# POSITIVE YOUTH DEVELOPMENT STEM
# LEARN TO USE THE FORCE! ELECTROMAGNETS

Activity Plan v3

**Objectives:**

- Understand the basics of how electrons move through a circuit.
- Explore the concept of electromagnetism to have a basic understanding of how electromagnets do physical work.
- Create a simple electromagnet and be able to define the components of the system and their purpose.
- Describe how electric energy can be converted to magnetic energy.

**Life Skills:**

- Explore careers and educational degrees to understand how these skills are used in the workplace.
- Practice their observation and data collection skills to improve their problem-solving abilities.

**Do Ahead:**

Order the 4-H Selenoid Kit from:

- Joanna Skluzacek joanna.skluzacek@wisc.edu

**Audience:**

Youth ages 10 – 16

**Time:**

90 minutes

**Supplies Needed:**

1. 4-H Electromagnetic Forces Kit
2. Pen/pencil and paper to record data
3. Wire clippers
4. Masking Tape
5. *Optional: electric drill*

**Table of Contents:**

# 1. Introduction

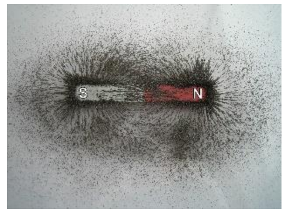
*Hard disk for PC*

"disque dur - hard disk" by abdallahh is license CC BY 2.0

Electromagnets are used in a wide variety of items you find in your home and the world around you. Invented about 200 years ago, electromagnets are a critical technology used to solve many of today's challenges. Examples include motors, speakers, doorbells, smart locks, induction heating stoves, hard disk drives, and magnetic levitation.

In the following experiments, we are going to create two simple electromagnets and explore their ability to do work. In this context, work is defined as a force acting over a distance. The electromagnet performs work when it moves objects using magnetic forces, which are created by magnetic fields.

In the first two experiments, we will create an electromagnet to observe magnetic fields using a compass and use electromagnets of different strengths to pick up objects. In the final activity, we will build an electromagnet to pull a bolt through a pipe.




*Magnetic fields*

"iron filings tracing the magnetic field of a bar magnet" by daynoir is licensed under CC BY-NC-SA 2.0

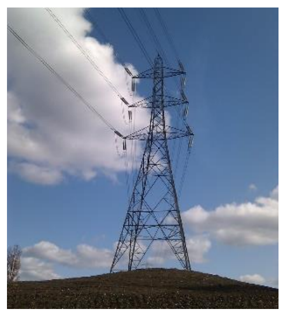
Throughout these experiments, we will begin to understand how these magnetic fields vary in different materials, how they are used, under what conditions they work best, and how to alter the force (strength) produced by the fields. Although electromagnets have been around for centuries, they are still an active area of research and improvement. Electromagnets are fun devices which exhibit the interesting phenomenon of electricity and magnetism.

# 2. Background: Electricity and Magnetism

To understand how electromagnets work, let's start by looking at the word "electromagnet". If we break this word down, we see the word "electro," meaning electricity, and the word magnet. An electromagnet creates magnetic fields using electricity. To understand how, first we must understand electricity.

Electrons are the basic unit of electricity. Electrons are negatively charged particles in atoms. Electrons move around the nucleus of an atom and can be shared between atoms or transferred to other atoms. If you have ever been zapped by a door handle in the winter, you have felt the power of electrons!

Groups of electrons can form electric charge. Charge can be positive (lack of electrons) or negative (surplus of electrons). The movement of electrons is called **current**. This current of electrons flows when a pressure, or **voltage**, is present. Batteries provide a voltage and can be used to power things. Batteries have two terminals: a [red] positive terminal and a [black] negative terminal. When a battery is being used in a circuit, electrons move from the negative to the positive terminals; this means that current is flowing. The current can be used to, for example, light a lightbulb. Eventually, the battery discharges: the voltage decreases and less current can flow. We call this a **dead battery**.



*Electricity power line*

"electricity pylon" by fsse8info is licensed under CC BY-SA 2.0

Now that we understand electricity, let's discuss magnets. Magnets are materials that produce magnetic fields. Magnetic fields are invisible but are responsible for the force that pulls on other ferromagnetic materials such as iron or steel. Only **ferromagnetic materials** (steel, for example) will work as magnets. This is because the material has **dipoles** inside it which can align together. Dipoles are molecules with an area of positive and negative charge. When the dipoles align, it creates a magnetic field. We call one side of the material the **north pole** and the other side the **south pole**. Not all materials have this property, so not all materials can be magnets. In permanent magnets, the dipoles are always aligned so the material is always creating magnetic fields (you just cannot see the fields). For example, refrigerator magnets are permanent magnets.

*Electromagnet*

Combining both electricity and ferromagnetic materials creates an electromagnet. Electromagnets are temporary magnets: the magnetic field can be turned on and off using the electricity. In the 1800s, it was discovered that when electrons are moving (this is called current), a magnetic field is created around the electrons, even without ferromagnetic material. When the electrons stop (no current is flowing), the magnetic field goes away.

Suppose now that current is flowing around a ferromagnetic material by wrapping a wire around a steel bolt. Sometimes, when the current stops flowing, the magnetic field remains in the steel bolt. This is because the ferromagnetic material was affected by the magnetic field! The dipoles of the material stay aligned, even after the current stops flowing. This interesting effect can be used to create permanent magnets out of normal iron or steel. To remove the magnetic field, the dipoles must be scrambled. This can be done using an oven, or by hitting the material with a hammer.

The following experiments will explore the concepts of electricity and magnetism by creating and using electromagnets. Several different electromagnets will be created which differ in coil number and voltage.

# 3. Experiments

## Experiment 1: Observing Magnetic Fields

This activity is designed to help us understand magnetic fields generated by electromagnets. Magnetic fields are invisible but can be observed using a **compass**. A compass is a permanent magnet designed to use the earth's magnetic field to show us which way is north and which way is south. The electromagnet we are about to make creates a stronger electromagnetic field than the earth so we can move the compass needle from north to south to help us understand how electrons are flowing through our circuit.

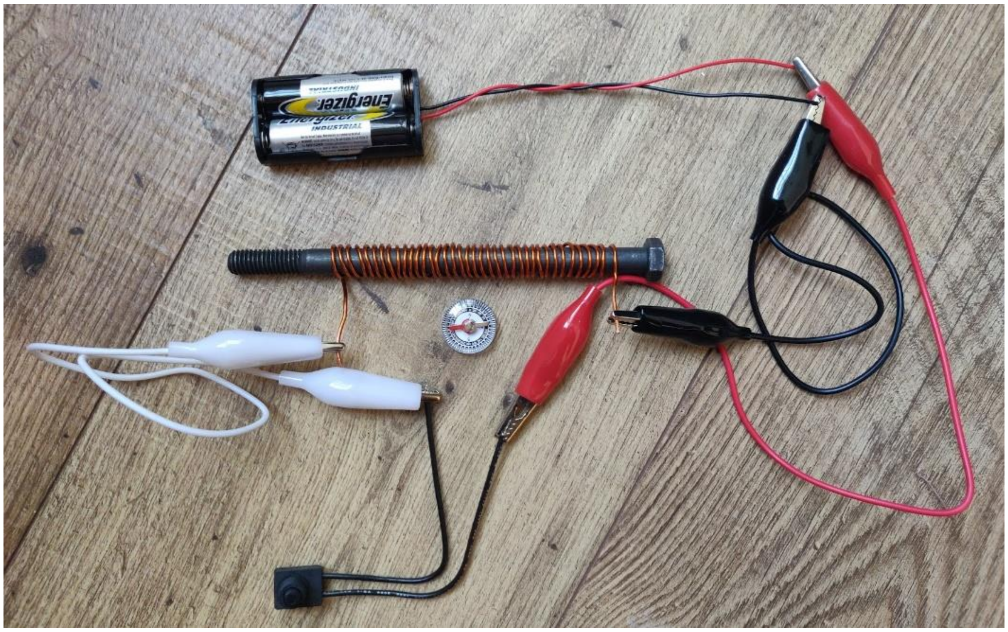


*Figure 1: Example of electromagnet with compass from Experiment 1.*

### Using a Compass:

ⓘ ***PLEASE NOTE:*** *The compasses provided in the kit will only estimate the direction. More expensive compasses will be much more accurate and should be used for outdoor adventures.*

1. Hold the compass in your hand and gently shake the compass three times. Which way is the arrow pointing?

2. Turn your body 180 degrees (so that you are facing the opposite direction). Which way is the compass pointing now?

3. Repeat the observations after moving around the compass needle to reset it (i.e. by shaking the compass). Do the new observations match the previous ones?

