At Home Experiments
Electricity and Magnetism

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Check with your Parents for any of the experiments below that indicate Adult Help under the materials section. Safety First!

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Experiment #1: Charge and Carry
Store up an electric charge, then make sparks.

Are you tired of electrostatic experiments that just won't work? This experiment will produce a spark that you can feel, see, and hear. You rub a Styrofoam plate with wool to give it a large electric charge. Then you use the charged Styrofoam to charge an aluminum pie pan. The entire apparatus for charging the aluminum plate is called an electrophorus, which is Greek for charge carrier. An even larger charge can be stored up in a device called a Leyden jar, made from a plastic film can.

**materials**

For the Electrophorus:
- A Styrofoam dinner plate (Acrylic plastic sheets also work well, as will old LP records)
- A piece of wool cloth (Other fabrics may work, but wool will definitely work.)
- A disposable aluminum pie pan
- A Styrofoam cup
- Hot glue gun or masking tape

For the Leyden jar:
- A plastic 35 mm film can
- A nail slightly longer than the film can
- Some aluminum foil.
- Tap water
- Optional: A neon glow tube (available from Radio Shack)

**assembly**

(15 minutes or less)

**Electrophorus:**

Tape or hot-glue the Styrofoam cup to the middle of the inside of the pie plate. (Most household glues won't work because they dissolve Styrofoam.) Place the pie pan on top of the upside-down Styrofoam plate or a piece of acrylic plastic.

**Leyden Jar:**

Push the nail through the center of the lid of the film can. Wrap aluminum foil around the bottom two-thirds of the outside of the film can. You may tape the aluminum foil in place. Fill the film can almost full with water. Snap the lid onto the can. The nail should touch the water.
to do and notice
(30 minutes or more)

Rub the Styrofoam plate with the wool cloth. If this is the first time you are using the Styrofoam in an electrostatic experiment, rub it for a full minute.

To charge the pie pan follow the next steps exactly:

1. Place the pie pan on top of the charged Styrofoam plate.

2. Briefly touch the pie pan with your finger. You may hear a snap and feel a shock.

3. Remove the pie pan using only the insulating Styrofoam cup (see photo). You may have to hold the Styrofoam plate down with your other hand.

The pan is now charged.

Discharge the pan by touching it with your finger. You will hear a snap, feel a shock, and, if the room is dark, see a spark. To make the largest spark, have the pie plate at least one foot away from the Styrofoam plate. You can also discharge the pie pan through a neon glow tube. Hold one of the two metal leads of the tube in your fingers and touch the other lead to the pie pan. The electric spark will go through the neon and make a flash that is easily visible. After charging the Styrofoam once, you can charge the pie pan several times. The pie pan is portable and can be used for many electrostatic experiments.

Charge the Leyden jar by touching the charged pie pan to the nail while holding the Leyden jar by its aluminum foil covering. You can make several charge deliveries by recharging the pan before touching it to the nail. Discharge the jar by touching the aluminum foil with one finger and the nail with another. Watch for a spark.

what's going on?

When you rub the Styrofoam plate with a wool cloth, you charge it negatively. That's because the Styrofoam attracts electrons from the cloth. Often, a plate fresh from the package will start with a positive charge. If it does, you will have to rub the plate long enough to cancel this initial charge before you can begin building a sizable negative charge. By using an electroscope (such as the one you can build with the Electroscope Snack), you can determine whether the Styrofoam is positively or negatively charged. Styrofoam is an insulator; it will hold its charge until it is discharged by current leaking into the air or along a moisture film on the surface of the Styrofoam.

When you place the pie pan on the Styrofoam, the electrons on the Styrofoam repel the electrons on the pan. Since the electrons can't leave the pie pan because it is completely surrounded by insulating air and Styrofoam, the pan retains its neutral charge. If you touch the pie pan while it is near the Styrofoam, the mobile electrons will be pushed off the pan and onto you. The electrons make a spark as they jump a few millimeters through the air to reach your finger. The air in the spark is ionized as the moving electrons knock
other electrons off air molecules. The ionized air emits light and sound. You can also feel the flow of electrons though your finger.

