Electromagnetic Forces

Daily life is subject to forces found in nature. A force is any interaction that, when unopposed, changes the motion of an object. For example, gravity is a force that keeps our feet on the ground. In order to jump into the air, your legs must overcome gravitational force. Electric and magnetic forces influence all aspects of daily life. Electromagnetism refers to the close interrelation between electricity and magnetism. Electric forces can produce magnetic forces, and magnetism can produce electric forces.

Electromagnetism is at the core of most music produced in the twenty-first century. Electromagnetism underpins how microphones, loudspeakers, and headphones work. The following activities are meant to help you discover electromagnetism.

Figure 1: Loudspeakers and many microphones rely on principles of electromagnetism.

Arizona Science Standards 2018*

4.P2U1.2 Electric currents
4.P2U1.3 Magnetic forces
5.P2U1.3 Balanced and unbalanced forces
6.P2U1.4 Forces act on objects at a distance
7.P2U1.1 Electromagnetic forces can be attractive or repulsive and can vary in strength

**Arizona Department of Education. "Arizona Science Standards." 2018. www.azed.gov/standards-practices*

Materials

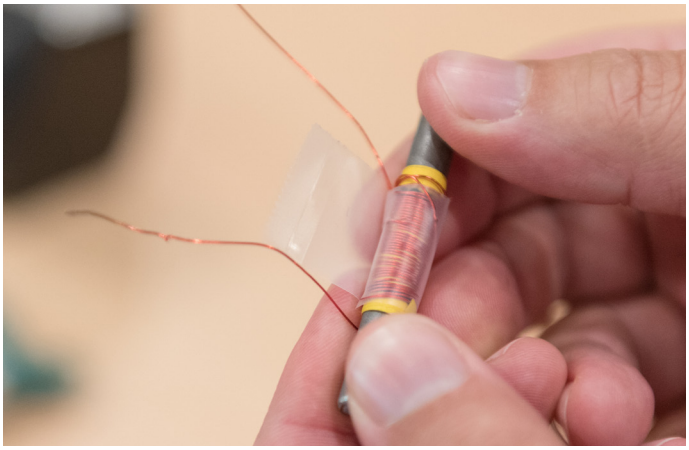
- 100 cm of very thin, **coated copper wire (28 AWG or smaller)**
  NOTE: Carefully scrape or burn the insulative coating from both ends of the wire using a lighter, sandpaper, or small razor.
- (1) **0.25 in. plain steel rod** cut into 5 cm lengths
- (6) **6 mm x 3 mm permanent magnets**
- (1) **3.5 mm mono audio plug to alligator clips** terminal adapter or 3.5 mm **audio terminal block (male)**
- (2) **Alligator clip test leads**
- (1) 9 V battery
- (1) Scissors
- (1) Tape
- (1) Paper—for both the speaker "cone"and to use when making the wire coil
- (1) Pen or Pencil
- (1) Plastic Cup
- (1) Paper Clip
- (1) Cell phone, iPod, Walkman, or other device with a 3.5 mm jack that can both play and record music/sound

Part I: Electromagnets

How does an electromagnet work?
How can I make one of my own?

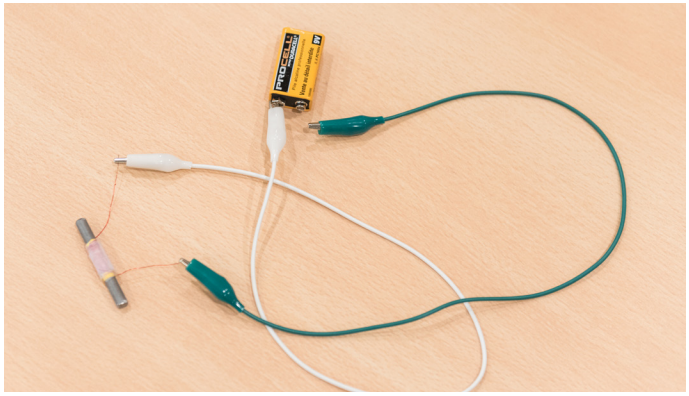
1. Cut a 2 cm strip of paper.
2. Draw two parallel lines approximately 1.5 cm apart lengthwise along it.
3. Wrap the strip of paper around the metal rod two times with the parallel lines showing. Cut off excess.
4. Tightly coil the wire around the rod at one of the two parallel lines, coiling in the direction of the other line. Keep each wrapping of the coil as close to the previous one as possible. Continue this process until you have a coil that is at least 1.5 cm wide. Leave approximately 5 cm of wire free on either side of the wire coil.

