm.With modern technology Pauli's claim seems difficult to justify. This paper follows the evidence that spin does not exist in free electrons and considers the consequences that alternative decision. Some further theoretical work is required, but it nevertheless demonstrates that the approach ultimately takes us to a precise value for the neutron's electric field strength and to the beginnings of an understanding of atomic orbitals and transitions.

The electron's magnetic dipole

A departure from historical theory

In the Quantum Mechanics' model of the world the electron has an intrinsic magnetic dipole – a permanent magnetic field – which is termed "spin". This model does not work for Electromagnetic Field Theory, so before we look at the electromagnetic model in more detail, let us consider the experimental evidence to see what *does* fit.

An experiment was performed in Frankfurt, Germany in 1922 by Otto Stern and Walther Gerlach. The Stern-Gerlach apparatus splits a beam of electrically-neutral silver atoms in two as shown in Figure 1. There is a strong magnetic field gradient between the poles, with the field strength nearer the S pole in Figure 1 being lower than the field strength near the N pole.

The beam of silver atoms is emitted from the source and travels through a magnet whose field has a high magnetic field gradient.

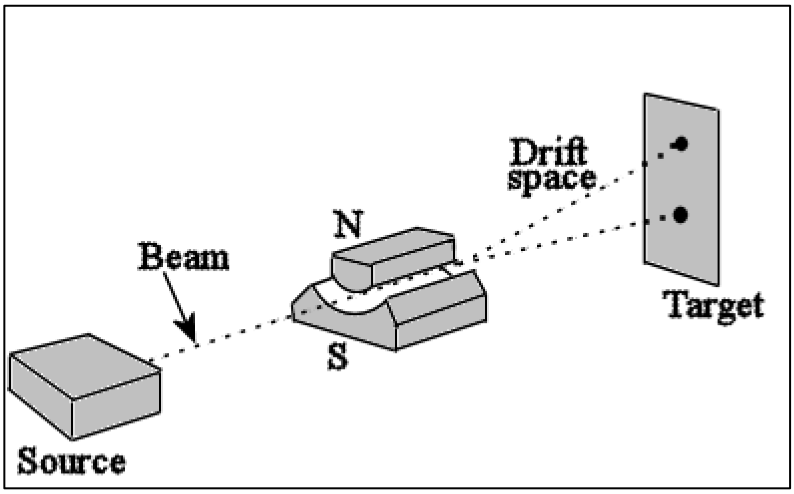

Figure 1

This splits the single input beam into two output beams. Silver atoms have a permanent magnetic dipole because there is an electron stuck in an electromagnetic trap within the atom. This dipole can take up two orientations in this experiment – some atoms orient themselves in the stable state, aligned with the magnet's field in the lower-energy configuration, and hence in an energy-conserving universe others must align themselves in the metastable state in opposition to the magnetic field in a higher-energy configuration. This leads to the splitting of the beam into two in the gradient of the applied field.

Is the Stern-Gerlach experimental result for free electrons in fact correct?

Unlike silver atoms, free-electron beams have *never* been observed to split into two in this or any other experiment. J. Van Huele and J. Stenson, in their paper "Stern-Gerlach experiments: past, present, and future" (J. Utah Academy of Sciences, Arts & Letters, 2004, 81, 206-212) stated that "Spin is a non-classical duplicity useful for classifying atomic states but not observable with free electrons". *(A few textbooks erroneously give diagrams of the Stern-Gerlach experiment using free electrons rather than silver atoms, claiming that the path of the electrons can be prevented from curving in the magnetic field by a transverse electric field*). This inability to observe the electron's intrinsic dipole in free electrons caused a serious problem to Quantum Mechanics in the 1920s, and in 1932 Pauli came up with an explanation, saying that the interaction of the charge with the magnetic field causes an incompressible blurring of the trajectories at least as great as the separation between the spin components. Essentially saying, the evidence says otherwise but we believe quantum spin to be true and we will therefore take the experiment to be imprecise.

