Objective

To learn how to build a simple electric motor and to determine which motor design produces the fastest rate of spin.

Introduction

So, what do windshield wipers, CD players, VCR's, blenders, ice makers, computers, and talking toys have in common? They all contain **electric motors!** In fact, if you walk through your house, it is possible to find as many as 50 electric motors hidden in electrical devices, appliances, and toys in every room in your home. They are a very important and vital part of modern life.

Have you ever played with **magnets** before? If so, you are well on your way to understanding how simple electric motors work. Magnets have a **magnetic field** with a north pole and a south pole. If you play with two magnets and try to push the north poles of each magnet together, the magnets will not go together. They will **repel** each other. The same thing happens if you try to push two south poles together. If two poles are the same, they will repel each other. If, however, you play with two magnets and bring the north pole of one close to the south pole of another, they will **attract** each other and stick strongly together—opposites attract!

An electric motor uses the attraction and repelling properties of magnets to create motion. An electric motor contains two magnets: a **permanent** magnet (also called a fixed or **static** magnet) and a **temporary** magnet. The temporary magnet is a special magnet, called an **electromagnet.** It is created by passing an electric current through a wire. The permanent magnet has a magnetic field (a north pole and a south pole) all the time, but the electromagnet only has a magnetic field when current is flowing through the wire. The strength of the electromagnet's magnetic field can be increased by increasing the current through the wire, or by forming the wire into multiple loops.

To make an electric motor, the electromagnet (the temporary magnet) is placed on an **axle** so it can spin freely. It is then placed inside the magnetic field of a permanent magnet. This is when things get interesting! When a current is passed through the electromagnet, the resulting temporary magnetic field interacts with the permanent magnetic field and attractive and repelling forces are created. These forces push the electromagnet (the loops of wire), which is free to spin on its axle, and an electric motor is born.

Which direction the loops of wire are pushed in can be predicted by **Fleming's Left Hand Rule for Motors.** Hold your left hand out, as shown in Figure 1.

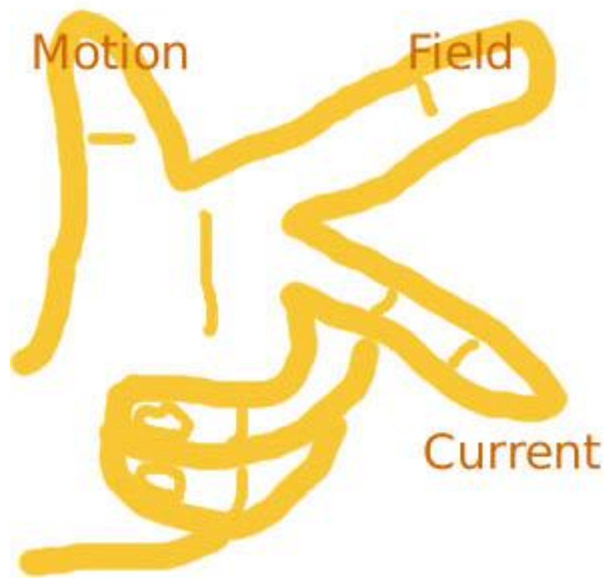

Figure 1. This drawing shows Fleming's left hand rule for motors. (ExplainThatStuff.com, 2008.)

Your pointer finger represents the direction of the field (from north to south) of the permanent magnet. Your middle finger represents the direction of the electric current (which flows from the positive terminal of the battery to the negative terminal of the battery). The direction of the force on the loop of wire (the electromagnet) is predicted by the direction of your thumb. The thumb, therefore, tells you which direction the electromagnet will spin. Try Fleming's Left Hand Rule on the example in Figure 2 and see if your thumb predicts the direction in which the electromagnet will rotate.

