Honors Physics Project

by James Hankins

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The original idea for my honors physics project was to create a handheld coil gun, but I was not absolutely sure on what materials to use to make the 'gauss pistol' very efficient. When I showed my project proposal to Dr. Stewart, he said that the gauss gun project had been done time and time again and that it would be more interesting for me to test out different materials and methods to create the coil gun. So, I have decided to change my project to testing out multiple methods and materials to find out what would make the most efficient gauss gun.

The plan for the project was to build a simple coil gun, test out different ways of building it and firing each a few times to find out the capabilities of the system, calculating everything to find out what would lead to the best gauss gun, and, finally, building that final gun that would be the best product of the tests and bringing it to demonstrate my findings. There were quite a few ideas I wished to test: variation in the amount of turns across the same length of coil, variation in the length across the same amount of turns of coil, variation in materials the coil was wrapped around, variation in the design of the coil, different projectiles to be fired from the coil, whether a camera flash circuit board would help, variation in the amount of capacitors, and whether two coils in parallel would work better than one. The following paragraphs will discuss my plans for each test and what I expected would happen.

The first two tests are very similar, testing the variations in the amount of turns and the length with all other variables constant. The plan for testing the variation in the turns was to test two coils, one that was 75 turns across 12.2 centimeters and one that was 25 turns across 12.2 centimeters. Because

$$B = \mu_0 \frac{N}{l} I$$

(B is the magnetic field, N is the number of turns, l is the length, I is the current, and μ_0 is the permeability of free space), changing the number of turns across the solenoid should change the magnetic field proportional to the change, e.g. the 75 turn coil should produce a field 3 times stronger than the 25 turn one. (Kurrelmeyer 177) The next test, testing the variation in the length, works under the same principles. The plan was to test one coil that was 25 turns across 12.2 centimeters and one that was 25 turns across 4.3 centimeters. From the same formula,

$$B = \mu_0 \frac{N}{l} I$$

, changing the length of the solenoid without changing the amount of turns should changes the magnetic field inversely proportional to the change, e.g. the 12.5 centimeter coil should produce a magnetic field around one-third as strong as the 4.3 one.

The next test is the variation in the materials the coil was wrapped around. The three materials to be tested was a PVC pipe, a copper tube, and the coil being held together with electrical tape on the outside but nothing on the inside of the solenoid, which will be the control for the test. Plastics are pretty much invisible to magnetic fields, so the PVC pipe should see no noticeable difference from the control. The copper tube should be a different matter because it is ferromagnetic, it is a solid containing "three elements only, Fe, Co, Ni, in an oxide of one of them, Fe_3O_4, or in alloys containing bordering elements Cr and Ni and Cu of that triad group." (Loeb 245) Ferromagnetic materials increase magnetic fields by a factor of 10 to 10000. This leads me to believe one of three things will occur, either the field will become extremely strong, sending the projectile out much faster, the projectile will also be magnetic and will stick to copper tube, or the tube will launch out of the coil because it is being pushed by the field in the solenoid.

The most interesting test to me is the variations in the design of the coil. The three types of solenoids to be tested are a normal cylinder, which will be the control, a cone shape with the end you point down range having a smaller radius than the friendly end, and a hourglass shape with the center having a smaller radius than the ends. The Biot-Savart Law says that

$$B_{(r)} = (\frac{\mu_0}{4\pi}) \sum_j i_j \oint_j \frac{dl \times \hat{n}}{|r|^2}$$

, or basically

$$B = \int \frac{\mu_0}{4\pi} \frac{Idl \times \hat{r}}{|r|^2}$$

(*B* is the magnetic field, *l* is the length, *I* is the current, and μ_0 is the permeability of free space, *r* is the radius of the loop), this means that when the radius of the coil is smaller the magnetic field will be stronger. (Cheston 145) That, in turn, makes the magnetic force stronger as you go toward the part of the coil with a smaller radius. If this holds true, then the cone solenoid should be better than the control. But where does this leave the hourglass coil? When the projectile travels toward the center, the force will get stronger, but when it gets past there the direction of the force depends on the material of the projectile, which will be discussed in the next paragraph.