4. Does the compass point in the same direction in both step 1 and step 2?

5. In the room you are in, what direction is north? Which direction is west? Does this match your expectations from looking at a map?

## Creating the Electromagnet:

**⚠ SPECIAL SAFETY NOTE ⚠ ALWAYS disconnect the wires from the batteries, switch, and wires when not in use. Leaving the connection for too long will cause the batteries to get hot and may cause a fire!**

The electromagnet that you are about to create will only work when properly connected to the switch and battery. Figures 2 and 3 below indicate how the connections should be made to form a **circuit**. A circuit is a complete path of electric current and usually includes a source of electric energy (e.g., batteries). The following steps will guide you through the process of creating the circuit with the materials in your kit.

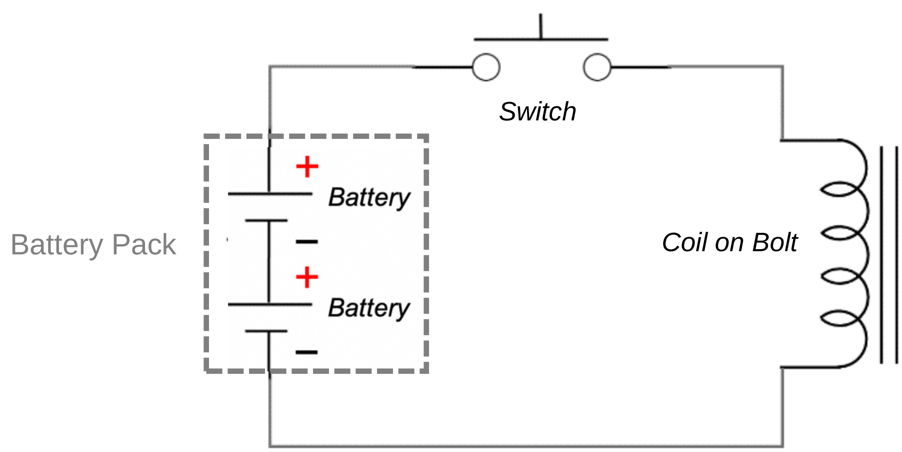



*Figure 2: Circuit Diagram consisting of the switch, battery, and coil.*

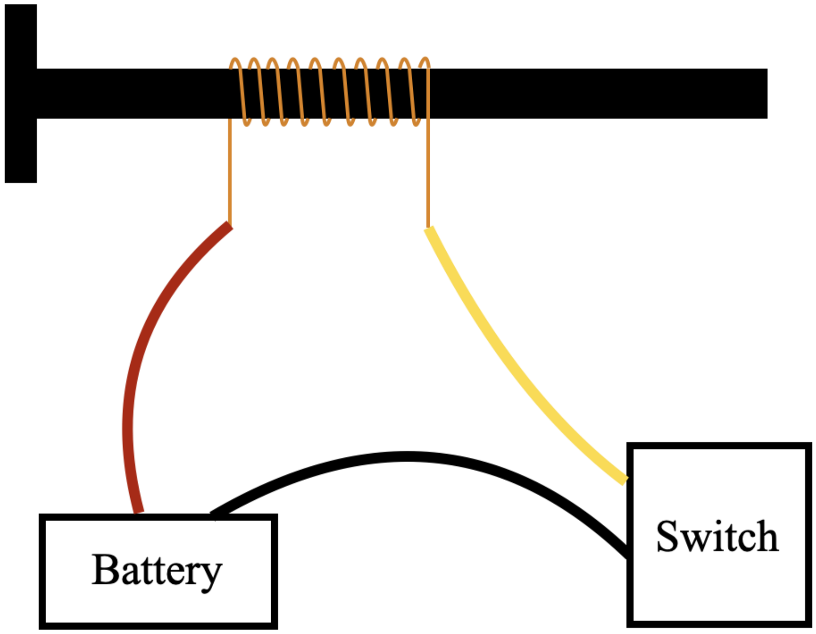



*Figure 3: Block diagram of the circuit consisting of the battery, switch, and coil. The red, yellow, and black curved lines represent your alligator clips.*

1. Locate the extra piece of wire included in the kit. Wind the piece of copper wire around the bolt 10 times with approximately ¼ inch spacing between each wrapping. This doesn't have to be exact. Make sure that you have at least two inches of straight copper wire at both ends of the coil to connect to the battery. Use the wire clippers or scissors to get rid of any excess wire. This is your electromagnet!

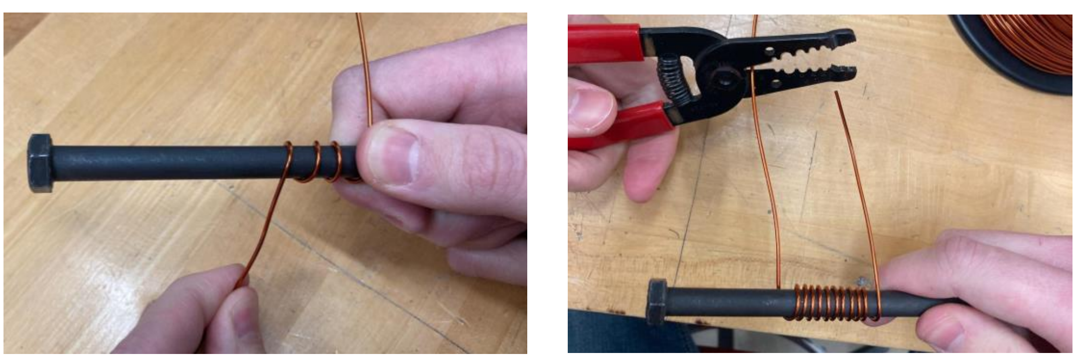


*Figure 4: A demonstration of wrapping the wire around the bolt to create the coil as detailed in step 1 of this procedure.*

2. Using sandpaper, rub off the protective layer on each end of the wire (approximately 1 inch from the end). Observe that the copper wire turns a lighter shade where it is rubbed by the sandpaper. This step will allow electricity to flow from the battery into the wire by removing the **insulating layer** that blocks electric current, usually used for safety reasons.

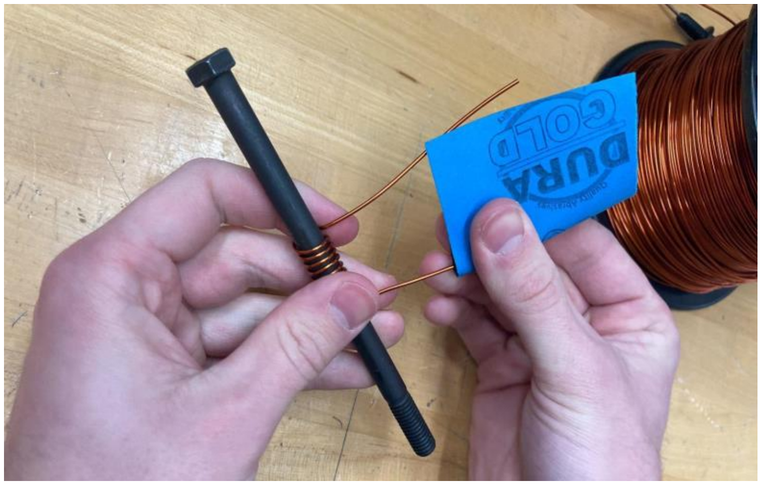
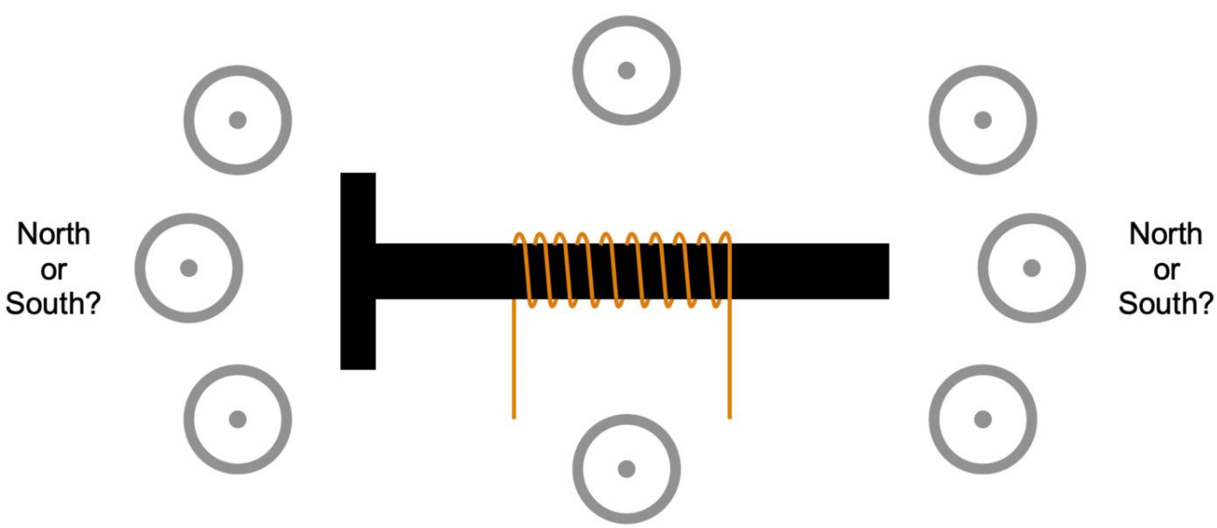