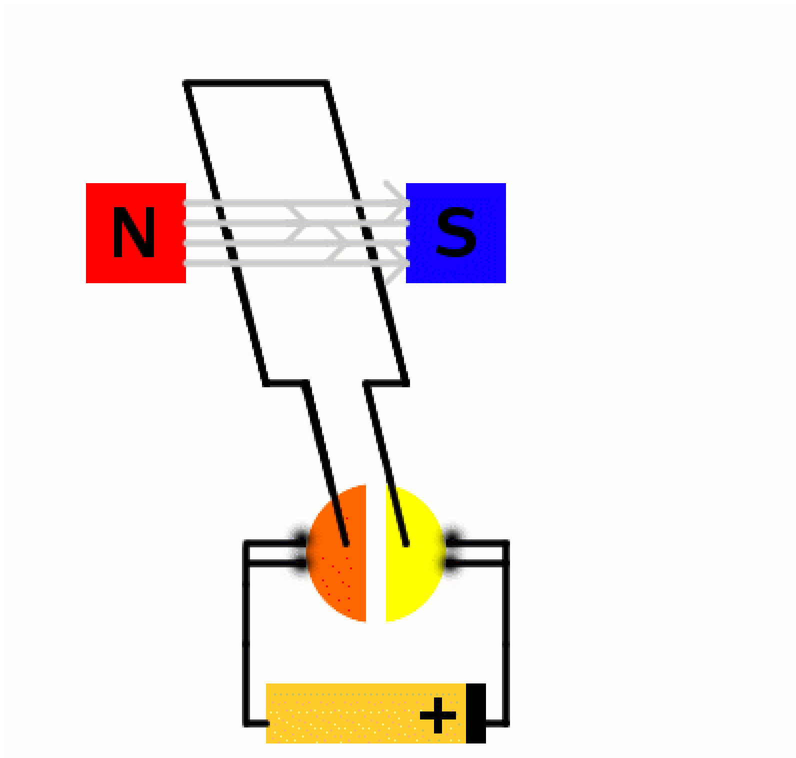

Figure 2. This animation shows the direction the loop of wire (the electromagnet) will rotate, based on Fleming's Left Hand Rule for Motors. (ExplainThatStuff.com, 2008.)

Questions to Start Background Research

Questions

- Where can you find electric motors? How many can you count in your home?
- What happens when two magnets get close together?
- What is the difference between a permanent magnet and a temporary magnet?
- How do you make a temporary magnet (an electromagnet)?
- How can you increase the strength of an electromagnet?
- What are the parts of a simple electric motor? Which of those parts can spin?
- What causes the spinning an electric motor?
- What does Fleming's Left Hand Rule for Motors tell you?

Materials and Equipment

- #2 pencil (4), *or* a wooden dowel or other round cylinder with approximately the same diameter as four pencils wrapped together
- Magnet wire, enamel-coated, 22-gauge (approximately 50 feet)
- Piece of cardboard, about the size of a sheet of paper
- Wire cutters
- Bare copper or brass wire, 18- or 20-gauge, or 6 straightened paper clips
- Nail, small
- Battery holders (3)
- Size D batteries (3)
- Strip of paper (3)
- Magnet

Experimental Procedure

You will be building and comparing three simple electric motors, called **Beakman motors**. The first motor will have 10 coil windings, the second will have 30 coil windings, and the third will have 50 coil windings.

Building Your Electromagnet

1. If you are using #2 pencils, tape four of them together. If you are using some other cylinder with a diameter similar to four #2 pencils skip to step #2.
2. Measure out about 2 inches of magnet wire (the coated wire if you're using the kit), and from that point on, begin winding your magnet wire 10 times around the taped pencils or cylinder. Cut the magnet wire with the wire cutters, leaving about 2 inches free (uncoiled) at each end.
    a. *Tip:* The magnet wire must be neatly coiled. If it is not, the weight may not be evenly distributed making it difficult for the electromagnet coil to rotate in the final motor setup.
3. Carefully slide the loops of magnet wire off the pencils or cylinder.
4. Now you need to wrap the loops so that they stay bunched together and form a tight coil. Wrap each free end of magnet wire around the loops of coil two times in the 3 o'clock and 9 o'clock positions, as shown in Figure 3. If desired, you can then knot the magnet wire to help the coils stay tightly bunched. The free ends of the magnet wire should form a straight line through the coil. The free ends will be the axle upon which your electromagnet (the loops of magnet wire) spins.