However, electrons are moved with great precision using strong electric and magnetic field gradients for focussing and directing electron beams. The Scanning Electron Microscope and its variants direct electron beams with great precision with no hint of splitting or blurring. Electron beam lithography directs electrons to accuracies of 22 nanometres and better. Even an old-fashioned Cathode Ray Tube Television manages to give a clear picture on the screen despite the field gradients involved in focussing and scanning the beam. To these very tight limits, electrons follow identical trajectories through the electric and magnetic field gradients. Pauli's speculative "blurring" seems incompatible with these results. So what happens if we instead accept that the experiment is telling the truth – that free electrons have no magnetic dipole? What then?

The physical world appears to be telling us that the free-electron dipole does not exist, therefore the electron dipole, when it exists, must be induced. This leads directly to the concept that in the Electromagnetic Field model of the world, the electron's magnetic dipole is extrinsic, or induced, as the experiment appears to be telling us. So let us summarise the behavioural differences between intrinsic dipoles and extrinsic (or *induced*) dipoles...

- A ***permanent*** dipole in a magnetic field will try and orient itself either in alignment with (the "stable" state) *or* in opposition to (the "metastable" state) the magnetic field. However, a permanent dipole releases energy when it turns into alignment as this is the lowest-energy configuration. By the Principle of Conservation of Energy other permanent dipoles must therefore move the metastable state of opposition to the field, which is the highest-energy configuration, so that there is no net global change in energy. This is what happens with a silver atom, which has an electron is trapped in a magnetic state.
- An ***induced*** dipole in a magnetic field will track the local fields it travels through them, every electron responding identically with the same induced rotation, so **-** as suggested by the experimental data **-** there is a single deterministic path for all electrons.

In the Field Theory model, an electron rotates to generate a magnetic dipole – we will now focus on that rather than continue to compare it further with other models of the world. A moving electric field induces a magnetic field. Figure 2 shows how the electron's electric field rotation creates a magnetic field (Figure 2 shows the equatorial plane of the electron). Here on the equatorial plane the moving electric flux lines which are normal to the axis of rotation create a magnetic field parallel to the axis of rotation from the equation $\mathbf{B}=\mathbf{v}x\mathbf{E}$, where **E** is the vector electric field strength at that point, **v** is the vector linear velocity of the field and **B** is the resulting vector magnetic field strength.

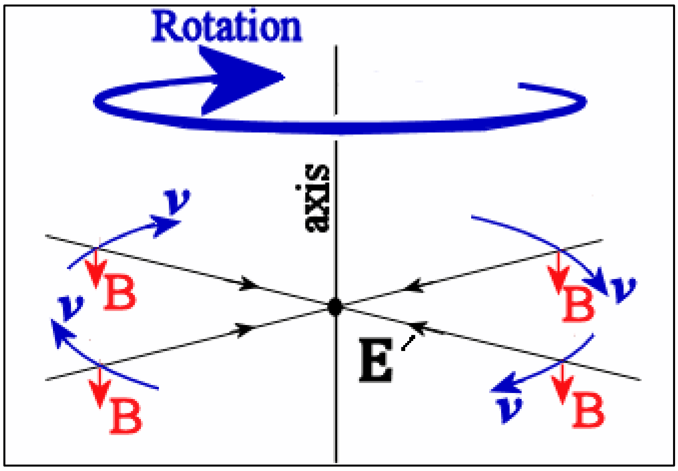

Figure 2

This rotationally-induced magnetic field is directed along the axis of rotation, so a magnetic dipole is the result. This dipole is induced only when the electron is rotating. Its magnetic field strength depends linearly on the speed of rotation. Note that away from the equatorial plane of the electron the electric field is not normal to the axis of rotation and the **v***x***E** term therefore creates a magnetic field that is at an angle to the axis of rotation.

So is this rotation as a solid object?

If an electron's electric field rotated as a rigid body then it is a simple task to show that rotating it by even a negligible amount would take an infinite amount of energy, so an electron could never rotate in all eternity. Fortunately for us there is no energy requirement that mandates that an electron must rotate as a rigid body. Figure 3 shows lines of electric flux around a charge, picked out in different colours...