5. Wrap scotch tape around the circumference of the wire coil to keep it from unraveling.

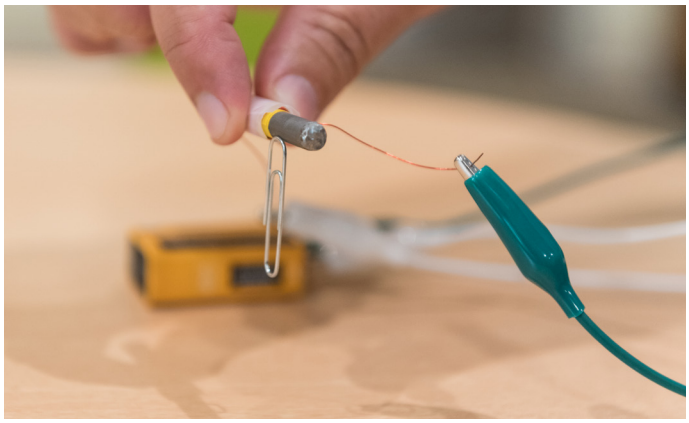


6. Connect each end of the wire coil to a different test lead. Then, connect the negative (-) terminal of the battery to one of the test leads. When ready, connect the positive (+) terminal of the battery to a test lead.

WARNING: Do not leave the battery connected to the electromagnet for more than a few seconds at a time. Always disconnect the battery immediately after use. The electromagnet and battery may become extremely hot if left connected for extended periods.



7. Try to pick up the paper clip with one end of the wire coil.



8. Disconnect the battery. Try to pick up the paper clip again.

Why does the paper clip stick to one end of the wire coil when the battery is attached?

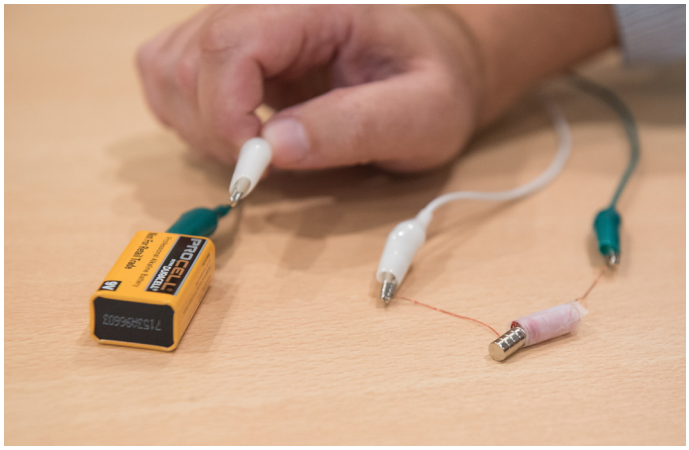
Connecting a battery to both ends of a wire creates a path or circuit along which an electric current can flow. A magnetic field is generated as electric current flows through a wire. The greater the current and the tighter that a wire is wrapped into a coil shape, the stronger the magnetic field that is produced.

Part II: Electric Motors

How does an electric motor work?
How can I make one?

1. Carefully slide the wire coil off of the metal rod. Remove the paper tube.

2. Place three of the 6 mm x 3 mm magnets in one end of the wire coil; the other three magnets should be visible outside of the coil.



3. Reattach the battery.
4. Disconnect the battery.

Why does the magnet move (either inward or outward) when the battery is attached to the coil?

5. Place the magnet into one end of the wire coil facing the opposite direction.
6. Reattach the battery.
7. Disconnect the battery.

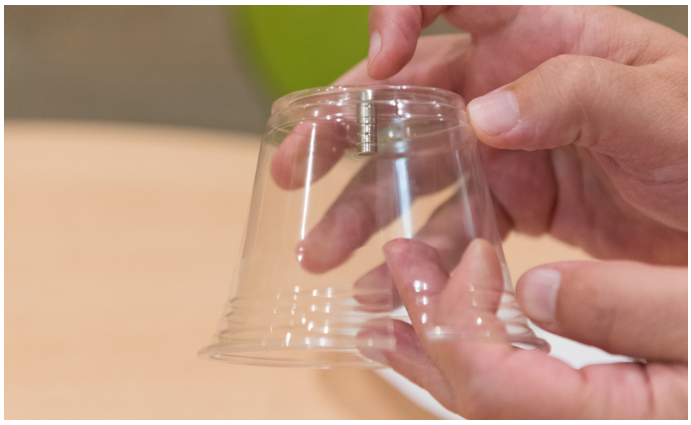
Why does the magnet change directions depending on which direction it is placed into the wire coil?

Magnetic forces have polarity, north to south, or negative to positive. Opposite polarities attract one another while similar polarities repel one another. The permanent magnet will either be shot from the end of the wire coil or sucked further inside, depending on which of its poles is facing into the electromagnet, as well as the polarity of the electromagnet. Remember, opposite polarities attract, and similar polarities repel. Electric motors rely on this same principle. An electromagnetic coil arranged around a central axis creates an oppositional force with the permanent magnets that surround it. This causes the motor to spin on its axis.

Part III: Loudspeaker

How does a loudspeaker rely on electromagnetism to create sound?

1. Speaker Chassis
   a. Make a single cut in the plastic cup from rim to base.
   b. Affix a stack of five magnets to the inside-center of the cup's base using a sixth magnet on the outside.