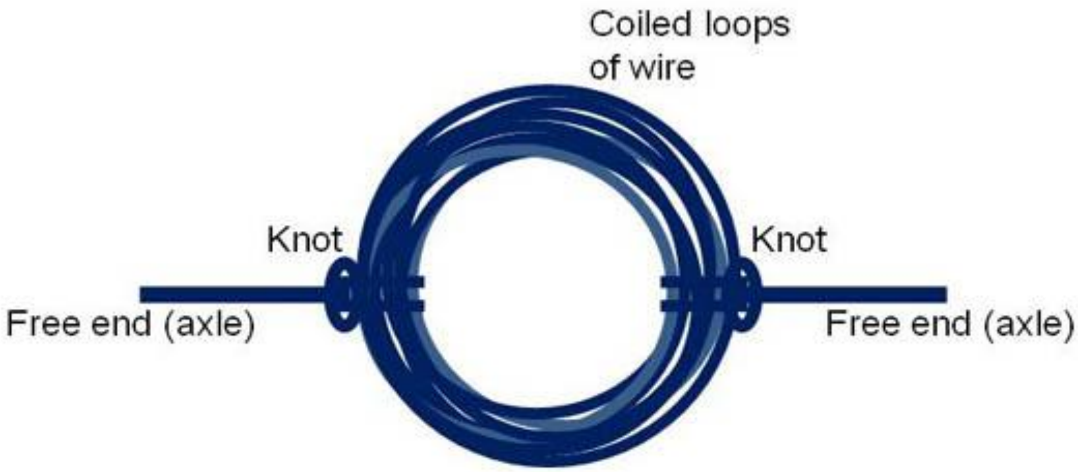

Figure 3. This drawing shows how the electromagnet and the axle that it spins on will look when it is formed.

4. Using a sharp knife, strip off the **insulating** material on *half* of the axles, as shown in Figure 4. The easiest way to do this is to hold the coil between your thumb and forefinger so it is standing upright (the coil is perpendicular to the floor) and then hold the coil off to one side of a table. (If you want to see an image of how to hold the coil, view the sixth figure in these assembly instructions for a Beakman motor.) Lay the axle on a piece of cardboard (to protect the table underneath) and scrape off the top half of the magnet wire with a knife. Be careful not to press too hard when you are scraping or you might cut the wire or cut into the table. Flip the coil around and then scrape the other axle. Scraping off half of the insulating material is done to provide a period of time when current can flow through the coil and create a temporary magnetic field, and a period of time when it cannot. When the bare copper of the axle is rotated down, bare copper will be touching the axle supports, and current will flow to the coil, creating a temporary magnetic field. When the bare copper is rotated up, insulated copper will be touching the axle supports, and no current will flow to the coil.
    a. *Tip:* Only strip off half of the insulation. Stripping off more will result in a motor that does not work.