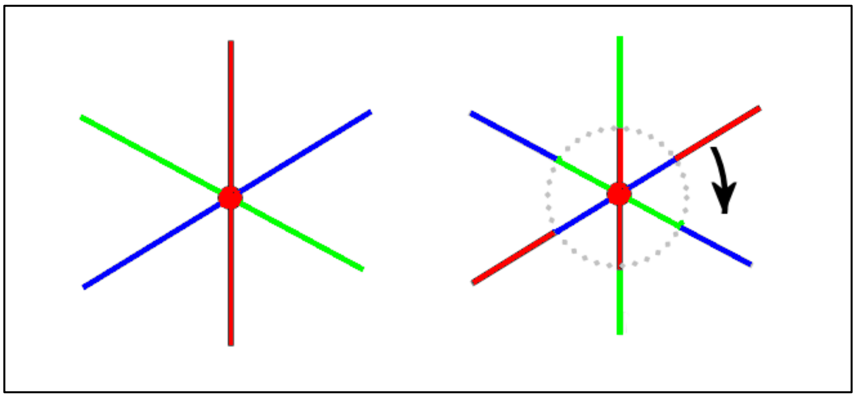

Figure 3

The left side shows the original flux lines, while the right shows the flux lines as they would be if the outer part of the field was rotated 60 degrees clockwise with respect to the stationary inner part shown within the dotted grey circle. As can be seen, the field distribution retains its integrity. More importantly, the energy in the field structure remains unchanged. There is zero energy cost to such a 'distortion' and accordingly the fields at different radii can rotate around the centre of the electron independently of each other with no energy penalty.

So what creates the rotation?

Let us now consider what will happen when an electron enters an electric field that is transverse to its direction of motion. Figure 4 shows the electric field interactions. The electron "e-" is shown travelling at velocity **v** entering a transverse electric field running from right to left.

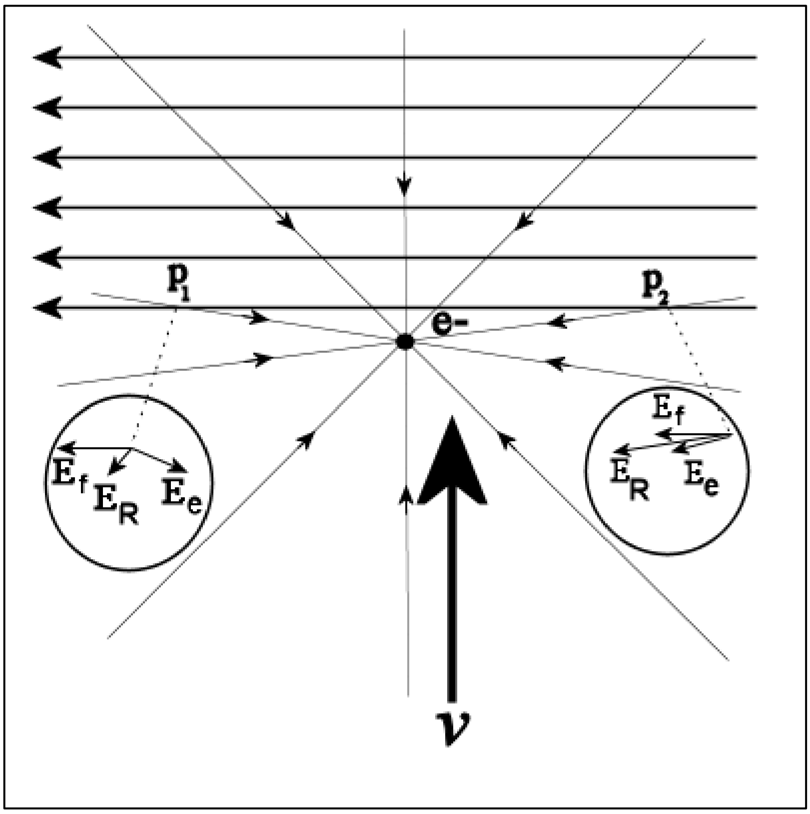

Figure 4

We will for now *completely* ignore the fact that the electron will be accelerated to the right by the electric field. That is a separate effect and can be treated as additive to any other effect; here we will analyse *only* those forces that lead to rotation.