*Figure 5: The sandpaper is used to rub off the insulating layer of the wire described in step 2 of this procedure.*

3. Set your compass next to the bolt wrapped with wire and observe which direction it is pointing. Add compass needles to the grey compasses in the drawing below to indicate the direction of the magnetic field! Feel free to place your compass at more locations and add those to the depiction as well. Can you determine which side of your magnet is the north pole and which is the south pole? Indicate this on your drawing by circling one of the two options on each side of the bolt.

   *Hint: The needle of the compass will point towards the south pole of the magnet (bolt). Does your picture look like the magnetic field diagram from Figure 6?*




An example of a completed compass!

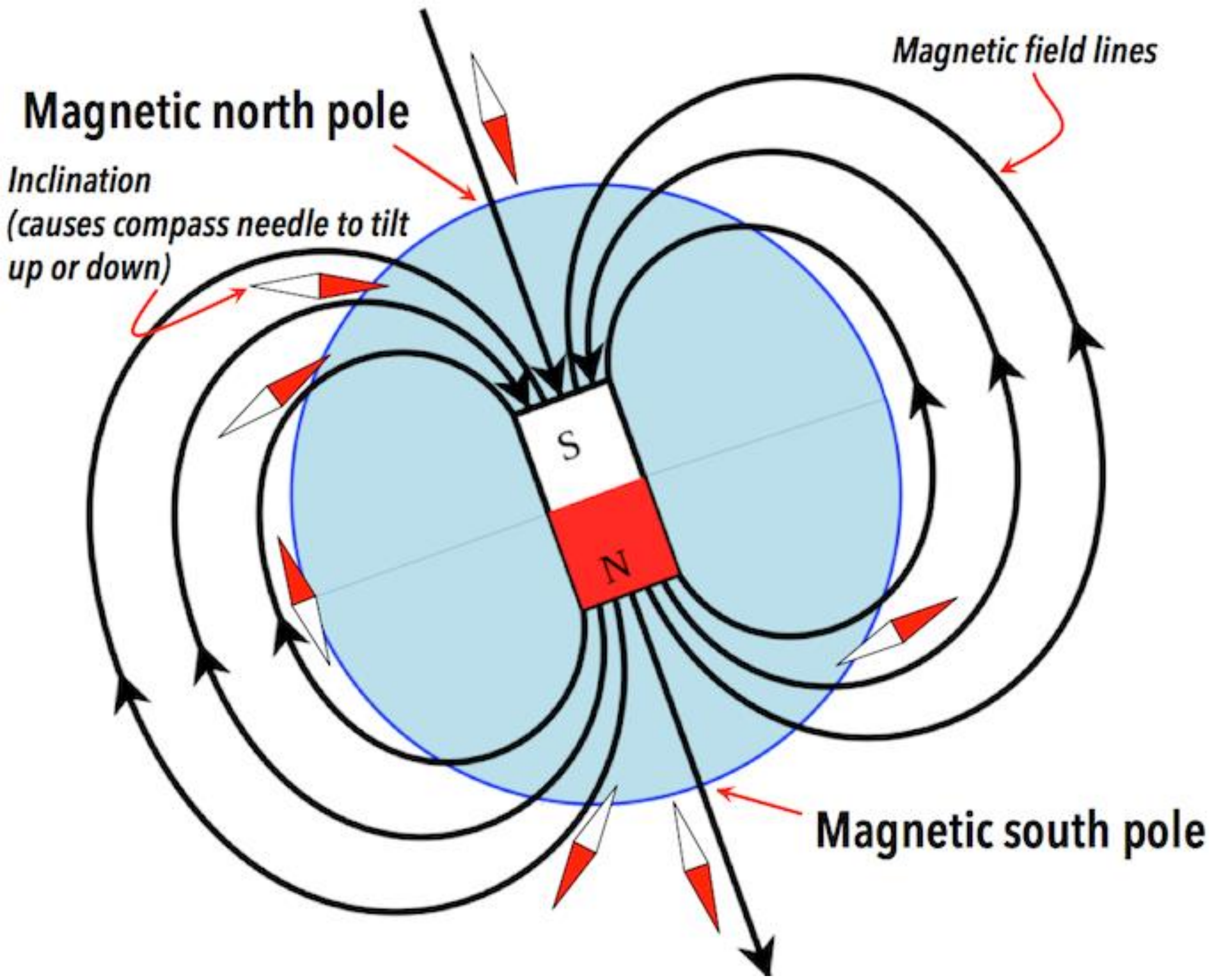



*Figure 6: A photo of the magnetic field lines surrounding the Earth. Picture from [https://openpress.usask.ca/physicalgeology/chapter/3-4-earths-magnetic-field-2/](https://openpress.usask.ca/physicalgeology/chapter/3-4-earths-magnetic-field-2/)*

4. Connect one end of the alligator clip to the positive wire on the battery holder and the other end of the alligator clip to one of the exposed wires on the switch.
5. Using a separate alligator clip, connect one end to the other exposed wire on the switch and the opposite end of the clip to one of the copper wires on the bolt. Make sure the alligator clip is clipped onto the copper wire where you used the sandpaper (Don't forget about that insulating layer!).
6. Using a separate alligator clip, clip one end to the free exposed wire on the battery holder and the other end of this same clip onto the free copper wire on your electromagnet.

Refer to the pictures below, as well as Figures 2 and 3 above, to help you connect the wires and form your circuit.