After the electrons leap to your finger, the pan has a positive charge. Physicists say the pan has been charged by induction. You can carry the positively charged pan around by its handle and carry the positive charge to other objects. If you bring the positive pan near your finger again, or near any object that can be a source of electrons, the pan will attract electrons, creating a second spark.

The low-pressure neon gas in a neon glow tube is easier to ionize than air that is at atmospheric pressure. If you discharge the pan through a neon glow tube, the spark will make a bigger flash of light.

[Image of neon glow tube]

When you touch a positively charged pie pan to the nail on the Leyden jar, electrons from the nail flow onto the pie pan. The resulting positive charge on the nail attracts electrons from your body through your hand onto the aluminum foil of the jar. The Leyden jar will then have a positive center separated from a negative foil outside by the insulating plastic of the film can. If you touch one finger to the foil and bring another finger near the nail at the center of the Leyden jar, a spark will jump as the negative charges are attracted through you to the positive nail. The beauty of the Leyden jar is that it can store charges from several charged pie pans, thus building up to a larger, more visible, more powerful (and more painful) spark.

**etcetera**

The Leyden jar is the forerunner of the modern-day capacitor. It was invented in 1745 at the University of Leyden by Pieter Van Musschenbroeck. Early Leyden jars were larger than a plastic film can and could hold more charge. The inventor discharged one through himself and wrote, "My whole body was shaken as though by a thunderbolt." At another time, a Leyden jar was discharged through 700 monks who were holding hands. The charge caused them to simultaneously jump slightly off the ground.

To give the Styrofoam plate a positive charge, try rubbing it with a plastic bread bag. Try rubbing it with other cloths, too. Try charging the Leyden jar in reverse. That is, while holding the nail, touch the aluminum foil with the pan.
Experiment #2: Electroscope

What's your (electrical) sign?

A commonly available brand of plastic tape can gain or lose negatively charged electrons when you stick it to a surface and rip it off. By suspending pieces of tape from a straw, you can build an electroscope, a device that detects electrical charge. A plastic comb will enable you to identify whether the pieces of tape are positively or negatively charged.

**materials**

- 4 plastic drinking straws with flexible ends.
- 2 plastic 35 mm film cans.
- Enough modeling clay to fill the film cans halfway.
- A roll of 3-M Scotch Magic™ Tape, 3/4 inch (2 cm) width. (Don’t substitute other brands of tape the first time you try this Snack. Once you know what to expect, you can experiment with other tapes.)
- A plastic comb and hair or a piece of wool cloth.

**assembly**

(5 minutes or less)

Press enough modeling clay into both film cans to fill them halfway to the top. Press the inflexible ends of two drinking straws into the clay in each can, and bend the flexible ends to form horizontal arms that extend in opposite directions. The heights of the straws should be the same.

**to do and notice**

(15 minutes or more)

Tear off two, 4 inch (10 cm) pieces of tape. Press each piece firmly to a tabletop or other flat surface, leaving one end of each tape sticking up as a handle. Quickly pull the tapes from the table and stick one piece on an arm of a straw in one film can, and the other piece on an arm of a straw in the other film can. Move the cans so that the two tapes are face to face, about 6 inches (15 cm) apart. Then move the cans closer together. Notice that the two tapes repel each other.

Tear off two more pieces of tape and press the sticky side of one against the smooth side of the other, leaving one end of each tape sticking out as a handle. Quickly pull the tapes apart and stick them to the two remaining arms. Bring the arms close together. Notice that these two tapes attract each other.