Consider first an arbitrary point p_1 on the left side of the electron's motion. Here the electron's field and the transverse field tend to oppose, so there is a reduction in the energy density; this side of the electron is therefore attracted into the transverse field. Consider next an arbitrary point p_2 on the right side of the electron's motion. Here the fields tend to reinforce each other, so there is an increase in the energy density; the right side of the electron is therefore repelled by the transverse field. This clearly creates rotational forces on the electron, causing it to rotate clock-wise in Figure 4.

Let us analyse this in more detail. Consider a plane parallel to the page in Figure 4. Any fixed radius from the centre of the electron describes a circle. On any such circle the electron's electric field energy density is constant. This is shown in Figure 5 which shows the effect of the different forces that result.

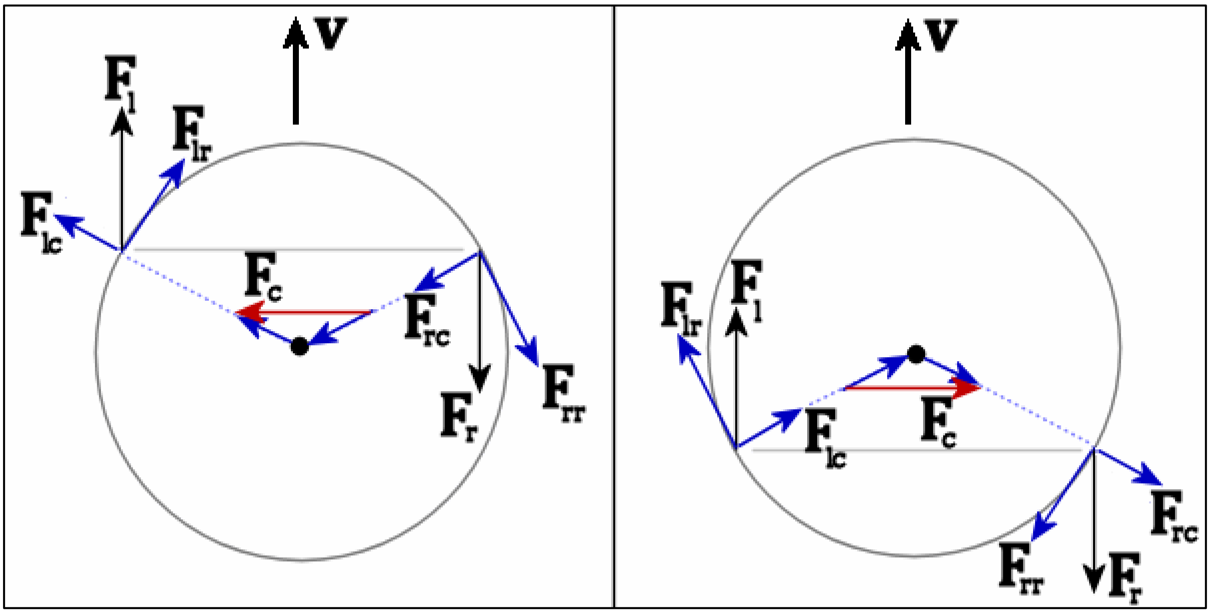

Figure 5

On the left of Figure 5 we have the circle describing a fixed radius from the centre of the electron; a light grey horizontal line represents the edge of the transverse field. $\mathbf{F}_l$ represents the attractive forces on the left and $\mathbf{F}_r$ the repulsive forces on the right as the electron enters the transverse field, with both vectors drawn in black. These resolve into rotational components ($\mathbf{F}_{lr}$ and $\mathbf{F}_{rr}$) and radial forces ($\mathbf{F}_{lc}$ and $\mathbf{F}_{rc}$), drawn in blue. The rotational forces are simply additive. The radial forces resolve at the centre of the circle (repeated, again in blue) into a left-wards translational force (shown as a red vector) that accelerates the whole electron to the left.

On the right of Figure 5 we have the same circle having entered more deeply into the transverse field, the edge of which is again shown by a horizontal line. Here we have both the rotational forces adding to the original ones, but in this case the radial forces resolve to give a right-wards translational force that accelerates the whole electron to the right, exactly cancelling the original leftwards force and ultimately bringing the transverse motion of the electron (from this effect!) to a halt.