The projectile tests go hand in hand with the coil design tests. The three projectiles that were going to be tested are a iron nail, a copper sphere, and a piece of quartz. First, the iron nail is ferromagnetic, meaning it should strengthen the magnetic field and its magnetic moment is toward the stronger field. This presents a problem with the hourglass solenoid, because when it passes the smallest point it will want to flip to point toward the stronger field, potentially destroying the coil. With the copper sphere, this should not be a problem as it is a sphere and it would not do anything if it flips in the coil. Quartz, on the other hand, is a diamagnetic material which means it is a "material for which the observed change is a decrease in [magnetic field]."

(Kurrelmeyer 242) This would be a problem, but the magnetic susceptibility of quartz is $-3.4 \times 10^{-7} \frac{m^3}{kg\ mol}$ which is not that strong, so it would not change the magnetic field that much. But, diamagnetic substances experience a repulsive effect from a magnetic field, so it would shoot out of the coil in the opposite direction, potentially causing harm to the user.

The next test I thought about when I saw the demonstration coil gun in lab. Originally, I had thought to build the circuit for the coil gun around camera flash, since it worked in the same fashion. But when I saw the coil gun in lab, which did not have a camera flash, I wondered if there would be any difference between the two circuits. The camera circuit (see Figures 1 and 2) has the capacitor bank replacing the capacitor, the coil replacing the bulb, the battery pack replacing the battery, and the switches replacing the old switches. This is a 'improved' version of the gauss gun made by Jeff (see bibliography), modified to increase the capacitance and add the charging switch. The simple circuit (see Figure 3) was a much easier build, i.e. less soldering, and because it has less parts, it should be less likely to mess up. But on the other hand, the camera circuit may have parts that help increase the current running through the bulb.

The next test is the most simple, the variation in the amount of capacitors. The plan for this was to fire the gauss gun with all three capacitors and then fire it with only one. The three capacitors were put in parallel to maximize the charge held, which will increase the current through the coil by the formulas:

$$C = \frac{Q}{\Delta V}$$

$$Q = I\Delta t$$

$$C\Delta V = I\Delta t$$

(*C* is the capacitance, *ΔV* is the electric potential, *I* is the current, and *Δt* is the time). (Kurrelmeyer 117) Since *ΔV* and *Δt* should be close to constant, the amount of capacitance should directly affect the amount of current going through the coil, which affects the magnetic force.

The final test is whether two coils in parallel will do better than one. If the coils are wired in parallel with each other (see Figure 4), it should increase the current going through the circuit, but not the individual solenoids since the current will have to be split between the two. The two solenoids together would match the length and the amount of turns of the single solenoid to keep the parallel part as the only variation. It is noteworthy that this would not be a multistage gauss gun, since it fires both coils at once instead of one after the other.

With all that decided on and theorized, I set out to build the basis to start experimenting on. I acquired all the necessary parts: a disposable camera with a flash, a 3/4 inch diameter PVC pipe, a 3/4 inch diameter copper (most likely an alloy) pipe, solder and a soldering iron, wires, iron nails, copper spheres (muzzleloader bullets), a bit of quartz, 3 1000 microfarad capacitors, a battery pack and AA batteries, two switches, electrical tape, and a LED light. I took apart the camera, removed the circuit board, and replaced the parts with my own (see Figures 1 and 2). After that, I created all the solenoids need for my testing. I made one that was 75 turns across 12.2 centimeters, one that was 25 turns across 12.2 centimeters, one that was 25 turns across 4.3 centimeters, and one that was 50 turns across 7.9 centimeters. I had also made some with differing forms, one that was conical and one that was a hourglass shape, both with 75 turns across 12 centimeters.

I soldered in the first coil, put in the iron nail, closed the switch to charge up the capacitors, opened that switch, and closed the one to fire the nail. And nothing happened. Confused, I repeated the process, making sure the LED on the circuit board was full lit to show that the capacitors were fully charged, flipped the fire switch, and nothing happened. I retrieved my multimeter and tested the potential difference on the capacitor bank, with the switches open, and it was zero. I charged the capacitors and tested it again, and the potential showed that they were fully charged. I closed the switch to the coil and tested the capacitor bank again, and they were uncharged. I switched out the coils and got the same result, and after switching out coils a few times I got the same result each time. Thinking that the nail may be too heavy, I put a small sewing needle in the coil, and it did not fire either. I got a compass and put it up to the coil and attempted to fire it one more time and the compass needle did not even move.