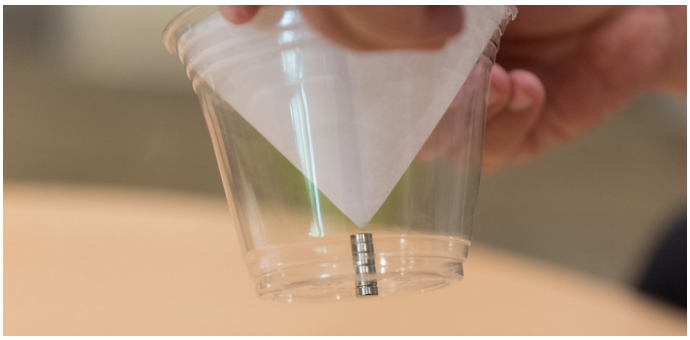
3. Speaker Cone
   a. Trace and cut a circle with a 12–16 cm diameter on a piece of paper.
   b. Find the center of the circle by folding it in half along its diameter in one place, opening it back up, and then folding it half again along its diameter in another place. The center of the circle is where the two folds meet.
   c. Cut a straight line along the radius of that

circle (i.e., from the edge to the circle's center).

d. Make a cone by sliding one side of the cut radius over the other.

e. Place the cone inside the cup with its vertex facing downwards.

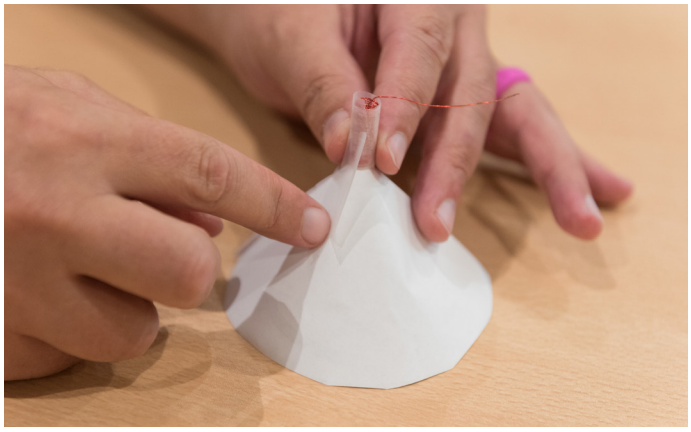
f. Adjust the height of the cone so that its vertex rests gently on the stack of magnets and its circumference rests on the rim of the cup. Depending on the diameter of the cup you use, the slant height of the cone may need to be more or less steep.



g. Place a small piece of tape on the inside of the cone to hold everything in place. Cut and remove the excess flap of paper formed on the outside of the cone.

8. Voice Coil

   a. Tape the wire coil to the outside vertex of the cone. Ensure that the bottom of the coil remains unobstructed.



2. Assemble the Loudspeaker

   a. Place the cone inside the cup so that the stack of magnets slides freely into the wire coil.

   b. Route the wire-ends of the voice coil through the cut in the side of the cup.

   c. Attach the wire-ends of the voice coil to the 3.5 mm audio adapter (alligator clips or terminal block).

   d. Insert the 3.5 mm jack into your audio player.

   e. Press play.

The electric current of an audio signal fluctuates rapidly, causing corresponding fluctuations in the magnetic field being generated in the wire coil. As in the electric motor, when the polarity of the magnetic field in the wire coil is the same as the polarity of the stack of magnets, an oppositional

force is created. As this oppositional force begins and ends so quickly, it can be felt as vibrations. These vibrations are transferred to the speaker cone and then to the surrounding air. The vibrating air causes our ear drum to vibrate, which our brain is then able to interpret as sound.

Troubleshoot:

- Tightly wound coils produce a more focused, stronger magnetic force than loosely wound coils. If the wires of your coil have large spaces between them, dismantle the coil and rewind per Part I.
- A secure connection between the voice coil and speaker cone will more effectively transmit the sound vibrations generated by the audio signal.
- Ensure the insulative coating has been scraped or burned off the ends of the copper wire. This coating does not conduct electricity.

Part IV: Microphone

How are microphones and loudspeakers related?

1. Connect the 3.5 mm jack to an audio recording device. On a cell phone, simply open a voice recording app or start a phone call with a friend in another room.
2. Speak LOUDLY into the speaker you have just made from very close proximity. Your recording device should pick up a faint signal as if from a microphone.
3. Play back the recording you just made with your homemade microphone on your homemade loudspeaker.

Microphones work similarly to loudspeakers, only in reverse—they take sound vibrations in air and convert them into fluctuating electric signals. While there are many different types of microphones, so-called "dynamic" microphones function identically to an electromagnetic speaker in that they have a small coil of wire suspended in a magnetic field. When sound vibrations cause that coil of wire to vibrate, it generates small amounts of fluctuating electric current. This electric current is then directed to an amplifier and then a loudspeaker, or into one of many technologies that "record" the fluctuations of this current for later use.