The Debate Over Electron Behavior.

There are a number of different ideas and theories about what is exactly happening to electrons inside the polywell. Here is a summary of these ideas:

1. Electron recirculation – Where are they travelling?
2. Electron recirculation – When are they moving fast? When are they moving slow?
3. The magnetic mirror line - Where do the electrons turn around?
4. The Whiffle ball – Are the electrons creating their own magnetic field?
5. Are the electrons mutually repulsive in the center?
6. Are electrons packing in the cusp points?

This is a very complex topic. I am also no expert. What is presented here are ideas that have developed in discussions with former employees who worked on the Polywell, physicists, papers, online information and, forum discussions. From all these interactions, I have attempted – here - to cobble together a picture of what the electrons are doing inside the polywell. This is hard to do with no data. This is also all volunteer.

We need data. We need hard proof of what is and is not happening inside the machine. As you start to think, plan and read about the Polywell you see that the topic is maddeningly complex. There is a good chance most theoretical analysis of the polywell is flawed. It is just hard to see how any one person, group, computer program or theory could catch all the factors in play inside the polywell. It makes one want to just build the thing and see what kind of results you would get.

If the polywell works, it would be a major invention, akin to the automobile or the computer. A cheap, clean way to produce abundant electricity; it would help stop global warming, help stop the energy crisis and make some people very rich. Not to mention, getting the US out of recession. This is not something we can afford to leave up to theory alone. The stakes are too high. We need data, not complex estimations. I do not care if the data indicates that the idea is a failure. I will accept that. We need to know. The discussions below will start to give you a taste of how complex the electron picture is alone. It should make you realize how badly testing of this idea is needed. We need to know for sure. As the famous physicist Richard Feynman said: “It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong.”

1. Where are the electrons recirculating?

Here is the setup: we have a polywell filled with ONLY electrons, NO IONS. We know the electrons will recirculate, from the center along the magnetic cusp lines. There are 14 cusps; Six for each side, and 8 for each corner. We know this because of Indrek's - electron only - polywell simulation and, because Bussard presented this in his Google presentation. Watch 52 minutes, 35 second in4. You can see Indrek's simulation here:

http://www.youtube.com/watch?v=ao0Erhsnor4&feature=related

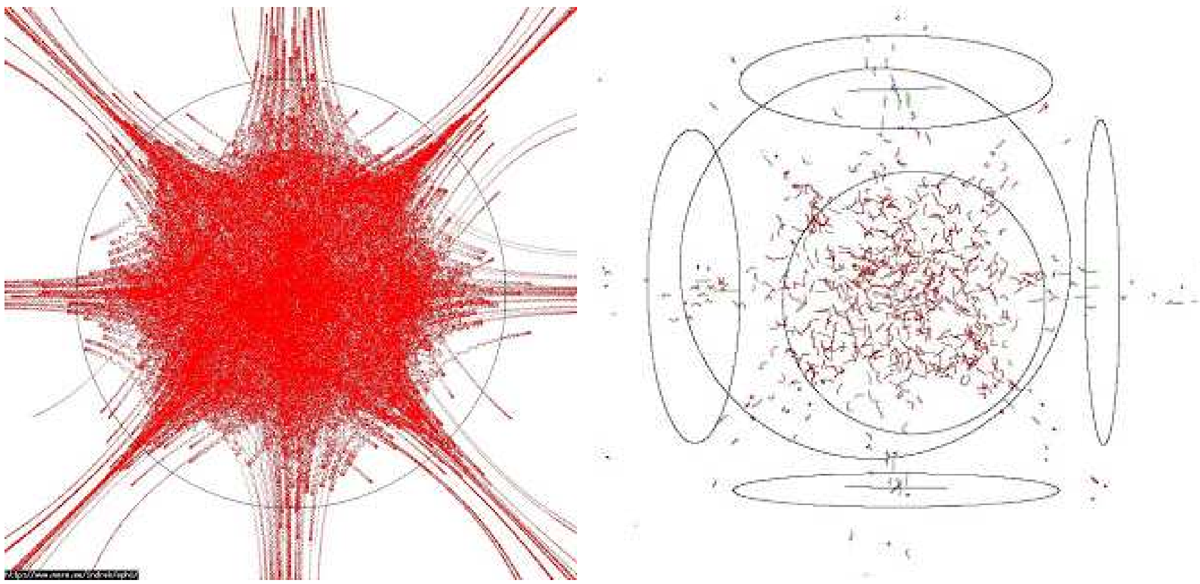

Figure 1: Two Images from Indreks' simulation showing electrons flowing to and from the cusps. Notice the electrons are CORKSCREWING along the magnetic field lines. They ride the cusp lines like a roller coaster, out and back into the middle.