Run the comb through your hair, or rub the comb with the wool cloth. Then hold the comb near the dangling tapes. Notice that the comb repels the piece of tape whose smooth side was in the middle of the "sandwich" and attracts the tape whose sticky side was in the middle. When you hold the comb near the tapes pulled from the flat surface, the comb will repel both tapes if they were pulled from a Formica™ surface; the comb may attract tapes pulled from other surfaces.

Try pulling other kinds of tape from various surfaces, or rubbing various objects together, and then bringing the tape or objects near the tapes on the arms. Bring your hand near the tapes and notice what happens.

**what's going on?**

When you rip the two pieces of tape off the table, there is a tug-of-war for electric charges between each tape and the table. The tape either steals negative charges (electrons) from the table or leaves some of its own negative charges behind, depending on what the table is made of (a positive charge doesn’t move in this situation). In any case, both pieces of tape end up with the same kind of charge, either positive or negative. Since like charges repel, the pieces of tape repel each other.
When the tape sandwich is pulled apart, one piece rips negative charges from the other. One piece of tape therefore has extra negative charges. The other piece, which has lost some negative charges, now has an overall positive charge. Since opposite charges attract, the two tapes attract each other.

When you run a plastic comb through your hair, the comb becomes negatively charged. Tapes repelled by the comb have net negative charge, and tapes attracted by the comb either have net positive charge or are uncharged.

You may have found that your hand attracts both positively and negatively charged tapes. Your body is usually uncharged, unless you have acquired a charge -- by walking across a carpet, for example. An uncharged object attracts charged objects. When you hold your hand near a positively charged tape, the tape attracts electrons in your body. The part of your body nearest the tape becomes negatively charged, while a positive charge remains behind on the rest of your body. The positive tape is attracted to the nearby negative charges more strongly than it is repelled by the more distant positive charges, and the tape moves toward your hand.

**etcetera**

Since some table surfaces will not charge the tape, be sure to test your surfaces before trying this Snack with an audience.

Charge leaks slowly off the tape into the air or along the surface of the tape, so you may have to recharge your tapes after a few minutes of use.

You can use your electroscope to test whether an object is electrically charged. First use the comb to determine the charge on a piece of tape, and then see whether an object whose charge is unknown repels the tape. If the tape is negatively charged and an object repels it, then the object is negatively charged. Don't use attraction to judge whether an object is charged: A charged object may attract an uncharged one. If tape is attracted to an object, the tape and the object may have opposite charges, or the tape may be charged and the object uncharged, or the object may be charged and the tape uncharged. But if the tape is repelled by the object, the tape and the object must have the same charge. The only way that tape and an object will neither repel nor attract is if *both* are uncharged.
**Experiment #3: Hand Battery**

Your skin and two different metals create a battery. When you place your hands on metal plates, you and the plates form a battery.

**Materials**
- A DC microammeter capable of reading 100 microamps.
- An aluminum plate and a copper plate, each about the size of your hand.
- 2 electrical lead wires with alligator clips at both ends (available at Radio Shack).
- Optional: FET input voltmeter that can measure up to 2 volts; a piece of wood or nonmetallic surface; plates made of other metals, such as lead or zinc (galvanized steel).

**Assembly**

(15 minutes or less)

Mount both metal plates on a piece of wood or simply clamp them to a nonmetallic surface. (If you prefer, you don't even have to mount the two plates. You can attach the wires as described below and then simply hold one plate in each hand. This has the benefit of allowing you to substitute other metals easily.)

Using the clip leads, connect one plate to one of the meter's terminals and connect the other plate to the other terminal. At this point it doesn't matter which plate attaches to which terminal.

**To Do and Notice**

(15 minutes or more)

Place one hand on each plate. You should notice a reading on the meter. If the meter doesn't show an electrical current, simply reverse your connections, attaching the copper plate to the terminal that the aluminum was connected to and vice versa. If there is still no current, check the connections and the wiring. If that doesn't produce current, try cleaning the plates with a pencil eraser or steel wool to remove oxidation.

Experiment with different metals to find out what combination produces the most current. Try pressing harder on the plates. Get your hands wet and try again.