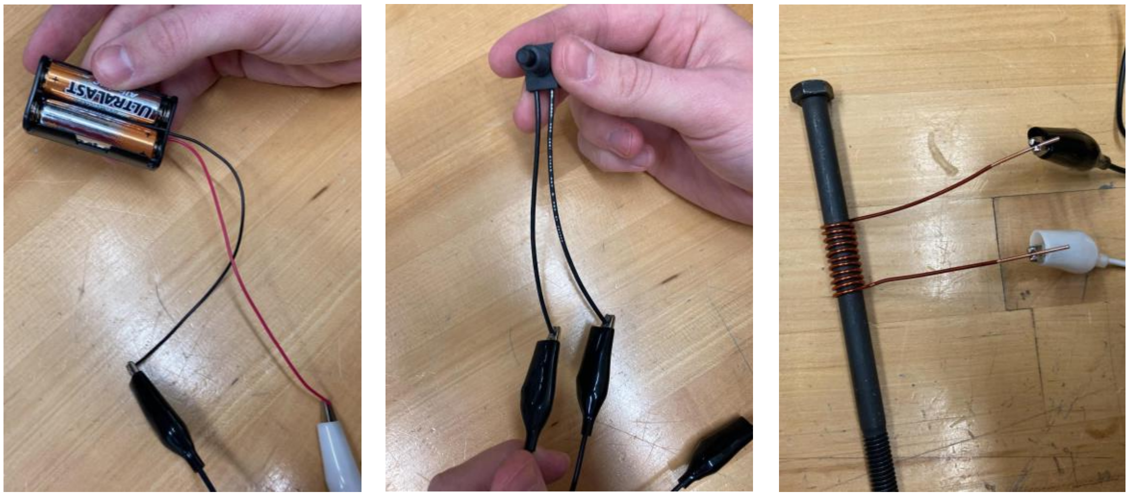
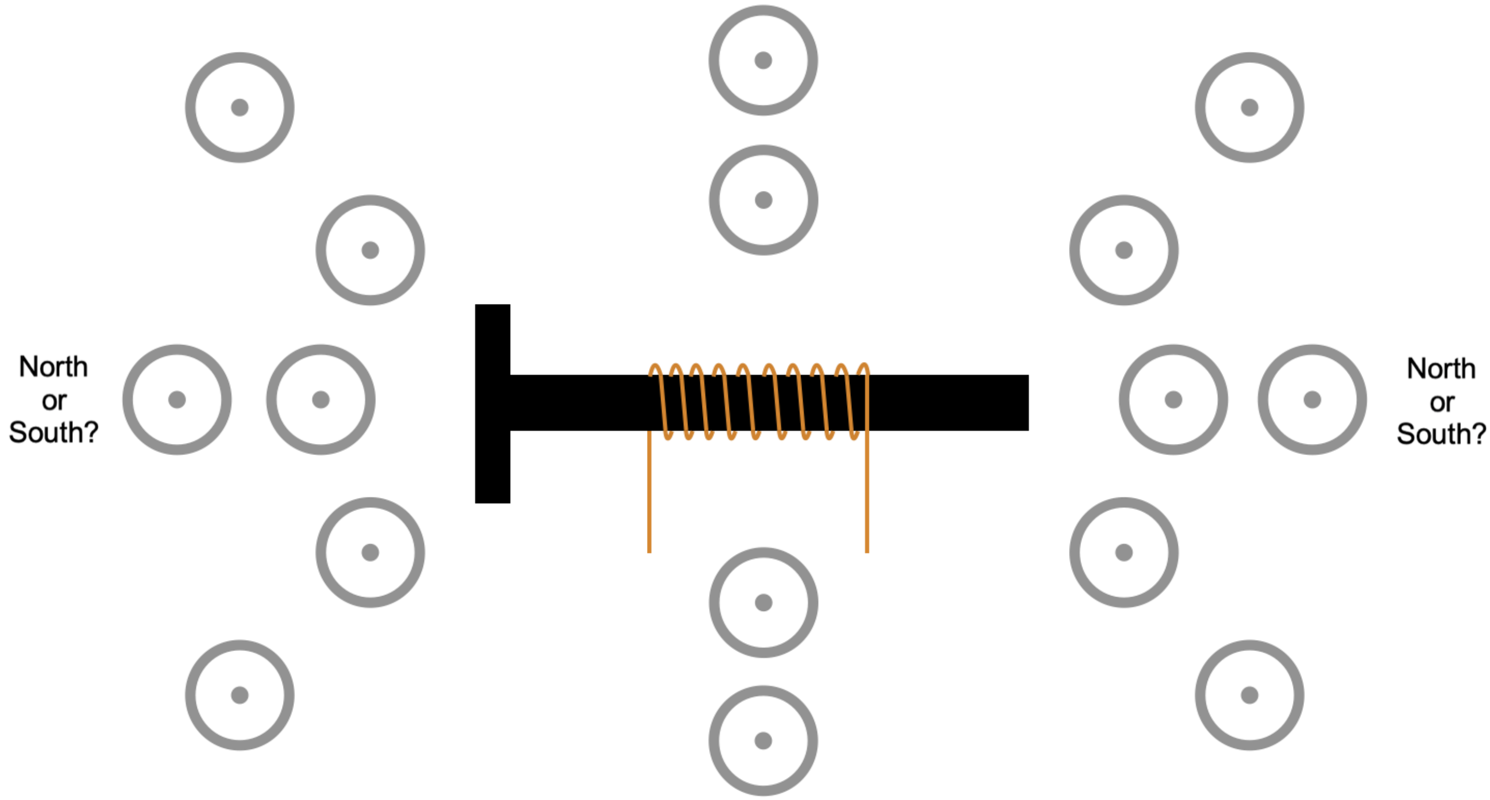


*Figure 7: The above photos show the alligator clip connections to the battery pack, switch, and coil from steps 4-6 of this procedure.*

7. Press the switch to create the electric circuit. Electricity from the batteries only flows to the electromagnet when the switch is pressed.
   i *Try to limit the amount of time the switch is on so that the batteries will last longer! For example, consider "pulsing" the current by only pressing the switch for 1 second at a time.*
8. Observe which direction your compass is pointing now. Has it changed direction?

9. Remove the alligator clips from the battery wires and switch them so that the clip that was on the positive wire is now on the negative wire and do the same with the other. Press the switch and observe what direction the compass is now pointing. Has it again changed direction? Why?

10. Add compass needle directions to the image depicted below. Feel free to place your compass at more locations and add those to the depiction as well. Is there a pattern? Pay special attention at the ends of the bolt. How far away from the bolt is the compass still influenced? Why? See the directions in step 11 of this procedure to finish your drawing!
    i *Hint: The compass needle should follow a circular path around the bolt since it follows the magnetic field lines.*




11. Complete the drawing from the previous step by adding connecting lines between each compass needle observation. Be sure to follow the direction of the of needle! Can you determine which side of your magnet is the north pole and which is the south pole? Indicate this on your drawing by circling one of the two options on each side of the bolt.
    i *Hint: The needle of the compass will point towards the south pole of the magnet (bolt). Does your picture look like the magnetic field diagram from Figure 6?*

12. ⚠ **VERY IMPORTANT** ⚠ After completing the activity, **disconnect** all alligator clips from the wire and battery. We will use the electromagnet in the next activity as well.

## + BONUS CHALLENGE:

Try changing the spacing between the turns of your coil from ¼ inch to approximately 1 inch on your same bolt. This can be done by pulling the coil apart as if it were a slinky. Does the behavior of the compass change as you move it around the bolt while the switch is pressed? Try different spacings between the coils and see if you can come up with a hypothesis about how changing the coil spacing may or may not affect your magnetic field!

## LEARN MORE:

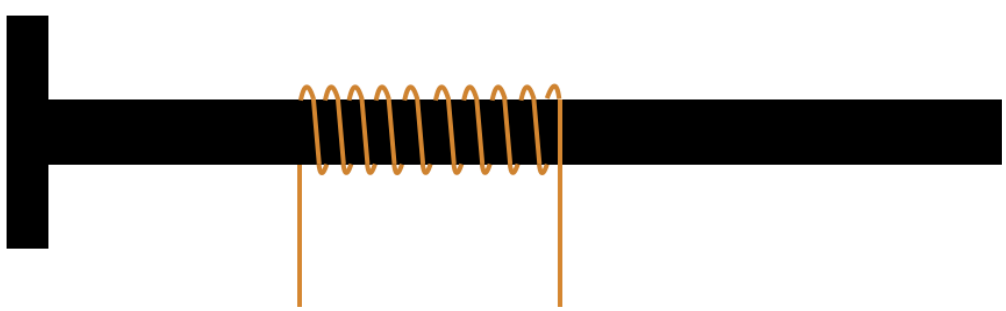
If you are interested in learning more about the history and uses of a compass, visit these links!

a. "How Does a Compass Work" - https://www.universetoday.com/77072/how-does-a-compass-work/

b. "Compass" - https://www.nationalgeographic.org/encyclopedia/compass/

## REFLECT AND APPLY:

1. Draw your compass next to the bolt shown below and add the direction the red arrow was pointing in Step 8. Draw a second compass and show what direction the needle was pointing in step 10. Write down why you think the compass changed direction.



2. In what jobs might someone use a compass?

3. When might you use a compass in your daily life?

## Experiment 2: Changing the Strength of a Magnetic Field

In this experiment, we will be creating a second electromagnet that is similar to the one we created in Experiment 1. The goal of this experiment is to understand how the magnetic field strength changes with:

1. Voltage supplied to the electromagnet by the battery
2. Number of turns of the copper wire
3. Materials used

You will use the skills from Experiment 1 to create a second electromagnet with more turns of copper wire around the bolt. Once you have created your electromagnets, you will experiment with the number of paperclips each electromagnet can pick up.

In Experiment 1, you followed a step-by-step guide to create an electromagnet with 10 turns of wire. In Experiment 2 and 3, you will be asked to do some steps without step-by-step directions. You can use the internet, an experienced adult, and/or trial and error to generate a solution and observe your results.