2. When are the electrons moving fast? When are they moving slow?

Imagine we had a magnetic field in a square. The top of the square is dense, the bottom is light. The top of the square has a dense magnetic field and the bottom has a light magnetic field. We set an electron on the square. Below are statements that can be made about this simple example.

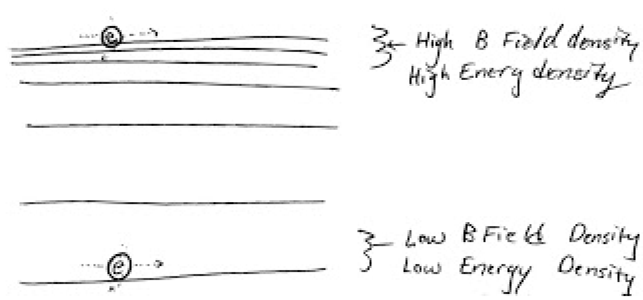

Figure 2: A scenario discussed below, two electrons placed in a high density and, a low density electric field.

A. The electron will align itself. All free floating electrons spin. This spin creates a diamagnetic moment, or a mini magnetic. The electron will act like a mini magnet. It will align its' magnetic field with the external magnetic field; it will turn.

B. The electron will not move. This is because of the Lorentz Force1. The Lorentz force is the force that all electrons experience in a magnetic field. The force is given as: Force = charge*(velocity vector X Magnetic Field). With no starting velocity, the velocity vector is zero, therefore the force is zero, therefore the electron will sit there. It will not move.

C. The electron sitting high magnetic field is more energized. That electron has more potential energy. This is from the equation for energy density[2]. Energy Density = e0/2*(electric field density)^2 + 1/2*u0 *(Magnetic field density)^2. So if the field lines are denser, then the energy density is higher. Energy goes up by B squared. Therefore the electron sitting in the higher density field has more potential energy. To restate, the setup is two electrons, one high energy and one low energy. They are both not moving and, both aligned.

D. Now kick the electrons. The one in the high field moves faster. This is because of the Lorentz Force. Force = charge*(velocity vector X Magnetic Field). If the Magnetic field is higher, the force is higher (assuming each electron gets the same kick). So, if you have a higher B field, you have a high energy, you have faster moving electrons. We also know that the electrons move along the cusps.

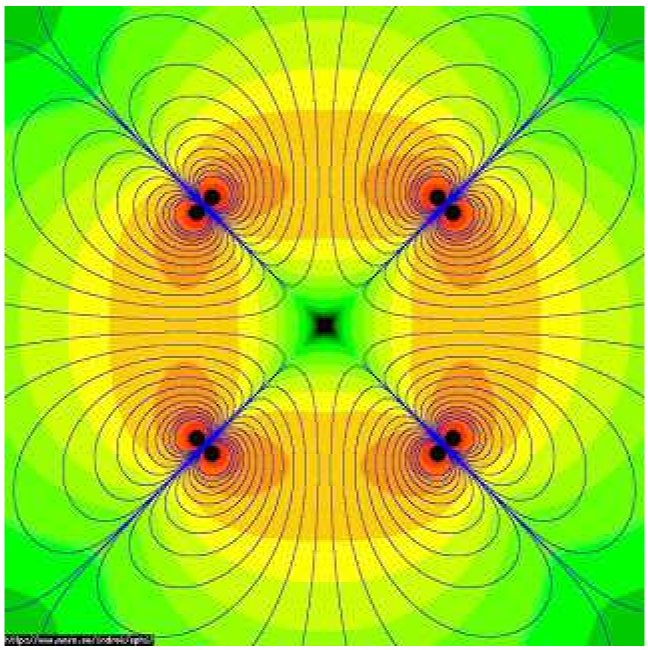

Figure 3: Magnetic field lines inside the polywell, taken from Indreks' simulation[6]. Electrons will move faster in the denser field, so recirculation occurs faster along the sides of the polywell and the cusp corners, then in the center. Some believe that electrons stop movement in the center.

