Electromagnetism: Magnets and Motors
Teacher Version

In this lab, we will see how electricity and magnetism can be used together to create motion. Our source of electricity will be from a battery, and our source of magnetism will come from, of course, magnet. With these two objects we will be able to create a motor, which will create motion in a piece of wire.

California Science Content Standards:

- **5. Electric and Magnetic Phenomena: Electric and magnetic phenomena are related and have many practical applications.**
- 5e. Students know charged particles are sources of electrical fields and are subject to the forces of the electrical fields from other charges.
- 5f. Students know magnetic materials and electric currents (moving electric charges) are sources of magnetic fields and are subject to forces arising from the magnetic fields of other sources.
- 5g. Students know how to determine the direction of a magnetic field produced by a current flowing in a straight wire or in a coil.

Prerequisites:

- Better for older students (grades 8-12)
- Requires assimilation of multiple concepts such as magnetism, insulation, electricity, etc.

Complete List of Material:

Part 1:

- 3 steel/iron nails (3 different diameters)
- 10 feet of coated 24 gauge wire
- paperclips
- 5 inches of string
- 3 nine volt batteries (new batteries work best)
- 9V battery connectors
- sandpaper
- scissors
- 4 alligator cable clips

Part 2:

- 24 gauge wire
- wire strippers or scissors
- permanent marker
- plastic or styrofoam cup
- 2 disk magnets (stronger magnets work better)
- paper clips
- 2 large rubber bands
- 2 alligator cable clips

Key Concepts:

- An **electron** is a negatively charged particle.
- The flow of these negatively charged is called an **electric current**.
- When the electrons flow in this current, they carry an electric charge, which causes electricity. This is the same electricity used to power many machines that you see everyday. Batteries are used to store electricity until you are ready to use it.
- Electricity is closely related to magnetism. You are familiar with magnets. Motors work by using electromagnets. This means that the magnetic part of something is turned on and off by using electricity.
- Motors use electrical energy (from electricity) to create **mechanical energy**. In other words, motors are responsible for the movement of many devices including cars and computers. In fact, small motors and magnets are important parts of many kinds of medical equipment. Can you think of any other devices that use motors?
- A **conductor** is an object that allows a charge to flow. Depending upon a material's conductance, electricity can flow freely through the material. Metals are good conductors of electrical current. Another thing to consider when talking about electricity is resistance.
- **Resistance** is the opposition of electron flow. Materials with a high resistance are not good conductors of electricity since they keep the current from forming. The wire is a good conductor, and the coating that protects it does so because it has high resistance. In order for the current to complete the circuit, it must be allowed to flow from the wire to the paperclip with little resistance. To do so, we must remove the insulation (what allows the resistance to occur).

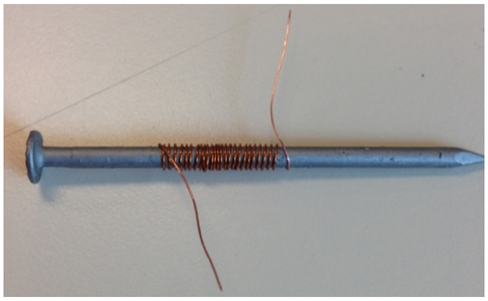
Introductory Mini-lecture:

All metals contain small magnetic fields in small regions of atoms called domains, but their poles are all facing different directions so the small magnetic fields cancel each other out. It takes a lot energy to maintain a magnetic field, so cancelling out the small fields requires less total energy. Certain metal such as iron or steel create stronger magnets because they are easier to align. When the iron is subjected to the magnetic field from the coil, the domains align based on the magnetic field of the coils (to understand the directionality of the magnetic field, see the right hand rule diagram at the end of the Teacher Version), and the combination of these small magnetic fields creates one stronger temporary magnet. This can be used for picking up household items such as a paperclip. In an industrial setting, using a lot more electricity, wire, and metal can create a magnet that can be used to pick up cars in a junkyard. In this experiment you will be seeing how the number of coils around a nail and the voltage going through the coil can affect the strength of the magnet by seeing how many paper clips you can pick up while they are chained together.

