

# Lab I - Electromagnet

Figure 1: A powerful electromagnet sorting out scrap metal!



## Motivation

In this lab we are going to make an electromagnet which is a type of magnet where the magnetic field is produced by the flow of electric current. Electromagnets have many applications and we find them in almost every electrical device, such as motors, generators, loudspeakers, hard disks, scientific instruments, and magnetic separation equipment<sup>1</sup>. In addition, electromagnets are also used to move heavy pieces of scrap metal or even entire cars!

As a second part of this lab we are going to make a motor operating through the interaction of magnetic fields and current-carrying conductors. Can you imagine how such a motor can be made using a regular battery, copper wire, and a small battery?

## History

One of the important discoveries in electromagnetism was that magnetic fields are created by electric current. It was the Danish physicist and chemist Hans Christian Oersted who first discovered this in 1820.

One day he attempted to heat up a wire by passing a strong current through it. In the room where he carried out the experiment, close to the wire, there was a compass needle. Oersted discovered that the compass needle moved when he turned on the current and thus confirmed a direct relationship between electricity and magnetism. And just like that, one of the most beautiful relationships in physics was discovered. Two years later the British scientist William Sturgeon invented the electromagnet which was an insulated horseshoe-shaped piece of iron that was wrapped with bare copper wire. Because at the time, insulated wire was not yet invented!<sup>2</sup>.

Building upon Oersted's experimental work, the French physicist André-Marie Ampère began developing a mathematical and physical theory to understand the relationship between electricity and magnetism.

<sup>1</sup><http://en.wikipedia.org/wiki/Electromagnet>

<sup>2</sup><http://physics.kenyon.edu/EarlyApparatus/Electricity/Electromagnet/Electromagnet.html>

He managed to show that two parallel wires carrying electric current repel and attract each other, depending on whether the current flows in the same or opposite directions, respectively. Some years later, Lorentz derived the equation for the force on a point charge due to electromagnetic fields, and it was now possible to calculate the force on wires carrying electric current.

## 1 Magnetic Force Between Wires

In this part we will consider the forces generated by and acting upon charges in motion.

### 1.1 Theory

The flow of an electric current down a conducting wire is due to the motion of electrically charged particles through the conducting medium. Further, the Lorentz force states that a force is exerted on charges moving in a magnetic field. It seems reasonable that a force will be exerted on a current-carrying wire when it is placed in a magnetic field. This is in fact the sum of forces exerted on moving charges in the wire. Let us now try to find an expression for the force acting on a wire in a magnetic field.

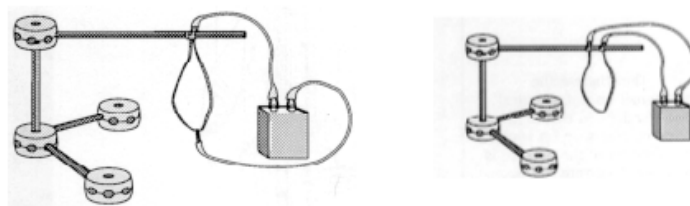
We use magnetic part of the Lorentz force as our starting point and rewrite it for a charge  $q$  traveling a length  $L$  in a wire, we then have

$$\begin{aligned}\mathbf{F} &= q\mathbf{v} \times \mathbf{B} \\ \mathbf{F} &= q\frac{L\hat{\mathbf{n}}}{t} \times \mathbf{B} \\ \mathbf{F} &= IL\hat{\mathbf{n}} \times \mathbf{B}\end{aligned}$$

where  $\hat{\mathbf{n}}$  indicates the direction the wire is oriented in. We see that the magnetic force on a current-carrying wire is also perpendicular to both the wire and the magnetic field with direction given by the right hand rule.

### 1.2 Procedure

Figure 2: The setup used to show the force on two current carrying wires (aluminum strips).



1. The equipment will be set up and demonstrated by a lab supervisor (figure ??<sup>3</sup>).
2. Observe how the aluminum strips are connected to the power source. Which one is a parallel circuit and which one is a series circuit?
3. Note how the the aluminum strips interact with each other when they are in series. What happens when they are parallel to each other?

<sup>3</sup>Figure is taken from [http://www.exploratorium.edu/snacks/circles\\_magnetism\\_IV/index.html](http://www.exploratorium.edu/snacks/circles_magnetism_IV/index.html)

## 2 Solenoid Magnet

### 2.1 Theory

It may not be obvious, at least at first glance, that a solenoid is able to create a magnet field quite like the field from a regular magnet. But due to effects of cancellation, the strongest part of the field is parallel to the axis of the solenoid. In fact, components of the magnetic field in other directions are canceled by opposing fields from neighboring coils, and outside the solenoid the field is much weaker due to this cancellation. For a solenoid which is long in comparison to its diameter, the field is very close to zero outside the coil, while being strong inside, see figure 3.