E. We know that there is a higher magnetic field at the cusps, or the corners of the polywell. This can be seen above, in a picture of the magnetic field lines, taken from Indreks' simulation. It seems reasonable then to assume then that these recirculating electrons would move faster at the corners of the device and slower in the middle. Some believe that they come to a complete standstill in the middle. This Picture is not universally agreed upon. Therefore, our picture of electron re-circulation looks like this:

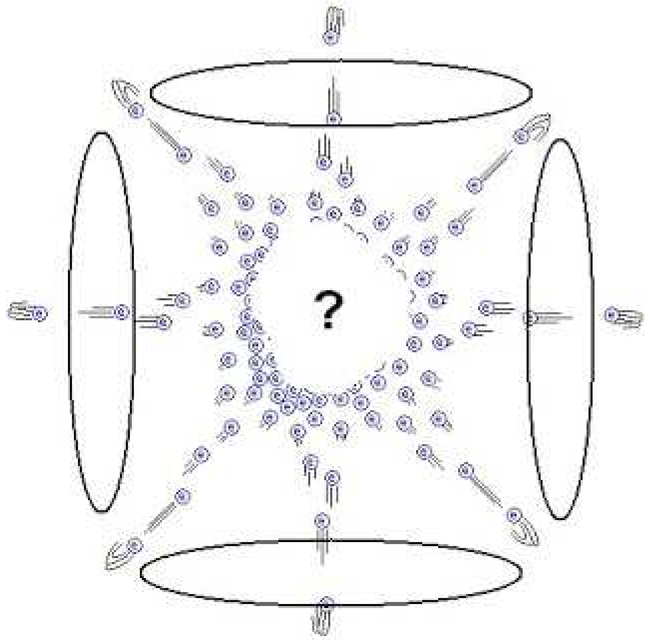

Figure 4: Hypothesized picture of electron recirculation inside polywell. Note electrons are moving from the center to the corners and recirculating back. The picture is somewhat simplified because the actually electrons would be corkscrewing instead of moving in straight lines. The big question is speed. The electrons should move faster in the denser field, so they will move faster in the cusps then in the center of the polywell.

3. The magnetic mirror line - Where do the electrons turn around?

As the electrons travel up the cusp lines they move faster. They reach some point where they turn around. This U-turn point is where the electron hits a magnetic mirror. I will explain magnetic mirrors as best I can, borrowing from a lecturer from the University of Texas at Austin5. These notes look at both the electric and magnetic field effects on the particle. Therefore I would imagine this scenario is more comprehensive then the energy density and Lorenz force arguments I was using above. Since both are approximations anyways, both can shed light on electron behavior inside the polywell.

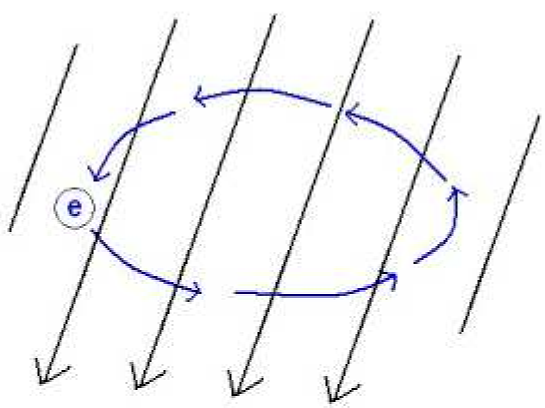

Figure 5: This is a picture of an electron in some fictitious electric and magnetic field.

Let us assume this that the fields are not varying with time. It just sits there. The above particle has some energy. If the magnetic field remains unchanged, and the particle does not move, then the energy of the particle remains constant. The equation that gives the particles total energy, is shown below

$$\text{Total Particle Energy} = \frac{\text{Mass Of Particle}}{2}\left(U_{\parallel}^{2} + V_{E}^{2}\right) + \text{Magnetic Moment} * \text{Magnetic Field} + \text{Electric Charge} * \text{Electric Field}$$

Unfortunately, I do not know what the U and Ve is specifically referring too. The U is most likely the part of particle's velocity which runs parallel to the magnetic field lines. This is the velocity we care about, since it would be about the speed at which the electrons ride the magnetic field lines inside the polywell. The Ve is probably the velocity of the particle relative to the electric field. Here are some statements that can be made about electron behavior in such a field.