After these attempts, I thought that maybe the camera flash circuit may be messing up the system. I took everything apart and made the gauss gun without the circuit board (see Figure 3) and tried to fire the nail to no avail. I tried testing it again with the compass next to it, and the compass needle did not move. I made sure all the circuitry was correct, wrapped all the spots where I soldered with electrical tape so that there was no current going around the coil instead of through it, but nothing I did could make the compass needle to even twitch.

There are many way that this project could have, and probably did, go wrong. One of the biggest difficulties I had was attempting to complete the project in only two days. I was only able to go home during the Thanksgiving break, which meant I only had a few days to purchase the materials and complete this project.

Another error of mine was that I probably did not have enough capacitors to create enough current to fire the gauss gun. The formulas

$$\frac{C\Delta V}{\Delta t} = I$$

$$B = \mu_0 \frac{N}{l} I$$

$$F = IlB$$

$$F = \mu_0 N \left(\frac{C\Delta V}{\Delta t}\right)^2$$

$$F = ma$$

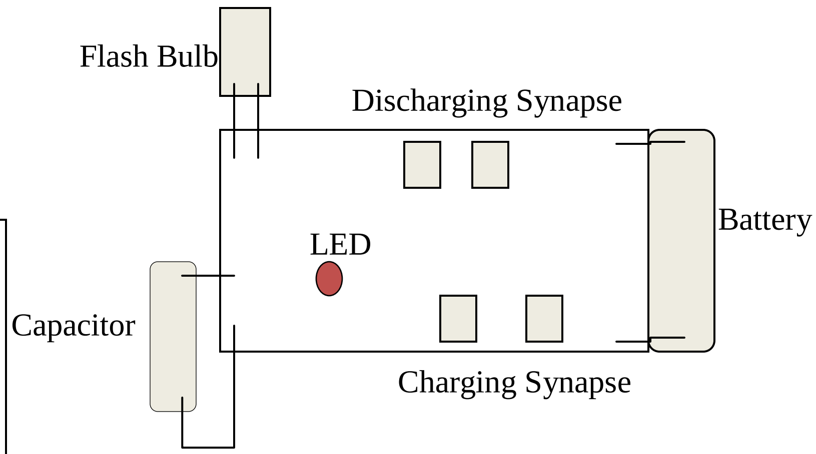
$$a = \frac{\mu_0 N \left(\frac{C\Delta V}{\Delta t}\right)^2}{m}$$

shows the relationship between current and acceleration of an magnetic object in the solenoid (*a* is acceleration, *m* is mass, *F* is force, *C* is the capacitance, *ΔV* is the electric potential, *I* is the current, *Δt* is the time, *B* is the magnetic field, *N* is the number of turns, *l* is the length, and μ_0 is the permeability of free space). With these equations, 3000 microfarads and the nail having a mass of one gram would only produce an acceleration of $7.63\text{x}10^{-6}\,\frac{m}{s^2}$. Even if the ferromagnetic material increased the magnetic field by 10000 times, it still would only be $7.63\text{x}10^{-2}\,\frac{m}{s^2}$, which over one second of current would only be $7.63\text{x}10^{-2}\,\frac{m}{s}$. I do not think that $7.63\text{x}10^{-2}\,\frac{m}{s}$ would be enough to notice, or even the force to produce that would overcome the friction of the surface. I made this mistake because the coil gun made by Jeff (see bibliography) just used the capacitor in the camera, which I assumed to have a capacitance of around 1000 microfarads since the capacitor in my flash circuit board looked the same as my 1000 microfarad ones. This was a huge thing to overlook.

In conclusion, I learned quite a few things from trying to get this coil gun to work. First, coil guns are more difficult to make than I thought, and take more than a few days to perfect and make one fire. Second, I should test everything, including capacitors, before I start soldering. I can say that I now have a firm grasp on the physics concepts behind this, now that I have had to go and try to figure out what went wrong.

Figure 1

Circuit Board



A piece of metal would be pressed down across the synapses to charge or discharge the capacitor.

The LED would light up when the capacitor is charged.