The net effect is that the electron hops very slightly to the left and picks up rotation. Remember that we are dealing only with the effect of the electron entering the transverse field and still ignoring the normal acceleration of the electron to the right once inside it.

Since there is perfect mirror symmetry there is no net linear force on the electron along the direction of motion, so were it not to rotate it would not affect the electron at all. However, if we add an arbitrary amount of kinetic energy to the left side and take the same amount away from the left side, there is a reduction in linear kinetic energy as the electron picks up rotational energy – the sum of the linear kinetic energy and the rotational energy *after* the electron enters the transverse electric field is the same as the linear kinetic energy *before* the electron enters the field. This is of course essential from the Principle of Conservation of Energy, and is best seen by analogy. Figure 6 shows a mass-less beam linking to large identical point masses M_1 and M_2 of mass "m" travelling together at velocity "$\boldsymbol{v}$".

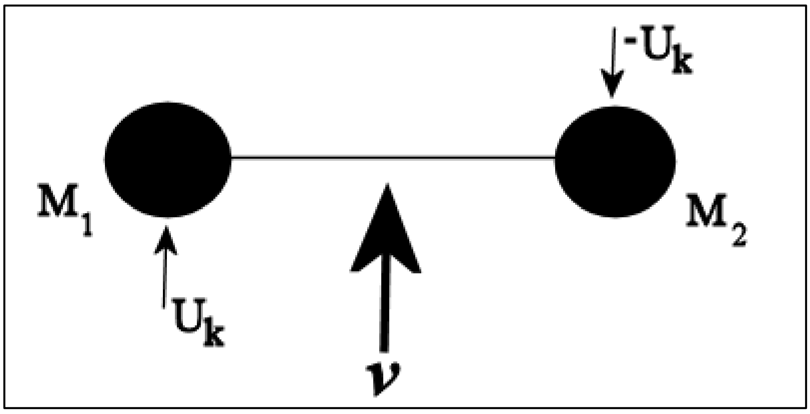

Figure 6

Then add a certain amount of kinetic energy U_{kdiff} to the left side, and remove the same amount from the right side. The total kinetic energy U_{knew} on the left mass is now...

$$U_{knew} = \frac{m\boldsymbol{v}^2}{2} + U_{kdiff}$$

Hence the new velocity v_{Lnew} on the left is...

$$v_{Lnew} = \sqrt{\frac{2U_{knew}}{m}}$$

$$= \sqrt{v^2 + \frac{2U_{kdiff}}{m}}$$

On the right the new velocity is...

$$v_{Rnew} = \sqrt{v^2 - \frac{2U_{kdiff}}{m}}$$

The linear velocity is now the average new velocity, which observation shows is less than the original velocity, so there is a reduction in the linear kinetic energy. On the other hand a rotational energy appears to make up the difference.

For example, if each mass was 1kg travelling at 1 meter/second, and half a joule were added to the left and taken from the right, the new instantaneous left hand linear velocity would be 1.4 meters/second, and the right would be zero. The total linear velocity of the joint masses would be the average of those two, or 0.7 meters/second, so some linear velocity is lost. The rotational velocity (after taking away the linear velocity) is 0.7 meters/second faster than the centre of motion on the left and 0.7 slower on the right, so the rotational velocity is 0.7 meters/second. The kinetic energy is therefore half of what was originally and the rotational energy is the difference.

In the same way the electron loses linear kinetic energy on entering the transverse field, exchanging that lost linear kinetic energy for rotational energy. When the electron leaves from the other side of that same field the rotation is reversed and returned to kinetic energy,, and whilst in the transverse field the electron will travel at reduced velocity.

In the particular situation where the transverse electric field is *induced* from the motion of the electron through a magnetic field then the rotational magnetic dipole will be aligned with that magnetic field. Since there is a reduction of total magnetic energy when a magnetic dipole is in alignment with a magnetic field, magnetic forces will pull the dipole into the magnetic field in the same way that one magnet is drawn towards another, speeding the electron up and compensating for what would have been the drop in linear kinetic energy. Hence in this case the electron does not slow down so much and the rotational energy is effectively associated with a drop in magnetic field energy.