*Figure 8: Electromagnet picking up paper clips from Experiment 2.*

### Creating the Electromagnets:

1. Create a second electromagnet with 40 turns by winding the copper wire around a bolt with approximately ¼ inch spacing between each wrapping. This does not have to be exact. Remember to leave two inches of wire unwound on each side to attach the alligator clips.
2. Using sandpaper, rub off the protective layer on each end of the wire (approximately 1 inch from the end). Ensure that the wire turns a lighter shade where it is rubbed by the sandpaper, this means you have successfully removed the insulting layer.

3. Using the same setup as Experiment 1, hook-up the 10-turn electromagnet to the battery, press the switch and see how many paperclips it can pick up. Repeat using the second electromagnet with 40 turns of wire.

   The 10-turn electromagnet picked up _______________ paper clips!

   The 40-turn electromagnet picked up _______________ paper clips!

   Which one picked up more paper clips? Why do you think that is?
   i *Hint: Although the second electromagnet has more turns (40 vs. 10), it might not pick up more paper clips. Why?*

4. Hold the 10-turn electromagnet against a bare bolt (a bolt with no copper wire) as shown in the picture below. If you only have access to two bolts, you will need to slide the 40-turn coil off the second bolt for this step. Use the alligator clips to power the electromagnet and slowly pull the bolts away from each other. Describe what you observe. Was it easy or hard to pull the bolts apart? Can you lift the second bolt using the electromagnet?

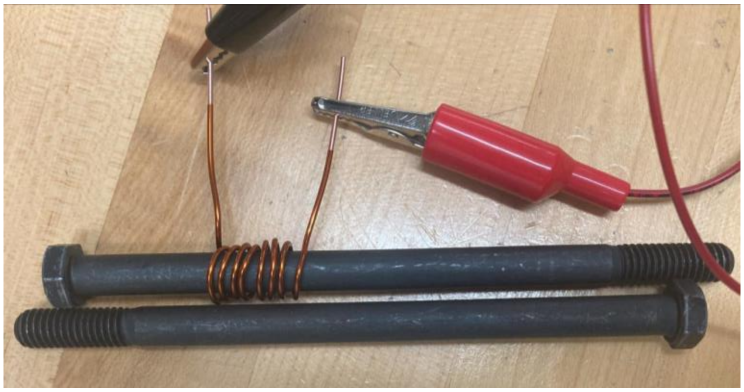


*Figure 9: Placement of the coil next to the second bolt as instructed in step 4 of this procedure.*

5. Now use the 40-turn electromagnet and repeat the previous step. Describe what you observe. Was it easier or harder to pull the bolts apart than with the 10-turn electromagnet? Can you lift the second bolt using the electromagnet?

6. We are now going to add a second set of batteries in what is called a **"series"** connection where the positive terminal of one battery pack is directly connected to the negative terminal of the second battery pack. Using alligator clips, connect the *black* wire of the first battery pack to the *red* wire of the second battery holder as seen in the images below.

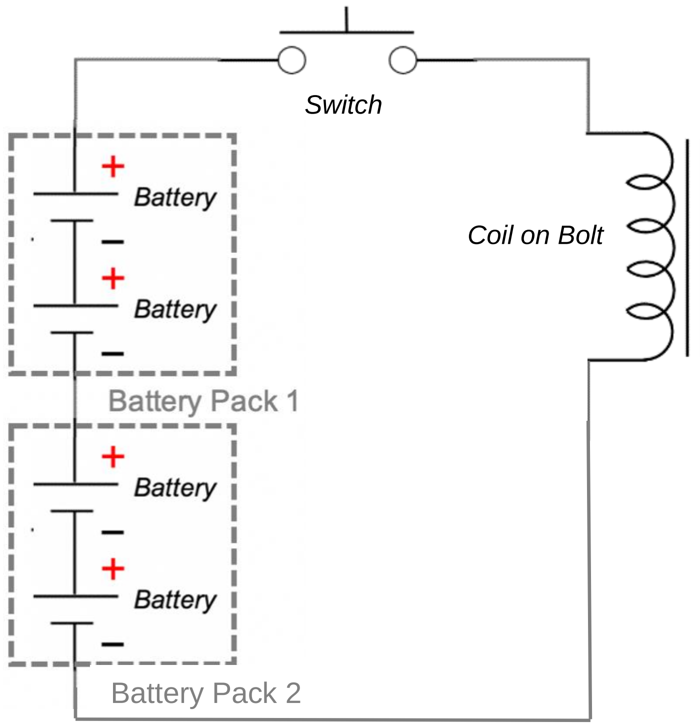



*Figure 10: Circuit diagram consisting of the two battery packs in series, the switch, and the coil. Note that the battery packs themselves are made up of two individual batteries in series.*

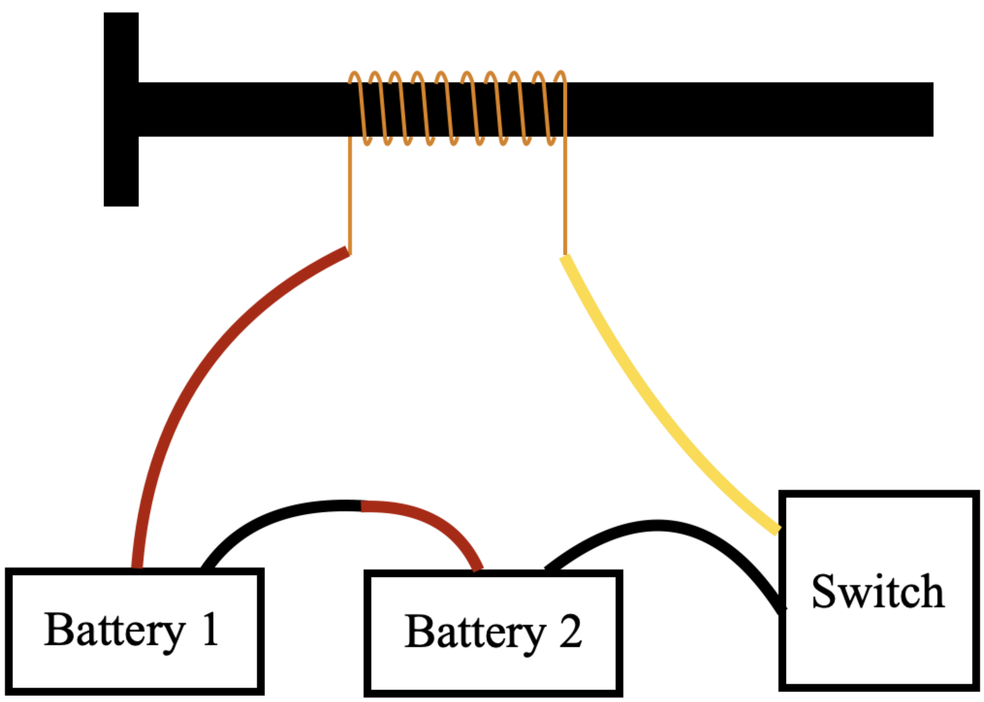



*Figure 11: Block diagram of the circuit consisting of the battery, switch, and coil. The black wire of the first battery pack is connected to the red wire of the second battery pack.*

7. Repeat step 3 using the series battery configuration.

The 10-turn electromagnet picked up _______________ paper clips!

The 40-turn electromagnet picked up _______________ paper clips!

How did the number of paperclips that were picked up change? Do the electromagnets feel stronger or weaker in this configuration?

i *Hint: Although the voltage is larger with two batteries connected in series (end-to-end), the number of paper clips picked up might remain the same. Why is this?*

8. Repeat steps 4-5 using the series battery configuration.

Using the 10-turn electromagnet, describe what you observe. Was it easy or hard to pull the bolts apart? Can you lift the second bolt using the electromagnet?

Using the 40-turn electromagnet, describe what you observe. Was it easy or hard to pull the bolts apart? Can you lift the second bolt using the electromagnet?

Do the electromagnets feel stronger or weaker in this configuration?

9. Disconnect the batteries and reconnect in a "**parallel**" configuration. This means that both negative ends of the battery packs are connected and both positive ends of the battery packs are connected (red to red, black to black). See the diagram below for a visual representation of where your wires should be placed.