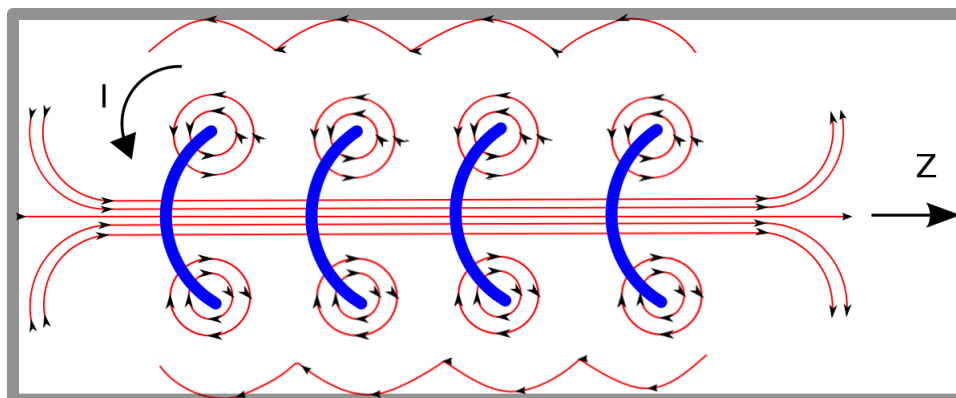


Figure 3: An illustration of the field inside and outside a solenoid. The field is strong the inside, while being weak (close to zero) on the outside.

To calculate the magnitude of the field inside the solenoid, we use Ampere's law which in this case gives us

$$B = \mu \frac{N}{L} I$$

where  $N$  is the number of turns and  $L$  is the length of the solenoid.<sup>4</sup>

### 2.2 Procedure

We want to construct a solenoid by wrapping a copper wire around a cylindrical object.

1. Take a long length of insulated copper wire and wrap it around and around a plastic or paper tube - you may alternatively use a battery. Make the turns preferably as close together as possible.
2. Use some tape to hold the turns close together and remove the plastic or paper tube.
3. Strip the insulation off of both ends of the wires; about 1 centimeter in length.
4. Place a small magnet in the middle of the tube and connect each end of the wire to a battery. **Important:** Leave the current on only for a short period of time or connect a resistor in series with the battery. The wires and battery may become warm and catch fire.
5. Observe what happens.
6. Try turning the solenoid upside-down on top of the magnet and re-connect with the battery. Observe what happens.

<sup>4</sup>A complete description of the field from a solenoid can be found in [our website](#)

### 3 Electromotor

In this last part we will use our knowledge about Lorentz force to construct a simple homopolar motor. Such motor works without the need for a commutator which is an electrical switch that reverses the current direction periodically. The practical applications of homopolar motors is restricted since they must be used with low voltages and produce relatively small torques. However its simple principle of operation clearly shows the beauty of electromagnetism.

#### 3.1 Theory

The name homopolar indicates that the electrical polarity of the motor does not change and it works by rotating along a fixed axis parallel to the external magnetic field produced by a permanent magnet. As the motor moves through an external magnetic field, the current carriers in the conductor experience a push that is perpendicular to both their velocity and to the external magnetic field. This force induces a torque around the axis of rotation and we have simple motor.

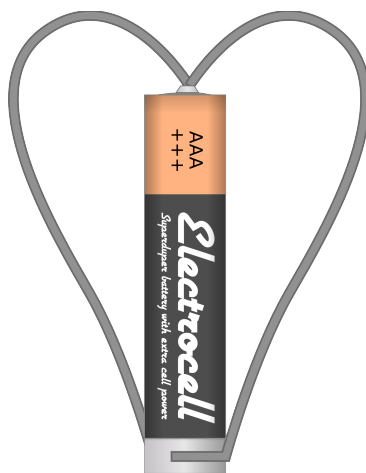


Figure 4: Schematic representation of the pretty, heart-shaped homopolar motor.

In this exercise, you may choose to make the simple homopolar motor or the pretty one. The simple is easier and faster to make, while the pretty is, well, prettier - and a lot more fun! Or you can make both if you have the time.

#### 3.2 Procedure 1 - The Pretty Homopolar Motor

We want to make a motor using a regular battery, a heart-shaped wire and a small magnet.