If this rotation were the only source of the electron's magnetic dipole rather than it being at least partly intrinsic, then unlike a permanent dipole which takes up one of two orientations, any induced dipole will take up only one orientation – that of alignment with the magnetic field. Hence for an induced dipole there is only one deterministic path through any magnetic field structure, not two.

Some Properties of a rotating Electron

Next, let us speculate on some of the likely properties of that induced rotation (this work has yet to be completed, and the detail equation of how the rotating fields of a charged particle lead to magnetic resonance has still to be developed, but we can still consider likely behaviour):-

1. The induced magnetic dipole field will be a product of the electric field strength and the rotation. We can use the equation $\mu=k_e q_e \omega$, where μ is the dipole strength, q_e is the electron's unit charge, and ω is the angular speed of rotation. k_e is a derived electromagnetic constant. As should be clear from Figures 2 and 3, the dipole strength will change with increasing radial distance from the centre of the electron.
2. A moving electric field has momentum, and where the electric field is rotating that momentum gives rise to an angular moment and therefore to gyroscopic behaviour. That moment is dependent on the energy density (equivalent to mass density via $E=mc^2$), in turn proportional to the square of the electric field and thence the square of the unit charge. So we can write $g=k_g q_e^2 \omega$ where g is the gyroscopic moment, q_e is the electron's unit charge, and ω is the angular speed of rotation. k_g is another derived electromagnetic constant. Again, it may change with increasing radial distance from the centre of the electron.
3. The precession rate of a magnetic dipole in an external magnetic field is simply the restoring torque (given by the external field strength times the magnetic dipole strength), divided by the gyroscopic moment. Hence $p_e = B\mu/g$, where p_e is the precession frequency and B is the external magnetic field, giving $p_e= Bk_e q_e \omega/(k_g q_e^2 \omega) = k_0 B/q_e$ where $k_0 = k_e/k_g$. Since measurements show that there is a single precession frequency for any particle, then although both the magnetic dipole and the gyroscope moment may change with increasing radial distance from the centre of the electron, the value of k_0 must be the same at all radii for any given unit charge on the particle, as we can reasonably infer that the gyration frequency must be the same for all radial distances from the centre of the electron as we would otherwise see a band of resonant frequencies rather than a single spot frequency. Stronger unit charges give rise to reduced resonant frequencies.

Hence in this model the precession rate of the induced dipole in an external magnetic field does not depend on the frequency of rotation of the electric field, but only on the external field strength and the unit charge. This further means that the geometry of the above equation $p_e = k_0B/q_e$ is therefore equivalent for all particles with a polar field structure. So if the electron has a unit charge of 1.602×10^{-19} coulombs and precesses at 2.8025×10^{10} Hz in a one Tesla field, then the unit charge of a neutron q_n, precessing at 1.91667×10^{7} Hz in the same magnetic field, is...

$$q_n = 1.602\times10^{-19} (2.8025\times10^{10}/1.91667\times10^{7}) = 2.3424\times10^{-16} \text{ coulombs}$$

The neutron's field is therefore about three orders greater than the electron's field in magnitude. To find how much stronger the neutron-neutron force is than the electron-positron force we can perform the calculation for the neutron-neutron force at the stationary peak attraction in Figure 5 and find it is six orders greater.

Using the model of a proton[2] of a central neutron-like strong electric field surrounded by a positron-strength electric field, we know that the proton's central core field precesses at 4.25781×10^{7} Hz and will therefore have a unit charge q_{pc} of...

$$q_{pc} = 1.602\times10^{-19} (2.8025\times10^{10}/4.25781\times10^{7}) = 1.0544\times10^{-16} \text{ coulombs.}$$

The proton may be expected to have a second precession frequency associated with its outer field, which, being the same strength as the electron, would give the same precession frequency; this is impossible to see as it will be masked by precession from the electrons that are part of the experimental apparatus so it remains conjecture. The neutron-proton core force will be about half that of the neutron-neutron force if the dimensions of the neutron and the proton core are similar, and the force between proton cores will be about a fifth of that between neutrons.