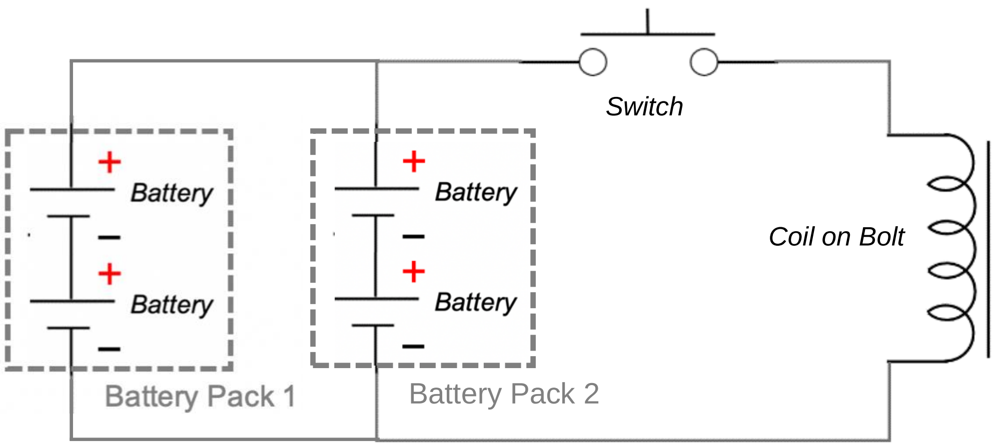



*Figure 12: Circuit diagram consisting of the two battery packs in parallel, the switch, and the coil. Note that the battery packs themselves are made up of two individual batteries in series.*

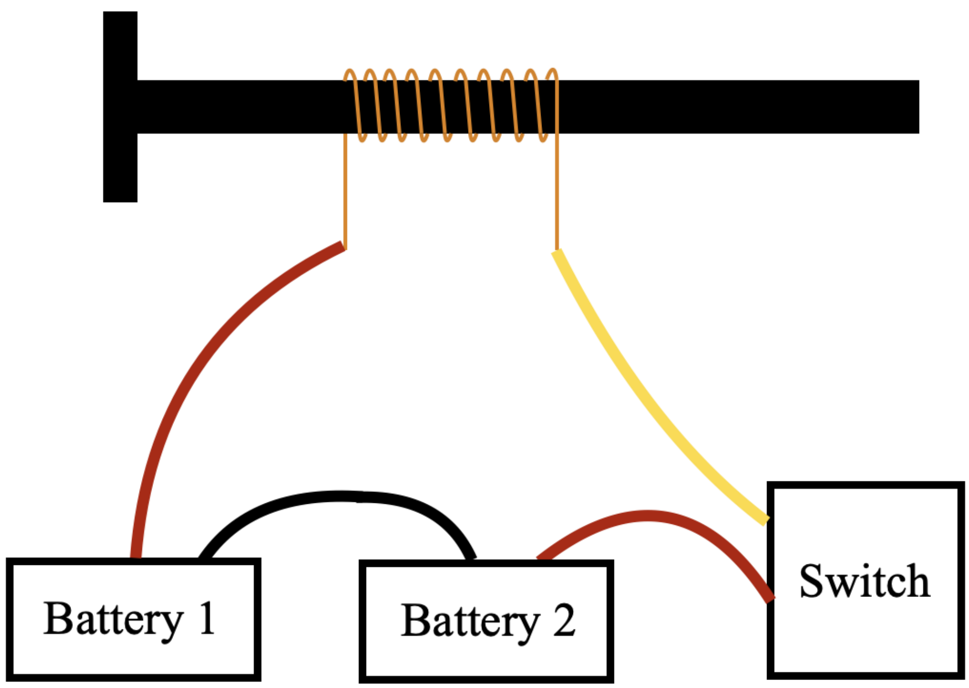



*Figure 13: Block diagram of the circuit consisting of the battery, switch, and coil. The black wire of the first battery pack is connected to the black wire of the second battery pack.*

10. Repeat step 3 using the parallel battery configuration.

⚠ Do not operate the electromagnet for an extended period of time in this configuration unless you are confident the batteries have the same voltage. If one battery is dead and the other is full, using them in a parallel connection can cause battery heating and damage!

The 10-turn electromagnet picked up _______________ paper clips!

The 40-turn electromagnet picked up _______________ paper clips!

How did the number of paperclips that were picked up change? Do the electromagnets feel stronger or weaker in this configuration?

11. Repeat steps 4-5 using the parallel battery configuration.

Using the 10-turn electromagnet, describe what you observe. Was it easy or hard to pull the bolts apart? Can you lift the second bolt using the electromagnet?

Using the 40-turn electromagnet, describe what you observe. Was it easy or hard to pull the bolts apart? Can you lift the second bolt using the electromagnet?

Do the electromagnets feel stronger or weaker in this configuration?

12. Without unwinding the copper coil, slide it off the bolt. Can the bolt still pick up paper clips?
    i *Hint: The bolt will likely remain magnetic and lift paper clips. Why do you think that is?*

*Figure 14: A magnetized bolt picking up several paper clips, the result of step 12 of this procedure.*

13. With an adult's help and supervision, hit the bolt with a hammer or drop it onto a hard surface. It is highly recommended that you drop the bolt onto a surface that will not be damaged by the bolt, such as a concrete floor. Can the bolt still pick up any paperclips? If so, hit the bolt again. Why do you think this reduces the magnet's strength?

After hitting/dropping the bolt once, the electromagnet picked up _______________ paper clips!

After a second time (if necessary), the electromagnet picked up _______________ paper clips!

14. Attach the empty (no bolt) copper coil to your battery circuit the same way you have been and try to pick up paperclips. Can the coil without the bolt work as an electromagnet? Why or why not?

The coil without the bolt picked up _______________ paper clips!

15. Unravel a paperclip so that it is straight and place the tip of the paper clip anywhere from a quarter to half of the way into the coil as shown below. What happens to the paperclip when you flow current through the coil by pressing the switch?
    i *Hint: If the battery is not dead, expect to see some movement from the paper clip. Make sure the paper clip is not stuck on the coil!*

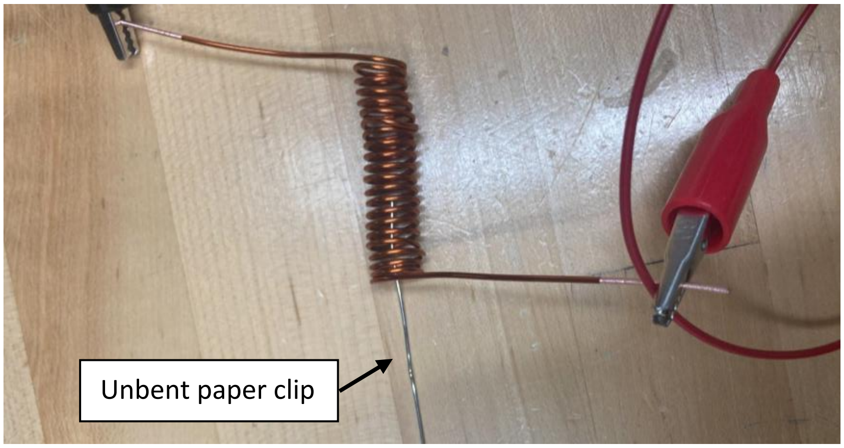



*Figure 15: As in step 15 of this procedure, an unbent paperclip is inserted inside the coil attached to our circuit.*

## + Bonus Challenge:

Try making a chain out of the paper clips instead of picking them up individually. How long can you make the chain before the electromagnet will no longer pick up the linked paperclips? Try picking up the paper clips in different ways and configurations. Be creative! Can you make any observations or generalizations about how well the electromagnet picks up different loads (i.e. paperclips)?