Figure 2

Coil Gun with Circuit Board

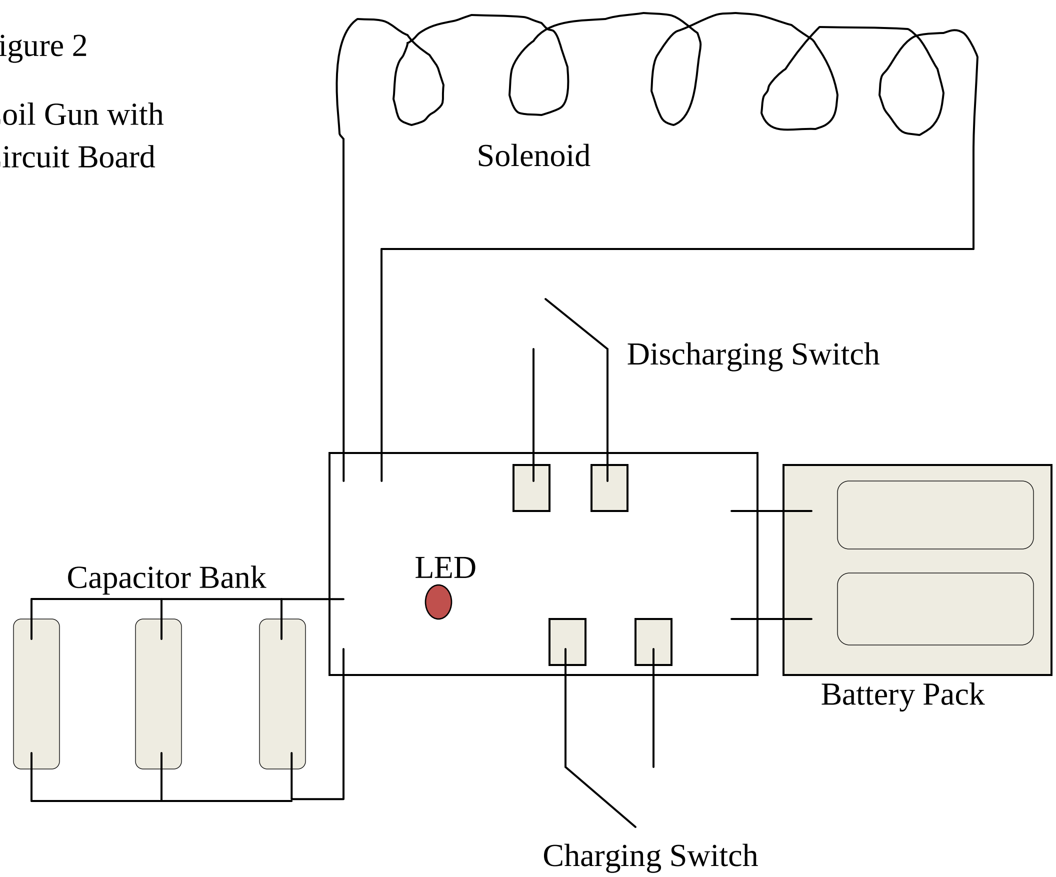


Figure 3

Coil Gun without Circuit Board

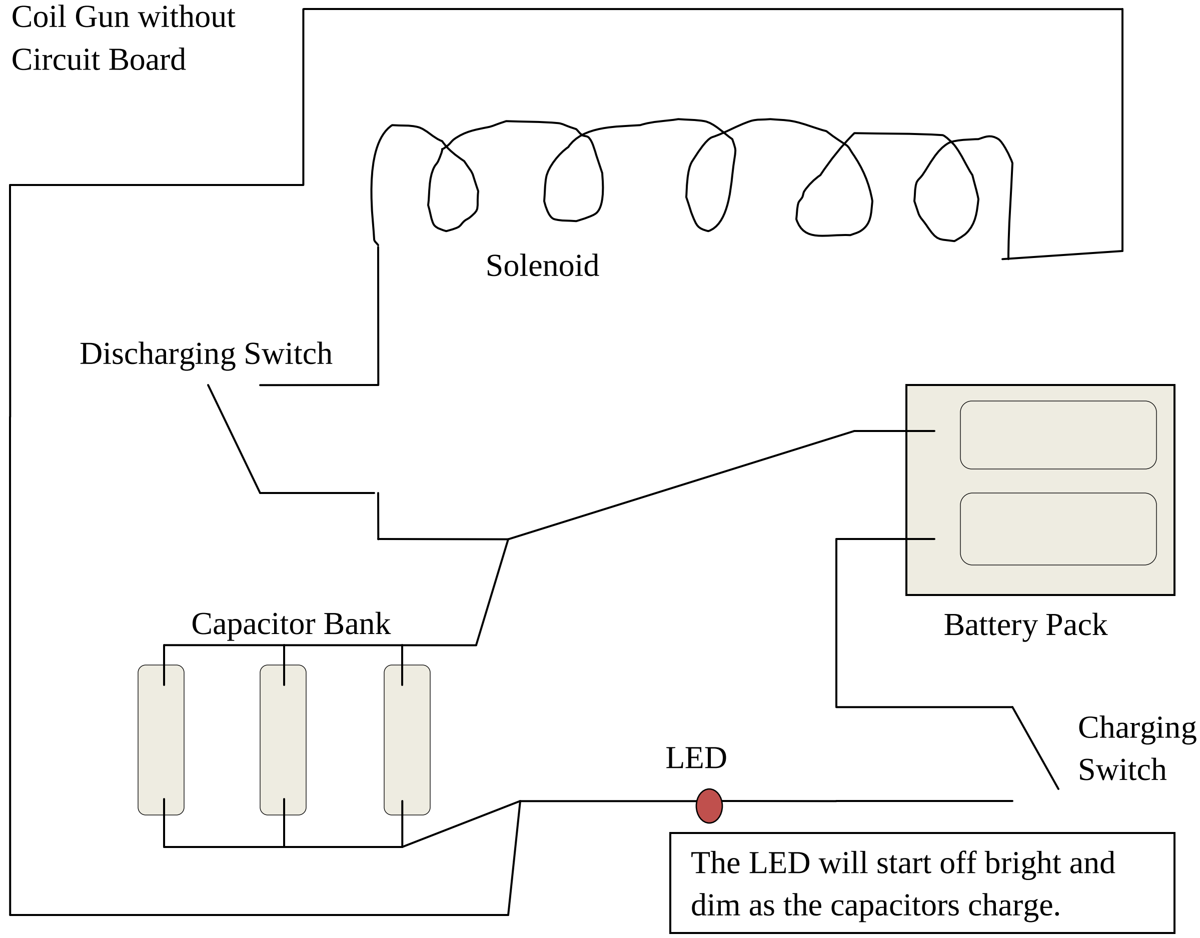
