Coil Guns: Accelerating projectiles using magnetic fields

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The world of projectiles is one all too often dominated by Physics I concepts. From the simplest projectiles thrown by hand, to standard bullets and even extending to the most complicated multi stage missiles the military has created to date, all of these projectiles are "Physics I weapons" as I like to call them. In some form all of these weapons involve some visible interaction between two physical objects resulting in an intense forward velocity of said projectile. Whether it be calculating the torque of the elbow and speed of the hand as it releases a spear or the amount of potential energy lost to heat, light and sound as a bullet is fired from a gun, the majority of projectiles created in this day and age are done so using the laws and principles learned in our earliest physics courses. However an elite group of projectile launchers exist. These "Physics II weapons" move beyond the realm of the visible. These weapons use magnetic fields generated by flowing current to propel a projectile forward. The most significant of these "Physics II weapons" are the rail gun and the coil gun. Though both equally impressive, for my project I decided to build and test a coil gun. Using this gun I will demonstrate a world of projectile weapons not often seen by the common man, and show that this high velocity world is not dominated solely by the principles of physics I.

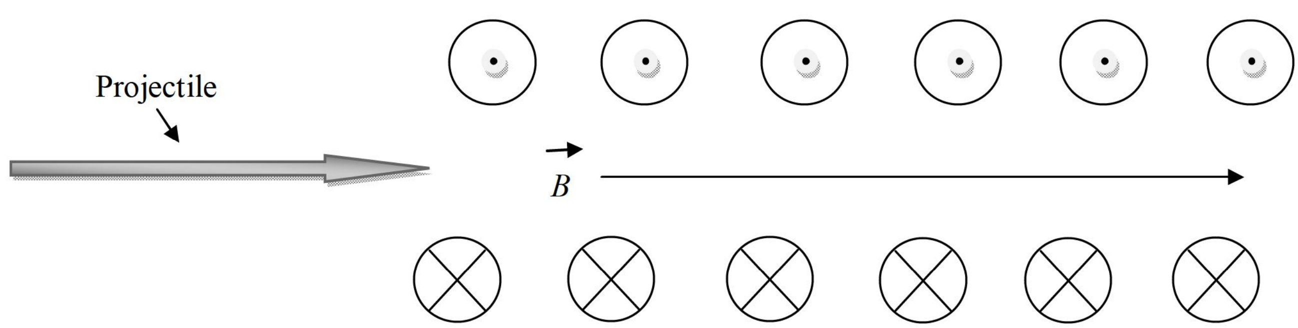
Coil guns are excellent tools when it comes to explaining several key concepts in physics II. Coil guns have relatively simple designs that consist of 5 main components. The first and probably easiest to mess up component is the coil. The coil is basically a super powered solenoid that which consists of many wraps of wire around some sort of insulting tube. The next component is the Capacitor bank. Unlike standard capacitors, coil guns use banks of what are known as flash capacitors. When accessed, these capacitors release all available stored current resulting in an extremely powerful burst of electric current over a very short period of time. This nearly instantaneous burst of current creates a magnetic field that propels the third component, some ferromagnetic projectile, down the tube and out of the barrel. The fourth component is a power source either DC current from some sort of battery or AC current from a wall outlet. The final component is a switching mechanism to switch between charging the capacitors and passing the current through the coil. A basic chipset can be used to wire these components together but said chip is optional and in lieu of the chip all the components can be directly wired to each other. These components describe what is necessary to build the most simplistic of coil guns however; there are some varieties of coil guns that require much more intricate systems to function properly.

There are two main varieties of weapons in the coil gun world: single-stage and multi-stage. A single stage, as described above, involves a single coil producing a magnetic field giving the object a single moment of acceleration. This gun is simple because there is no real timing involved. The only important thing with a single stage coil gun is quickly switching the current on and off. The reason for this necessity will be explained later. A multi-stage coil gun relies on the same concepts as a single stage with one key difference. In a multi-stage gun there are several coils of wire lined up end to end basically creating a long tunnel of several independent solenoids. What this does is allow for multiple moments of magnetic acceleration giving the ferromagnetic object much more velocity as it leaves the barrel. However, these guns are tricky to build because current must be passed through these coils precisely the moment the projectile enters them. This leads to an extremely picky bit of timing that can be solved using an array of complicated methods. This was an issue I was not prepared to overcome and as such a single-stage gun was constructed.

Construction of a coil gun requires some basic knowledge of physics II. In nearly all sets of coil gun instructions I could find, the writer seems to forget to mention which direction to run current through your coil. Unless you have basic knowledge of magnetic fields you could wind up building a coil that produces a field in the wrong directing and subsequently launches the projectile backwards out of your gun and into yourself.....this is obviously incorrect. However with simple application of the right hand rule one can determine which way the magnetic field will point and avoid this embarrassing debacle.