## Learn more:

If you are interested in learning more about circuit configurations and the uses of an electromagnet, visit these links!

a. "Series and Parallel Circuits" - https://en.wikipedia.org/wiki/Series_and_parallel_circuits

b. "Electromagnet" - https://en.wikipedia.org/wiki/Electromagnet

c. "What Are The Uses Of Electromagnets?" - https://www.universetoday.com/39295/uses-of-electromagnets/

## REFLECT AND APPLY:

1. What did you observe from Experiment 2?

2. How did the number of turns of the copper wire around the bolt change the number of paperclips you could pick up?

3. How did you increase the voltage going to your electromagnet?
   i *Hint: What did you do when you used two batteries?*

4. Did changing the voltage to the electromagnets change the number of paper clips attached?

5. Why did the bolt still pick up paperclips after the coil was removed?

6. What happened to the bolt after being hit with the hammer?

## EXPERIMENT 3: BUILDING AN ELECTROMAGNETIC PLUNGER

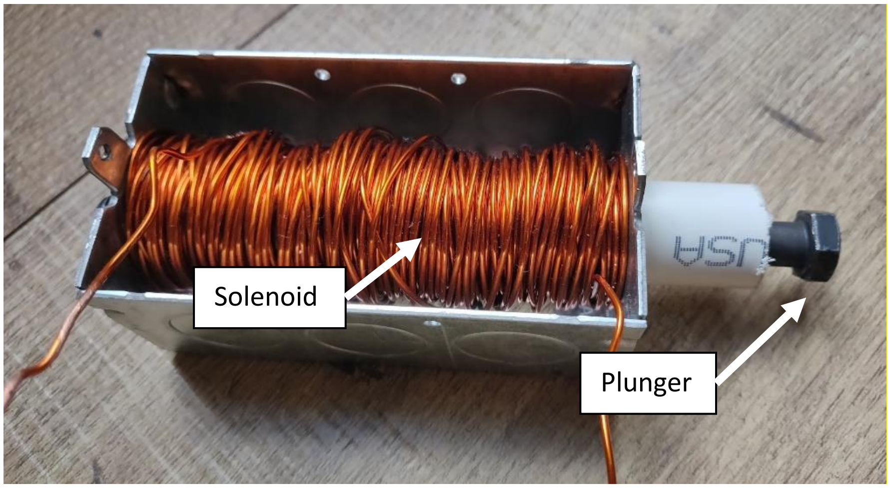
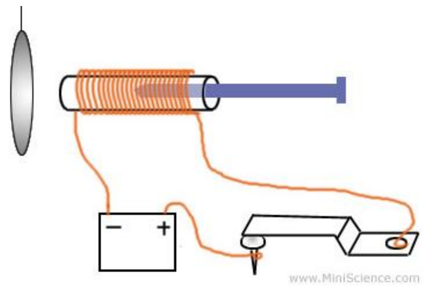



*Figure 16: Example of complete solenoid and plunger from Experiment 3.*

In this final experiment, we will create a working solenoid. A **solenoid** is a coil of wire that acts like a magnet when current flows through it. The wire coil we used in the previous two experiments (without the metal bolt inside) is an example of a solenoid. We can use a solenoid to build a plunger system that moves a bolt through the center of the coil and pushes an object (see Figure 6). This is the basic principle of a doorbell (see the picture on the right). Pressing a doorbell button, which is an electric switch, creates an electric circuit that pushes an object into a bell to make a sound. A spring inside the doorbell then pushes the bolt back to its original position when the doorbell is no longer pressed.




*Doorbell diagram*

Picture from: https://old.miniscience.com/projects/Solenoid/index.html

The challenge of this activity is to push a marble by making the strongest electromagnet solenoid possible with the materials provided in the kit. You will measure the distance the marble travels from a tabletop or platform to where it meets the floor (the time suspended in air).

You have limited supplies to use in the kit, so it is recommended you draw your plunger design and circuit before you begin to build. Planning is an important skill in engineering!

i *Optional materials to use:* ***Electric drill***

## Drawing a Prototype:

Use the space below to draw your battery set-up, alligator clip connections, switch, and solenoid (wire coil around a PVC pipe) from the supplies in your kit. Think about what will make a strong electromagnetic field. How did you pick up more paper clips in Experiment 2?

### PREPARING THE HOUSING BOX AND PVC PIPE:

1. With an adult's help, remove the metal hole covers on each end of the housing box using a pair of pliers.
   ⚠ **CAUTION**: the metal edges may be sharp and can cut skin! Be careful!

*Figure 17: A pair of pliers is used to remove the metal hole covers from the box as detailed in step 1 of this procedure.*

2. On the PVC pipe, mark the maximum length the solenoid can be and still fit in the housing using a marker or other writing tool.

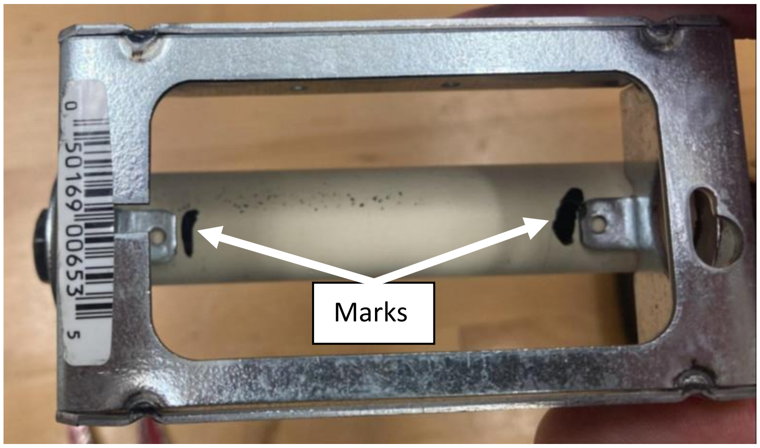



*Figure 18: An image showing the marks for the maximum possible length of the solenoid from step 2 of this procedure.*

3. Cut/trim the provided paper to fit between the two marks, which creates a long strip of paper that will be rolled around the PVC pipe in the next step.

*Figure 19: As explained in step 3 of this procedure, use a pair of scissors to cut the provided paper into a strip that fits between the two marks on the PVC pipe.*

4. Wrap the trimmed paper around the PVC pipe and tape it down. Do not wrap the paper too tightly otherwise it will be difficult to slide the coil off the pipe in a later step.
   i *Hint: Ensure you can still rotate the paper tube around the PVC pipe even after it's been taped. If it is too snug, remove the tape and try again.*

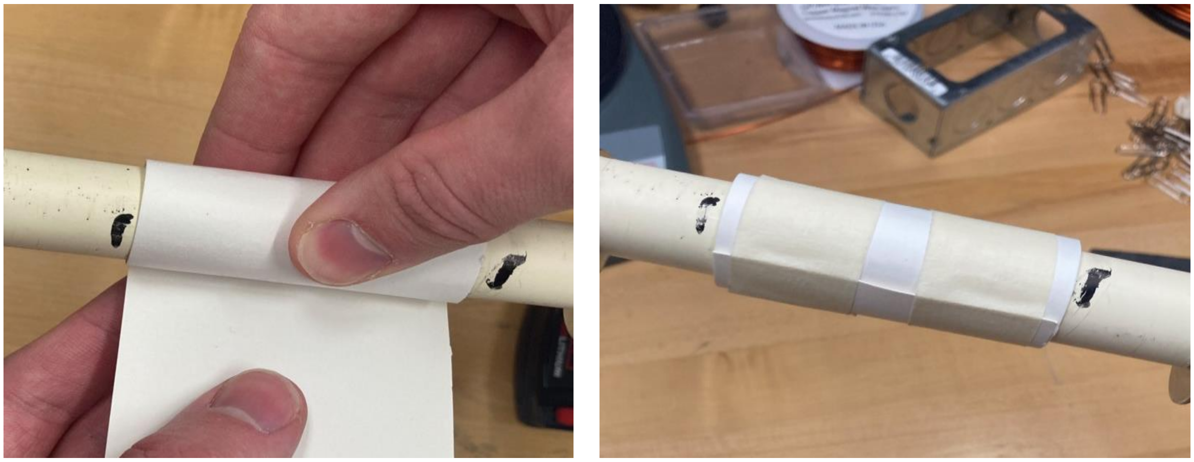


*Figure 20: The strip of paper is wrapped around the PVC pipe and taped in the manner described in step 4 of this procedure.*

### WINDING THE COIL:

There are two options for winding the coil (pick whichever option works best for you):

1. Hand-wind the coil (time consuming, but easy to do)
2. Use an electric drill (faster, but requires access to a drill and must be done with adult supervision)

**Option 1: Hand-wind the Coil**

Loosely coil the magnetic wire around the paper/PVC pipe set-up. As you probably guessed, the more turns the better. This will take time and patience as you will want to have several hundred turns of the copper wire. Make sure your finished solenoid will fit into the housing box. Too many turns of the wire will produce a solenoid that is too large to fit. Make sure to leave about 2 inches of wire on either end of the coil to attach to your circuit.

Now, skip "*Option 2"* below and continue to the "*Finishing the Solenoid"* section.