1. If the field is constant with time, the particle gains or loses no total energy as it moves around the field. This is the ideal case. No process like this can occur without losing some energy, or it would break the 2nd law of thermodynamics. Ideally, energy would just be transferred from kinetic to potential and back as the electron moves. As the particle speeds up, kinetic energy increases, potential energy decreases and total energy remains constant. The opposite happens when the particle slows down. The particle loses kinetic energy – transferring it to potential energy.

2. You can rearrange the above equation in a field that is constant in time. In this case, the author was interested in the velocity parallel to the magnetic field lines.

$$\text{Velocity Along Field Lines} = U_{\parallel} = \pm\left(\frac{2}{\text{Mass}} * (\text{Total Particle Energy} - \left[\text{Magnetic Moment} * \text{Magnetic Field} - \text{Electric Charge} * \text{Electric Field}\right] - V_{E}^{2}\right)^{1/2}$$

From this equation the author determines there are three mathematical cases for a magnetic mirror.

Case 1:

$$\text{Total Particle Energy} > (\text{Magnetic Moment} * \text{Magnetic Field}) + (\text{Electric Charge} * \text{Electric Field}) + \left(\frac{\text{Mass} * V_{E}^{2}}{2}\right)$$

In this case the electrons can move in any direction. Up or down the magnetic field lines. They DO move "up" the magnetic field lines due to the Lorenz force described above. The Lorenz force is the force an electron experiences due to a magnetic field.

Case 2:

$$\text{Total Particle Energy} < (\text{Magnetic Moment} * \text{Magnetic Field}) + (\text{Electric Charge} * \text{Electric Field}) + \left(\frac{\text{Mass} * V_{E}^{2}}{2}\right)$$

In this region, where the above mathematical statement is true, the electrons are prohibited from going. Essentially what this is stating is that the electron energy is not high enough to overcome the “containment” energy.

Case 3:

$$\text{TotalParticle Energy} = (\text{MagneticMoment} * \text{MagneticField}) + (\text{Electric Charge} * \text{Electric Field}) + \left(\frac{\text{Mass} * V_z^2}{2}\right)$$

This case, represents the line between the two regions. It represents the mirror point, the point where the recirculating electrons would have to turn around. A nice analogy can be made using a marble in a bowl. This analogy is shown graphically in figure Six.

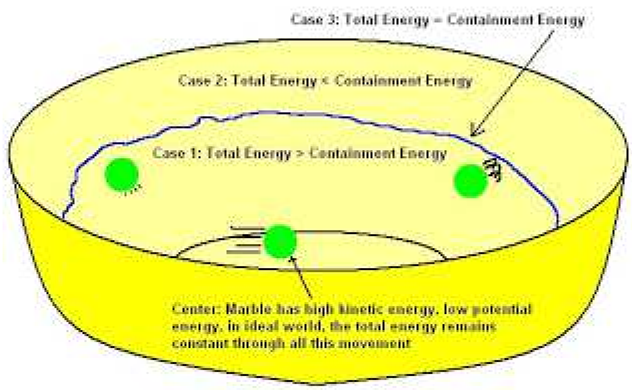

Figure 6: A simple analogy explaining magnetic mirrors: a marble in a bowl. The highest the marble can reach as it rolls around in the bowl is the blue line. This is the 3rd case, where the total energy of the electron matches the containment energy at that point. The lid of the bowl is the maximum energy the system can contain. Any electron with a total energy higher than that maximum, would fly out of the system.

Here is an important point. This containment is magnets containing electrons. The magnetics are creating magnetic mirror lines, which the electrons cannot cross. There are no ions in this picture. It seems there would be a completely different potential well for the ions. One created by the electrons. Below is a fictitious drawing of what these magnetic mirror lines might look like inside the polywell.