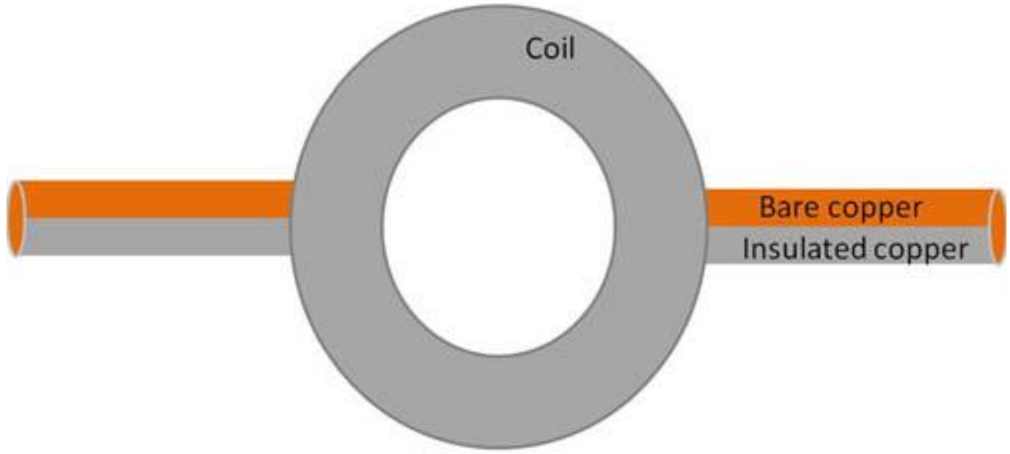

Figure 4. This drawing shows the parts of the axles to strip of insulating material.

Building Your Axle Support

1. With the wire cutters, cut two equal lengths of stiff, bare copper or brass wire, approximately 6 inches long. Two straightened paper clips are also possible alternatives.
2. Bend each wire around a small nail to form a loop. Slip the wires off the nail. Now each axle support should look like the end of a safety pin. Each one should look like a loop with two legs.

Building Your Electric Motor Base

1. The battery holder makes a good electric motor base because it is heavy and stabilizes the electromagnet as it spins. Wind the free ends of your axle supports (the two legs) into the holes in the plastic at each end of the battery holder, as shown in Figure 5.

Building Your Electric Motor

1. Insert each axle into an axle support. Adjust the axle supports so that they are close to the coil, but not touching it.
2. Place the magnet on top of the battery holder, below the coil. Give the coil a few turns to makes sure it can spin freely and does not rub against the magnet.
3. Place the battery and a strip of paper inside the battery holder. The strip of paper is the on/off switch. When the paper is in place, it acts as an insulator and prevents current from flowing (the switch is off). When you pull out the paper, current can flow. It is like turning the switch on. Your finished electric motor should appear similar to the setup shown in Figure 5.