**Option 2: Use an electric drill (only use with adult supervision)**

If you have access to an electric drill, ask an adult to help you wind the copper wire using the drill. To do this, you will need a bolt, two washers and a nut for the bolt. These are all provided in the kit.

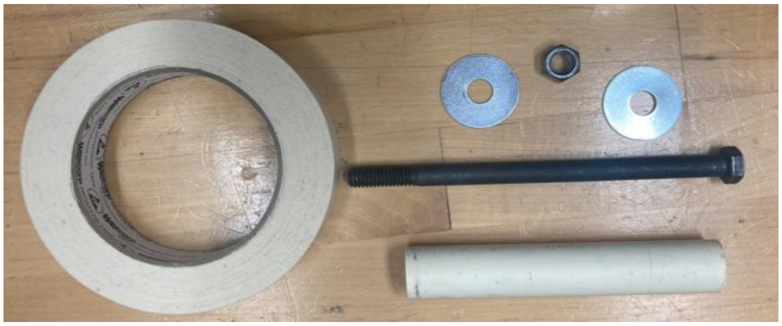


*Figure 21: The materials necessary for option two include masking tape, a bolt, a PVC pipe, two washers, and a nut.*

1. Place the bolt through the paper/PVC set-up as shown in the picture below. Use a washer on either side of the paper/PVC setup and then use a nut to secure the setup and hold the bolt in its desired position. Place tape around the exposed threads of the bolt to protect them when they are inserted into the drill in the next step.

*Figure 22: The result of step 1 of this procedure is a bolt with a PVC pipe sandwiched between two washers and secured using a nut.*

2. Load the bolt assembly into the drill and tighten down on the taped threads to hold it in place.


*Figure 23: The bolt setup from step 1 of this procedure is inserted into the drill using the instructions from step 2 of this procedure.*

3. Tape down the free end of the wire to the pipe, leaving 2 inches of wire length for the battery to be connected to. Slowly engage the electric drill to turn the bolt in the pipe with the help of an adult. The copper wire should start to wrap around the PVC pipe. Be sure that the wire does not wrap too tightly, as the coil will be removed from the pipe in a later step.
   ⚠ **CAUTION:** Electric drills can be dangerous power tools! Make sure to go slowly and always have adult supervision.

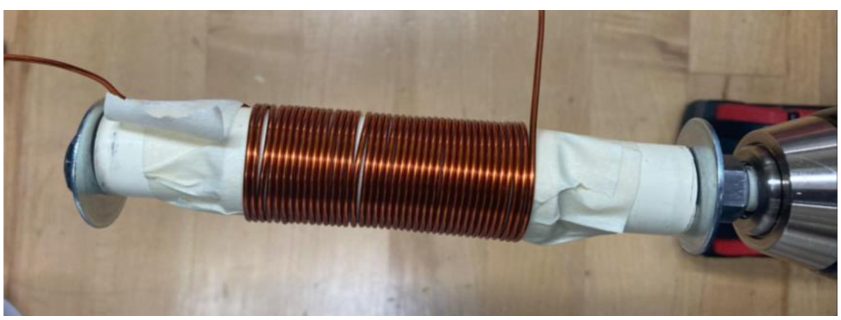


*Figure 24: An image of the coil being wound around the PVC as described in step 3 of this procedure.*

4. Continue to coil the magnetic wire around the paper/PVC pipe set-up. As you probably guessed, the more turns the better. This will take time and patience as you will want to have several hundred turns of the copper wire. Make sure your finished solenoid will fit into the housing box. Too many turns of the wire will produce a solenoid that is too large to fit.
5. When the coil is finished, remove the bolt from the drill and unscrew the nut to slide the bolt out of the PVC pipe and set it aside. Continue to the "*Finishing the Solenoid"* section.

*Figure 25: After completing step 5 of this procedure, the PVC pipe, bolt, washers, and nut should all be disassembled and separate.*

### FINISHING THE SOLENOID:

1. Slide the completed solenoid off the PVC pipe by sliding the paper off. It is okay if the paper rips or is damaged in the process of removing the coil; it was used to help the coil keep its shape in the previous steps and can now be discarded. Also, don't worry if the coil loosens slightly on one end when removed from the pipe.

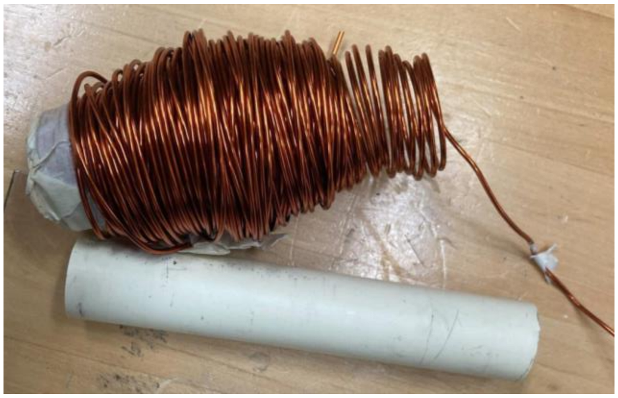


*Figure 26: The coil is removed from the PVC pipe and the paper is extracted using the instructions from step 1 of this procedure.*

2. Set the wire coil into the housing box and slide the PVC pipe through the holes at each end of the housing box.

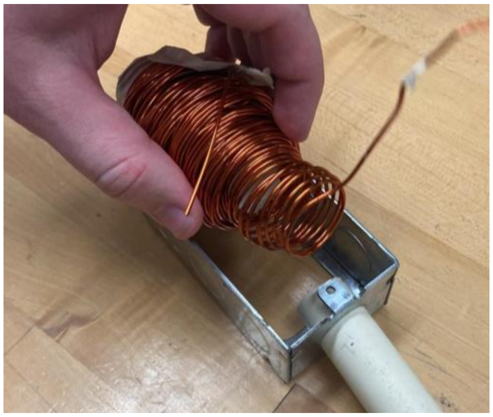
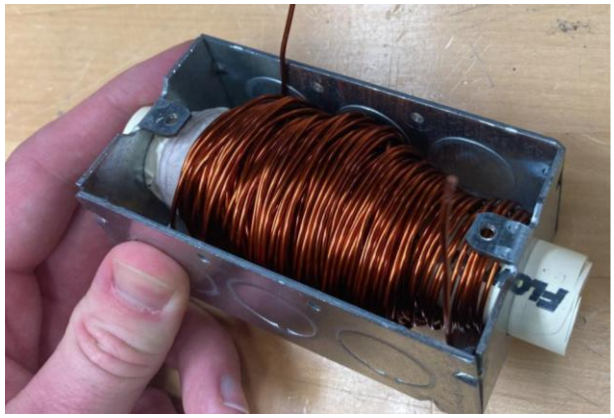



*Figure 27: The result of step 2 of this procedure is the coil placed around the PVC pipe inside the metal housing box.*

3. Sand the exposed ends of the copper wire to be attached to the battery circuit from experiment 1 and 2 (Don't forget about that insulating layer!).
4. Slide the bolt partway into the solenoid and connect the circuit. Observe what happens as you move the bolt back and forth with your hand. Record your observations below.

5. Add a marble to the plunger and have fun!

## + Bonus Challenge:

After making your marble launcher, you are halfway to making a doorbell. If you have a spring and bell at home (or something similar), try to adapt your solenoid to create your very own doorbell! Can you think of other ways you might be able to use your solenoid? Try some of them!

## Learn more:

If you are interested in learning more about solenoids and doorbells, visit these links!

a. "Solenoid 101: What is a Solenoid?" - https://www.tlxtech.com/articles/solenoid-101-what-is-a-solenoid

b. "Solenoid" - https://en.wikipedia.org/wiki/Solenoid

c. "How doorbells work" - https://home.howstuffworks.com/home-improvement/repair/doorbell3.htm

## Reflect and Apply:

1. How far were you able to shoot your marble?

   I was able to shoot the marble _________________________________ feet!

2. Is there a way to make your electromagnet even stronger?

3. Think about what you learned about electricity and magnets. In which careers or jobs do people use the types of skills you used in this project?

4. Do you know anyone who works with electricity, motors, or compasses as a part of their job? If so, share this experiment with them and ask them about their career.

**Sources:**


1. Science Buddies Staff. (2021, February 20). The Strength of an Electromagnet. Retrieved from https://www.sciencebuddies.org/science-fair-projects/project-ideas/elec_p035/electricity-electronics/strength-of-an-electromagnet



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