- Take a 15 cm piece of tin wire and straighten it out, as shown in figure 5a. Make a small bump on the middle of the wire.
- Bend the wire so that it is parallel to itself (Figure 5b).
- Attach a pack of neodymium magnets to the bottom of the battery (Figure 6a).
- Bend the parallel wire into an half-heart shape as shown in figure 6b. Make sure the height of the heart matches the height of the battery and magnet.
- Bend the lower end of the half-heart shape into a 90-degree angle (Figure 7a).
- Bend the parallel wires apart so that they make up a complete heart (Figure 7b).
- Place your heart shaped wire on top of the battery and magnet, just so that the wire touches the magnet on each side (Figure 8). Observe what happens.

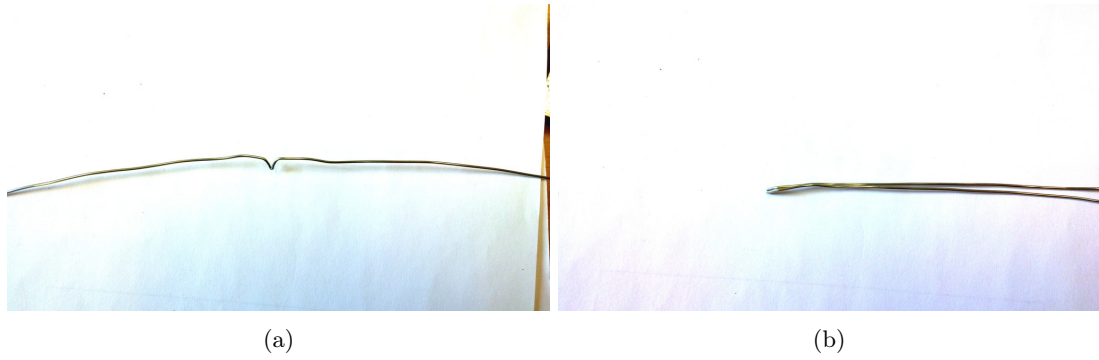


Figure 5

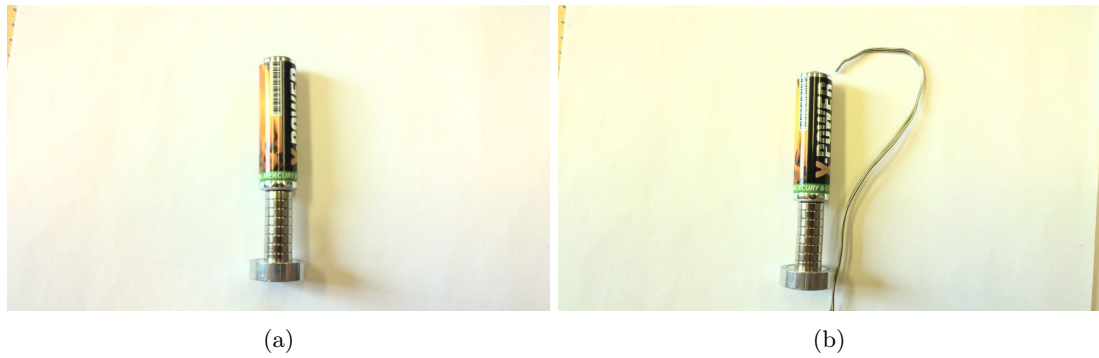


Figure 6

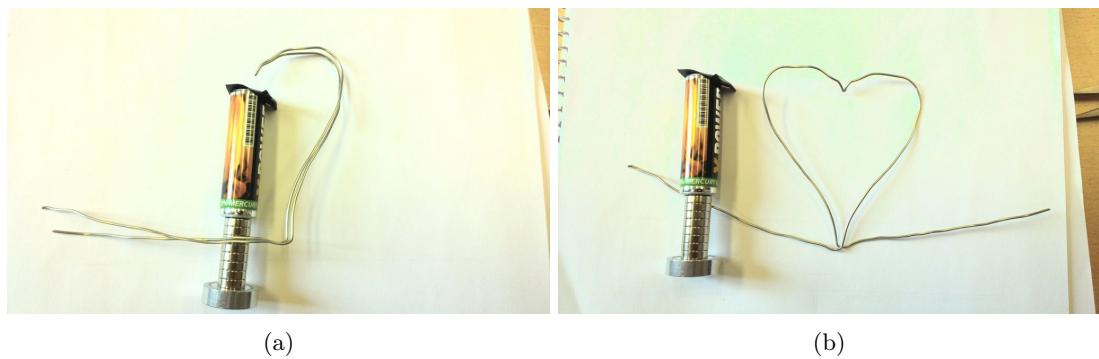


Figure 7

### 3.3 Procedure 2 - The World's Simplest Homopolar Motor

1. Attach the magnets to the head of a small screw.
2. Place the tip of the screw onto the bottom of a battery - with the magnets still attached, the screw should hold on to the battery by magnetic force.
3. Connect a wire to the top of the battery and the lowermost magnet.
4. Observe what happens.