Part 1 – Electromagnets

In this part of the lab, we will see how an electric current can create a magnet out of normal metal objects. The metal objects that will be used are several different size iron nails, and the electricity will be provided by nine-volt batteries. The reason the nail becomes temporarily magnetic is because the electric current running in a helical shape creates a magnetic field. We will experiment with variations of the components of the electromagnets to see how changing the various elements will affect the power of the magnets.

Effects of different amount of wires:



1. Wrap wire tightly around nail 10 times, leaving around 2 inches on each end. Remember to remove the insulation at the end of the wire using sandpaper or scissors. (See Figure 1)
2. Attach each end of the wire to battery using alligator clips.

****WARNING: AFTER THE CIRCUIT IS COMPLETED, THE WIRES WILL GET HOT.***

3. Straighten a paperclip.
4. On one end make a small loop that you can stick to the nail
5. On the other end make a little hook that you can tie the string to
6. Tie the string to the end of the hook and slide the paper clips over the string every two inches starting 2 inches away from the magnet.
7. Slowly pick the string up and count how many paper clips make it fully in the air before the paper clip attached to the magnet falls off.
8. Record number of paperclips on the chart below.
9. Change the number of wraps around the nail to 25, then 50. Make sure the first coil is the same distance from the flat nail head each time.
10. Record number of paperclips on the chart each time.

Number of wraps of wire	Number of paperclips
25	
50	

Effects of different voltages:

1. Wrap wire around nail 50 times.
2. Attach wire to 1 battery.
3. Slowly pick the string up and count how many paper clips make it fully in the air before the paper clip attached to the magnet falls off.
4. Record number of paperclips on the chart below.
5. Change the number of batteries to 2, and then 3, while keeping the number of loops around the nail the same (record number of paperclips on the chart each time).

Number of batteries	Number of paperclips
1	
2	
3	

Effects of different sized nails:

1. Wrap wire around the smallest nail 50 times.
2. Attach wire to 1 battery.
3. Slowly pick the string up and count how many paper clips make it fully in the air before the paper clip attached to the magnet and falls off.
4. Record number of paperclips on a chart.
5. Repeat steps 1-4 for the medium and large sized nails. Make sure the first coil is the same distance from the flat nail head each time.

Nail Size	Number of paperclips
Small	
Medium	
Large	

Concept Questions:

Q1. Why do you use steel or iron nails?
Steel or iron nails are used because it is easier for their domains to align than in some other metals.

Q2. Why do you use insulated wire as opposed to non-insulated wire?
The electricity wants to find the shortest path possible so in non-insulated wire if the wires are touching the electricity will go straight across as opposed to going around the coil.

Q3. Based on the data for changing the number of coils, why would you want to have thin insulated wire instead of thick insulated wire?
You want thin insulated wire because you are not working with high voltage so the wire insulation doesn't have to be as strong and with a thinner wire you can fit more coils around a smaller space which produces a stronger magnetic field.

Q4. Why do you think you hooked the paper clips to a string and held the magnet by one paperclip?
You want to see how much weight it can hold instead of how far the mantic field reaches. With the paper clip on the string the paperclips are far enough away that the magnetic field isn't pulling the weight of each individual magnet but the weight of all of them combined.

Part II- Electric Motor

In this part of the lab, we will see how electricity and magnetism can be used together to create motion. Our source of electricity will be from a battery, and our source of magnetism will come from, of course, a magnet. To power the motor, electrons must flow freely through a good conductor to create electricity. The voltage of the battery we are using will also dictate how well and how fast our current moves through our conductor. The conductor in our motor will be a thin piece of copper wire to transport our electrons. As electricity flows through the wire, the wire will begin to rotate. This is the motion we are looking for in our motor!

Procedure:

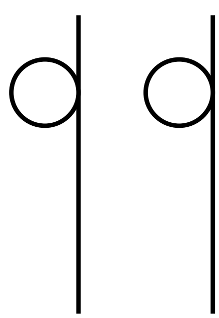
1. Make a coil of wire by loosely wrapping the wire around the fat marker (like a standard Crayola marker) least four or five times. Leave an inch or two of wire loose at each end of the coil.