Note:- It should be obvious that in the Electromagnetic Field model the proton core and the neutron have lower resonant frequencies than the electron but potentially higher energy levels involved in gyration because of their higher electric fields. In this model the particle precesses in a magnetic field and resonates to a varying degree in response to an incident passing electromagnetic wave of the correct frequency. In Quantum Mechanics a bullet-like photon of appropriate energy is absorbed and then emitted. The Electromagnetic Field model does not use a photon-as-particle concept, requiring only that atomic energy transitions are constrained to a fixed frequency/energy relationship by the mechanics of atomic orbits. The electromagnetic model of the photoelectric effect then requires resonant energy storage – ringing - in the photoelectric atoms in the region surrounding the atom that over time gathers all that stored energy from its neighbouring atoms so that the diffuse radiant energy coalesces into a single energy transition.

Electron Orbitals

The detailed equation of how an electron gathers rotation in traversing the increasing fields of the atom as it spirals in toward the nucleus have yet to be developed, but again, given what we already have, we can consider likely behaviour.

When an electron spirals into an atom it faces an increasing transverse field from the nucleus, the field lines of which it travels normal to. This means that some of its potential energy is converted into rotational energy, and the remainder into kinetic energy. The electron's potential energy (unit charge q_e) at a radius 'r' from a fixed unit nuclear charge q_n is given by

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

Zero potential energy occurs at 'r' equal to infinity. The kinetic energy to keep an electron in a stable orbit is found by equating the attractive electric force to the centripetal force of the electron's mass m_e as it orbits q_n.

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

The orbital kinetic energy needed is therefore:-

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

$$\frac{m_e v^2}{2} = \frac{q_e q_n}{8\pi\varepsilon r} = \frac{U}{2}$$

That is, a stable orbit always needs exactly half the potential energy. The behaviour of the electron in the atom (i.e. in "Orbitals") is such that we can confidently assume that only half the potential energy goes into kinetic energy, and the excess half into rotation. If the kinetic energy was more than half the potential energy the electron would enter the atom on a hyperbolic path and continue on that path to exit the atom in short order. If it was less the electron would spiral into the nucleus.

Hence the electron's kinetic energy at all orbits within the atom is exactly half the potential energy associated with that orbit. Under these conditions, where the electron's kinetic energy is half the potential energy, there is no fixed orbit – all orbits are stable - and the electron wanders freely in and out from the nucleus. As it wanders in towards the nucleus it builds up equal amounts of kinetic energy and rotational energy to add to its existing energies, consuming potential energy. The rotational energy creates an induced magnetic dipole, so magnetic effects will build up as the electron's orbit drifts inwards towards the nucleus. As the electron drifts back out again, rotational energy and kinetic energy are simultaneously restored to potential energy and the magnetic dipole weakens.

However, at certain precisely set orbits the electron's rotational energy can be fully discharged into electromagnetic radiation. After this happens the electron can still wander inwards towards the nucleus, but as it lacks the rotational energy to restore the potential energy fully, it cannot wander out beyond the discharge orbit – it is trapped within the

discharge radius by its lack of rotational energy. It may be spun up again by incident electromagnetic radiation at that same set discharge orbit after which it is again able to wander out into outer orbits. These discharge orbits seem to be mechanical in nature where conditions are right for precessing radiative discharge, apparently being a function of path curvature and kinetic energy. The details of the discharge mechanism remain a puzzle, but may be related to the spin charge/discharge cycles performed in the Powerball wrist exerciser. In this device the spin of a gyroscope can be spun up or down by a forced precession, possibly because a gyroscope that has a torque on axis number one and a fast spin on axis two, with a slow precession on axis three, is not necessarily discernible from a gyroscope with the same torque on axis one, a fast precession on axis two and a slow spin on axis three. The torque on axis one would be provided by radiant energy leaving as it discharged the rotation or arriving as it charged up the rotation.

References

1. "*Stern-Gerlach experiments: past, present, and future*"; Van Huele, J & Stenson, J; Utah Academy of Sciences, Arts & Letters, 2004, 81, 206-212)
2. "*The Nuclear Force and Limitations to the Lorentz Electrostatic Force Equation*"; Singer, Michael;1st May 2017.