## 4 Equipment list

- Neodym magnets

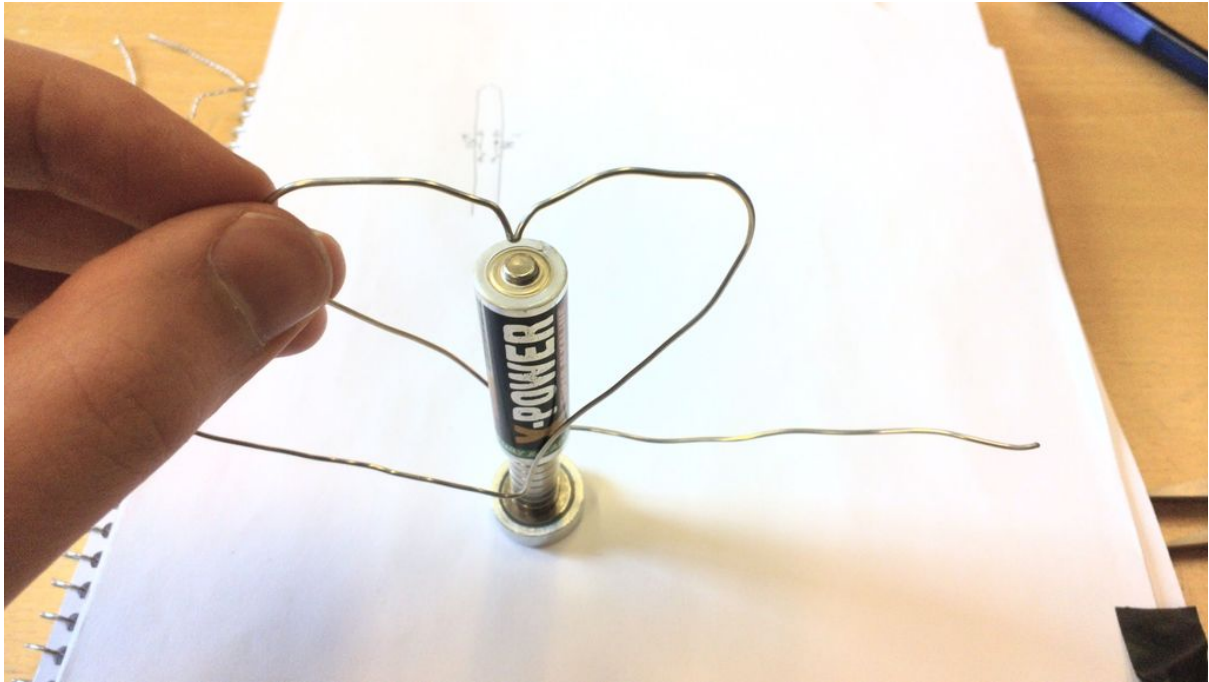


Figure 8

- Tin wire
- Batteries (regular)
- Tape
- Wires
- Aluminium foil
- Pliers

Lab journal: Electromagnet  
Prelab questions

Name: ..... Date:.....

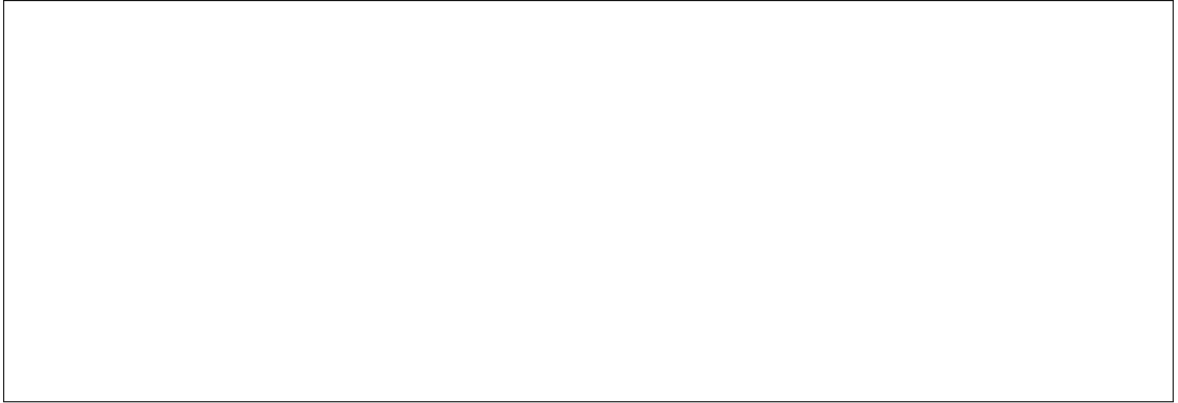
- What is the Lorentz force?
  - The force on a charge in electric field only.
  - The force from a point charge.
  - The force on a point charge in motion, due to electromagnetic fields.
  - Is the same as Coulomb force only.
  