2. Remove the coil from the marker and wrap the ends of wire around the coil to keep it from unraveling.

**NOTE: The loop must be even and the end wires as straight as possible so that the coil will spin evenly. If the wires are unbalanced, the coil will be weighted down on one side.

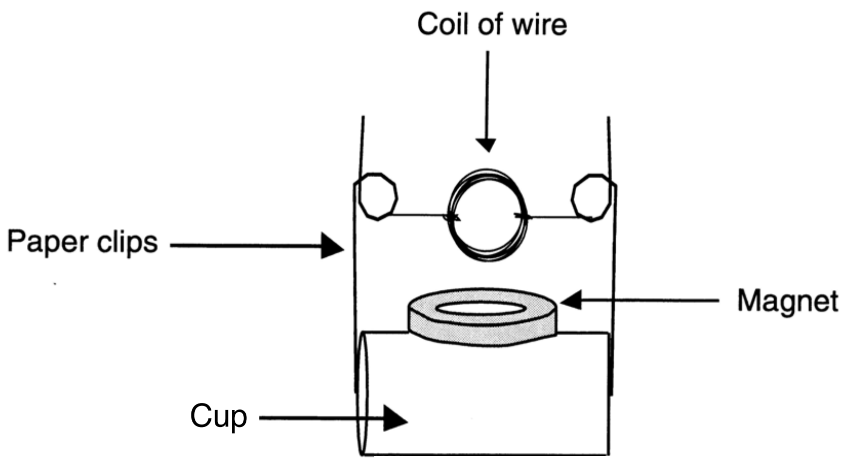
3. The wire has a coating on it that acts as insulation. Strip 0.5 - 1 inch of coating off each end of the wire using the sandpaper. Don't rub too hard or the wire will break! Make sure all of the coating is off on all sides of the two ends.

4. Straighten the two paper clips and make a loop in each by wrapping the end of the paper clip around a pen or pencil. The loops should be near the end of the paper clip.



5. Place the cup upside down on the table and place a magnet on the bottom of the cup. Then attach one paper clip to each side of the cup with a rubber band so that the loops face up.

6. Place the coil of wire so that the ends stick through the loops in the paper clips and the coil is above the battery. Make sure the spinning coil just misses the magnet and the paperclip loops are level.



7. Clip one alligator clip to each of the paper clips and hook the other end to the battery.

***WARNING: AFTER THE CIRCUIT IS COMPLETED, THE WIRES WILL GET HOT*

8. Give the coil a gentle spin; adjust the paper clips and coil until the coil spins continuously.

Different Testing Ideas:

How can we make our motor more powerful?

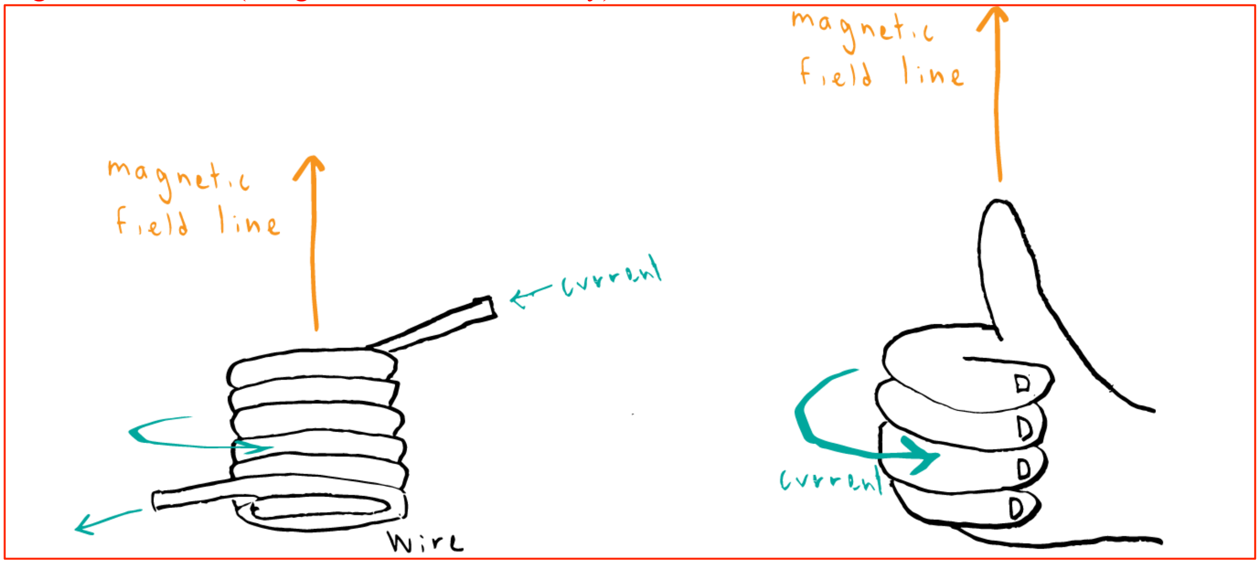
We can test your ideas on how to create a more powerful motor. We can increase the strength of the magnet we are using (use two magnets instead of one), vary how far we have the coil from the magnet, use a different type of wire (different resistance or conductivity), or change the number of coils we have in our wire. Which change makes the motor spin faster?