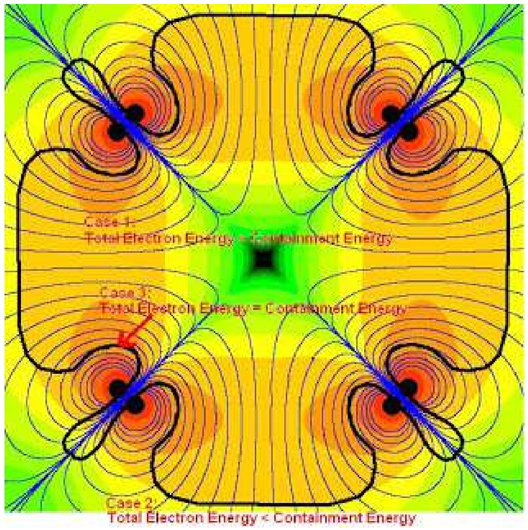

Figure 7: A possible magnetic mirror line picture adopted from Indreks' simulation6. Originally, this picture was a 2D image of the magnetic field lines (shown in blue), from some plane cut across the polywell. The magnetic field intensity is represented by the different colored regions. You can see the cusps very well in this image, there are cusp lines running out at each corner. There are also cusps at each side. A fictitious black line has been drawn representing the turn around point for the electrons. **I did this arbitrarily.**

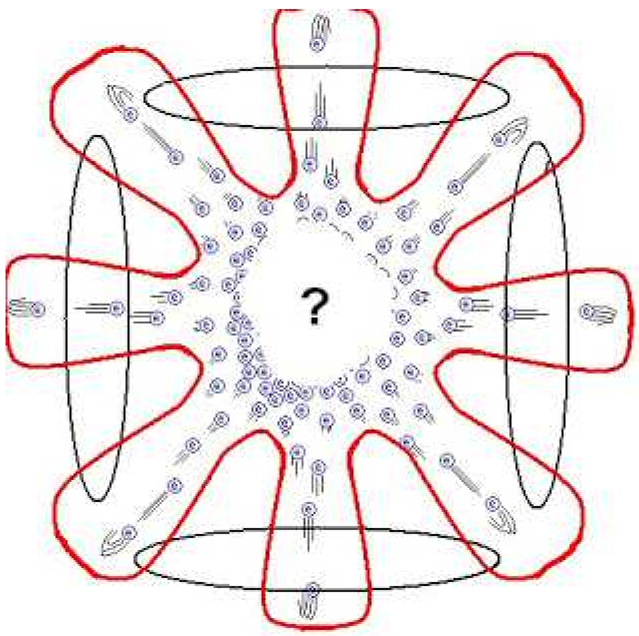

Figure 8: Electron recirculating picture, complete with magnetic mirror lines.

4. The Whiffle Ball Theory – Are electrons creating their own field?

The Whiffle ball hypothesis is a very critical part of the polywell. It can be explained as followed. All electrons have a diamagnetic moment. This is created by their spin. This moment behaves like a small magnetic. When a strong external field is applied, it can align the moments of the electrons in an object against the field. This creates a repulsive magnetic field. Thomas Ligon does a good job describing it, from “An interview with Thomas Ligon” on YouTube. He states the following:

“In that region, there is essentially next to no magnetic field. Everywhere else, where there is a magnetic field, electrons are passing through in small populations. These electrons will behave classically, following electromagnetic theory, the right hand rule and all the other stuff they normally do. In principal, Dr. Bussard believed that if you got the electron current inside the machine up high enough the cloud of electrons itself starts doing things to the magnetic field that one would not gather from studying a single electron. He believed that they would go diamagnetic and exclude the magnetic field and push it back.”

This is shown graphically below.