- How can we make a solenoid magnet stronger?
  - Increase the length of the solenoid.
  - Decrease the number of turns.
  - Use a iron core.
  - Increase the diameter.
  
- What characterizes homopolar motors?
  - The rotational axis is not fixed.
  - The electrical polarity does not change.
  - They require commutation.
  - They must be used with high voltages.

Lab journal: Electromagnet  
**Magnetic Force Between Wires**

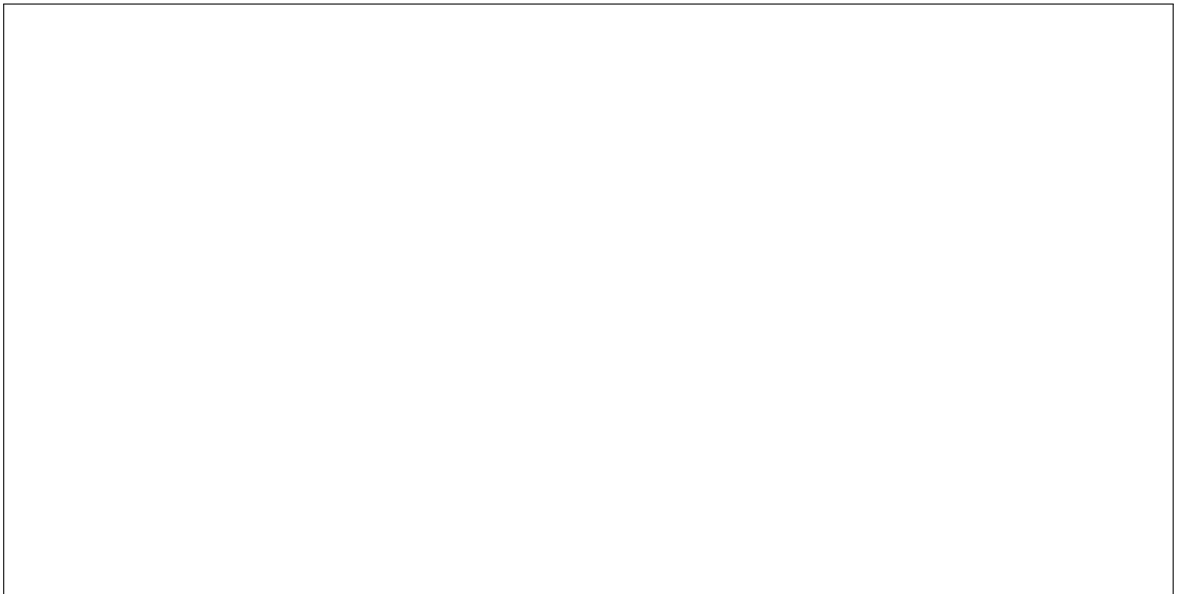
Name: ..... Date:.....

**Questions:**

1. In which case did the aluminum strips attract/repel each other? Explain why.



2. Make a drawing of the magnetic field for each case.





Lab journal: Electromagnet  
Solenoid Magnet

Name: ..... Date:.....

Questions:

3. Explain what you observe.

4. Why does what you see occur?

5. What happens when you turned the solenoid upside down?

6. What would happen if you could control the current and increase or decrease this? How does this relate to the number of turns in the solenoid?

concerned

**Questions:**

7. Explain what you observed.

8. How does this happen? Make a sketch that shows the direction of the Lorentz force caused by the magnetic field and the current through the copper wire. You may use figure 9 as a basis for your sketch if you like.

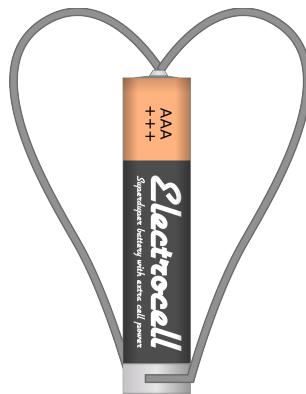


Figure 9: Fill out this sketch with the current, magnetic field and forces on the wires.

9. Why is there no need for any component that controls the rotation as we often do in for instance bipolar motors?

10. How can you make a homopolar generator?