To construct my gun several disposable cameras were harvested for components. Disposable cameras are great for making coil guns because they contain the quick releasing flash capacitors necessary for the project. Ten capacitors were harvested from the cameras as well as one chip for wiring all the components together. The tube chosen for the barrel of the gun was the ink cartridge from a PILOT G-2 gel pen. Though this hollow cylinder was perfect for the project, the explosion of ink in my office and subsequent trail to the bathroom may have generated some tension between the Custodial crew and I. To create the coil 26-gauge enamel-coated magnet wire was chosen. An enamel coated wire is the best option when creating the coil for these guns so that current doesn't pass erratically between the winds or coil layers like might happen if standard unprotected copper wire were used. A 26-gauge wire was chosen because the small size would ensure a large number of loops could be created in a small space yet it was still thick enough to not melt when the large amount of current was passed through it (hopefully). The tube was placed in an electric drill to make the tedious process of winding hundreds of loops of wire more efficient, plus playing with electric drills is fun. Seven layered coils, approximately an inch long, of the magnet wire were wound onto the ink cartridge half an inch from one end. Several inches of wire were left unwound from the coil at both ends of the coil so that it could be easily attached to the chip at a later time. The next step was to create a capacitor bank using the capacitors harvested earlier. First the capacitors were all discharged, and despite my best efforts several of these discharges took place on my skin *queue Dr. Stewarts laughter*. After the capacitors were rendered safe, all 10 were wired together in parallel making a rather robust capacitor bank which was then wrapped in electrical tape to ensure safety. Both the coil tube and the capacitor bank were then soldered to the chipset. Along with these two components, a SPDT (Single pole double throw) switch and a AA battery holder were wired to the chip. All of these components were mounted to the inside of a cardboard box and thus the coil gun was complete. Now that I had a finished product all that was left to do was to test it.

In order to test the gun a projectile was made by cutting the head of a one inch nail. The nail was then placed in the tube with its tip just inside the threshold of the coil. The switch was flipped to charge position, and the delightful high pitched whine of capacitors charging emanated from within the box. The capacitors were charged for 30 seconds after which the switch was flipped into fire position. The nail hurled forth from the tube flying across the room to my relief. The question at hand now is, how did this happen? What caused the nail to go flying when obviously no form of propellant was used? Though no visible interactions took place when the projectile was fired, what we couldn't see happening was the creation of a magnetic field within the loops of wire for just an instant as the energy stored in the capacitors flowed through the wire. Magnetic field forms within a solenoid, i.e. our coil, as shown below.



This magnetic field created by the coil accelerates the object placed behind it extremely quickly effectively pulling it through the tube. As the object enters the tube the current traveling through the wires ends and the magnetic field dissipates allowing the nail to travel through the coil and out the other end of the tube. If the current continued to flow and the magnetic field remained, as the object passed through the center of the coil, it would switch magnetic poles and begin to oscillate within the coil. Thus it is necessary to create the magnetic field for just an instant to pull the object into the tube and allow it to travel out the other end.

Further testing and calculations were performed in order to determine the muzzle velocity of the coil gun. To calculate this, the gun was placed at an elevation of .625 meters with its barrel parallel to the ground. The capacitors were charged for 30 seconds before launching the projectile and the launch distance was recorded. This was repeated 5 times.

Table 1: Data from test firings

Trial 1	4.27 m
Trial 2	4.4 m
Trial 3	4.29 m
Trial 4	4.47 m
Trial 5	4.24 m
Average	4.33 m
Gun Height	.625 m

The average distance was calculated to be approximately 4.33 meters and the muzzle velocity was calculated using the method below.

$$V_o = \frac{Distance}{\sqrt{(\frac{2h}{g})}}$$

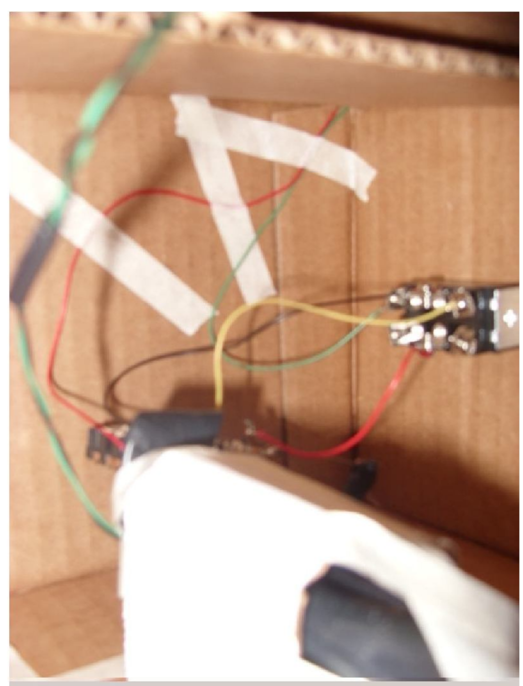
$$V_o = \frac{4.33}{\sqrt{(\frac{2 * 625}{9.81})}}$$

$$V_o = 12.13\ m/s$$

Using the basic concepts of electricity and magnetism found in the principles of Physics II, it was possible to create a coil gun that can fire a nail with a velocity of 12.13 meters per second. It may not be the most powerful coil gun in the world but it works just fine in demonstrating how magnetic fields can be used to create projectiles.

Figure 1: Picture of coil gun top view

Figure 2: Picture of capacitor bank and switch hookup



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