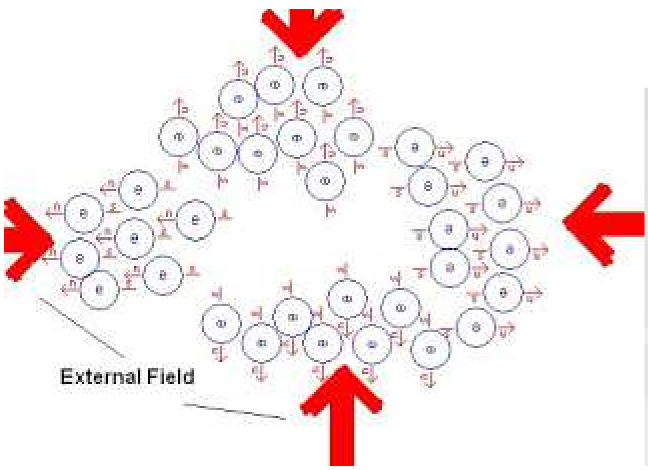


Figure 9 & 10: The first figure shows graphically how electron moments can align against an external magnetic field. This cases the electrons to create their own magnetic field in response. In materials, this means that something can behave like a magnetic, when a strong magnetic field is applied to it. An example of this is shown above, where a frog behaves like a magnet, and floats in response to about a 16 Tesla external field. This is believed to be happening inside the polywell. The some of the electrons in the cloud are aligning their moments against the external magnetic field. They are making their own field. This is supposed to push back the external field and help contain the electrons. This is the Whiffle ball effect. As of this writing, it is only a theory.

<u>5. Are the electrons mutually repulsive in the center?</u>
<u>6. Are electrons packing in the cusp points?</u>

Both these were comments made about electron behavior from Thomas Ligon’s interview.

“Lets assume you do not have any ions in here and you fill this machine up with all the electrons it will hold. The neat thing is, the electrons are mutually repulsive in the center here and they actually lose kinetic energy going into the center. The depth of the potential well occurs, when the center is space charge limited. Electrons are losing energy to the point where they basically come to a standstill. The electrons in the middle of this machine are not hot. They are nearly cold. They are lukewarm at best. When they get trapped, the electrons lose kinetic energy in here. Now if you start putting boron, or if you start concentrating ions in here, the ions themselves are positively charged and they will partially counteract the tendency of the electrons to repel each other. So you start getting whets called a virtual anode. It is a structure in which the ions themselves allow the electrons to come in with a little more kinetic energy."

Is this true? We need data to verify this.

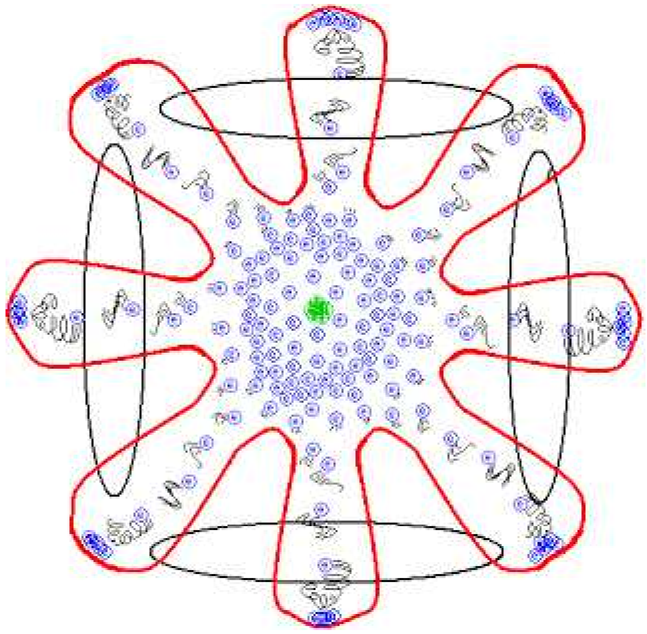

Figure 11: Hypothetical picture of electron behavior inside the polywell. This includes electrons moving faster at the cusps then in the center. It also includes packing at the edges, and a magnetic mirror line (in red) which shows where the electrons would turn around.

Sources:

1. http://en.wikipedia.org/wiki/Lorentz_force

2. http://en.wikipedia.org/wiki/Energy_density

3. http://en.wikipedia.org/wiki/Electron_magnetic_dipole_moment

4. "Should Google Go Nuclear" 52 minutes, 35 seconds in

5. http://farside.ph.utexas.edu/teaching/plasma/lectures/node22.html#e2.75

6. Mandre, Indrek. "Ephi - the Simple Physics Simulator." Web. http://www.mare.ee/indrek/ephi/.

7. “An Interview with Thomas Ligon” Web. http://www.youtube.com/watch?v=1HatEDkNnn8