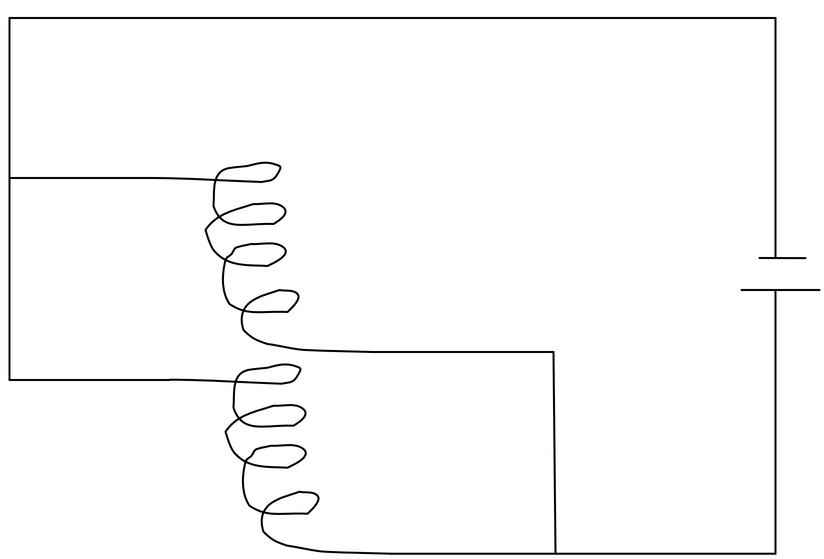


Figure 4

Coils in Parallel



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