The insulated wire forces the electricity to pass through all the coils of the wire. As in the electromagnet, this makes a temporary magnet out of the coils. It will be a magnet as long as electricity is flowing through the coils. If non-insulated wire is used, the electricity would take the shortest path open to it and would not go around and around the coils.

As in the other electromagnet, when an electron moves down a wire, it creates a weak magnetic field around the wire. By coiling the wire, we strengthen the magnetic field because we add up the effect of lots of electrons all moving around the coil in the same direction and all creating tiny fields. The more rounds of coiled wire, the stronger the field.

When this temporary magnetic field comes in contact with the magnetic field from the doughnut magnet, the attraction or repulsion is enough to push the thin wire coil around. The push/pull is just like bringing two doughnut magnets together... you can feel it! It's that alternating push/pull that keeps the motor going around and around. If you want to better understand the directionality of the push/pull you can look up the right hand rule for relating the direction of the magnetic field to the current through the wire (image below). If we want to make a more powerful motor, we can use more coils of wire (most industrial motors have hundreds) and stronger magnets.

Right Hand Rule: (image from Khan Academy)



Concept Questions:

Q5. *An electromagnet is a magnet that runs on electricity. An electric current runs through an object (such as our wire) to produce a magnetic field. So, can you think of anything else in the motor that is magnetic beside the disk magnet we placed on top of the battery?*
The wire acts as an electromagnet. The electric current from the battery runs through the wire and produces a magnetic field within the wire.

Q6. *An insulator is a material that resists the flow of electric current. The insulation around the wire we used keeps the electricity within the wire. Do you think we needed to use insulated wire in order for our motor to work? Why or why not?*
Yes we do need an insulated wire in order for the motor to work. In order for our wire to act as an electromagnet, we need the electric current to remain within the coils of the wire. This creates a stronger magnetic field. The insulated wire forces the electricity to pass through all the coils of the wire.

Q7. *Why do you think we coiled the wire?*
We coil the wire to create a stronger magnetic field. The electrons within the wire all move in the same direction, which creates a magnetic field. By coiling the wire, we can add up the effect of many electrons moving in the same direction each with its own magnet field.

Q8. *Why did we scratch the coating off the ends of the wires that touch the paper clips?*
The insulation around the wire keeps the electric current inside the wire, and it keeps electric current from getting inside the wire. We scratched the coating off the ends of the

wire to allow the electric current from the battery to flow through the wire.

Q9. What happens if we increase the voltage supplied by the battery (or replace the one battery with two batteries)?
Increasing the voltage will cause an increase in current flow, which can be interpreted as an increase in power input. This will cause the motor to spin faster. In an ideal motor, the spin speed should increase proportionally to the increase in voltage. But due to non-ideal effects (internal resistances in the wires, back electromotive force, ect) the spin speed will not quite increase proportionally to the increase in voltage.

Q10. What would happen if the area of the loop was increased?
An increase in the area of the loop would theoretically not increase the spinning speed of the loop. This is because while increasing the area would increase the magnetic field produced by the coil making it spin faster, it would also increase the back-electromotive force, which slows down the coil at the same rate.