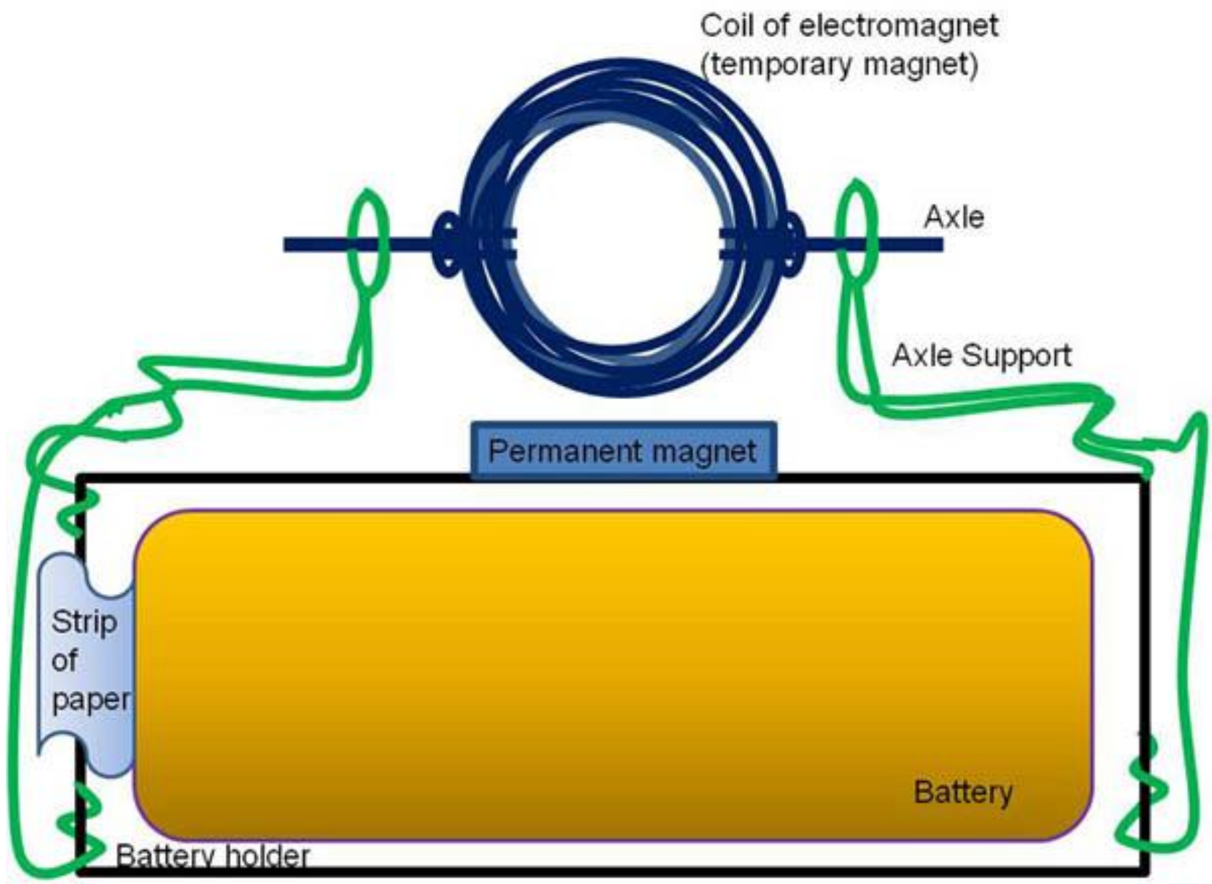

Figure 5. This drawing shows how to connect the electromagnet and its axles, the permanent magnet, axle supports, battery, and its paper switch to form a simple electric motor.

4. Repeat the steps Building Your Electromagnet through step 3 of Building Your Electric Motor, replacing the 10 windings with 30 windings, to form your second electric motor.
5. Repeat the steps Building Your Electromagnet through step 3 of Building Your Electric Motor, replacing the 10 windings with 50 windings, to form your third electric motor.

Testing Your Electric Motors

1. Now that you have built all three of the electric motors, it is time to test them.
2. Start with the 10 windings motor. With your finger, gently make sure that the electromagnet (the magnet wire coil) can easily rotate 360 degrees. If it can not, the weight is not distributed correctly, and you will need tinker with the shape (or even re-coil the magnet wire) until it can rotate smoothly.
3. Use Fleming's Left Hand Rule for Motors to predict which way the motor should spin.
4. Remove the strip of paper from your first motor. The electromagnet should start to spin on its axles. If it does not, there may be a problem with your motor design. Try these troubleshooting tips:

a. Make sure the insulation is stripped from only half of each axel. If you strip too much it will not work.
b. Make sure the stripped part of the axels both face up. If they face opposite directions the motor will not work.
c. Go back to step 1 of Testing Your Electric Motor and make sure the electromagnet can rotate smoothly.
d. Make sure your battery is fresh. This motor will drain a battery quickly, even one that is not rotating.
e. Try repositioning the permanent magnet slightly. There is often a 'sweet spot' for the permanent magnet where the motor works the best.

5. Write down the direction of spin in your lab notebook. Just for fun, flip the magnet over. What direction does the motor spin now? Does this agree with Fleming's Left Hand Rule for Motors?
6. When you want to stop the motor, replace the strip of paper.
7. Repeat steps 2-6 for the 30 windings and 50 windings motors.
8. Once you have all three of your motors working, start them all at the same time. Visually inspect them to see how the rate of spinning compares. Which is slowest? Which is fastest? Why?