Repeat the above experiments with the plates wired to a voltmeter. For accurate readings you will need an FET input voltmeter.

Have one person put a hand on the copper plate and another person put a hand on the aluminum plate, and then have them join their free hands.
**what's going on?**

When you touch the two metal plates, the thin film of sweat on your hands acts like the acid in a battery, reacting with the copper plate and with the aluminum plate. In one of these reactions, your hand takes negatively charged electrons away from the copper plate, leaving positive charges behind. In the other reaction, your hand gives electrons to the aluminum plate, causing it to become negatively charged.

This difference in charge between the two plates creates a flow of electrical charge, or *electrical current*. Since electrons can move freely through metals, the excess electrons on the aluminum plate flow through the meter on their way to the copper plate. (In metals, positive charges cannot move.) In your body, both positive and negative ions move. Negative electrons move through your body from the hand touching the copper to the hand touching aluminum. At the same time, positive ions move in the opposite direction. As long as the reactions continue, the charges will continue to flow and the meter will show a small current.

Your body resists the flow of current. Most of this resistance is in your skin. By wetting your skin you can decrease your resistance and increase the current through the meter. Since two people holding hands have more resistance than one person, the flow of current will be less.

If you disconnect one of the wires to the current meter, the aluminum becomes negatively charged: Electrons pile up on the aluminum side because they cannot cross the gap in the wire. The copper becomes positively charged as your hand removes electrons from the metal. These piles of charge create a voltage, which is measured when the microammeter is replaced by a voltmeter.

Most batteries use two different metals and an electrolyte solution to create piles of charge and thus a voltage. (In this exhibit, your sweat acts as an electrolyte solution.) When the terminals of the battery are connected with a wire, this voltage produces a current.

**etcetera**

You can use other pairs of different metals in a circuit to produce a current. The success you have using various metals will depend on a metal’s electric potential, that is, its ability to gain or lose charges. Try various metals to see which produces the highest current reading. An electromotive series table (found in every chemistry textbook) shows the electric potentials of metals and allows you to predict which metals will work well in making a hand battery.

You can sometimes get a small current even between two plates made of the same metal. Each plate has a slightly different coating of oxides, salts, and oils on its surface. These coatings create slight differences in the surfaces of the metals, and these differences can produce an electrical current.

The slightly painful sensation of a fork tine touching a metal filling, the process of plating metals, sacrificial anodes used to preserve ship hulls and iron bridges, potato clocks, and dielectric unions to prevent deterioration of copper and iron plumbing are all everyday examples of metals transferring charges.
Experiment #4: Circles of Magnetism I

You can make a magnetic field that's stronger than the earth's!

Compass needles are little magnets that are free to rotate. Compases allow us to observe the direction of a magnetic field. Normally, they respond to the earth's magnetic field, orienting themselves parallel to magnetic field lines. If we create a magnetic field that is stronger than the field of the earth— for example, by using electric currents—a compass needle will orient itself parallel to the new field.

**materials**

- A 6- or 12-volt lantern battery.
- A 1 foot (30 cm) length of heavy wire that is rigid enough to stand by itself. (You can use the wire from a coat hanger.)
- A Tinkertoy™ set for building the stand (or another improvised stand).
- A flat, rigid support surface measuring approximately 6 x 6 inches (15 x 15 cm). (This can be made of posterboard or even a manila file folder.) It should have a hole in the center of it that is large enough for the wire to pass through.
- 4 or 6 small compasses, measuring about 1 inch (2.5 cm) in diameter.
- 2 electrical lead wires with alligator clips at both ends (available at Radio Shack).
- Adult help.

**assembly**

(30 minutes or less)

Construct a Tinkertoy™ stand (or the equivalent), and lay the flat support surface in position on the stand. (See the photo and the diagram above.)

If the coat hanger wire is painted or varnished, scrape the coating off to expose about 1 inch (2.5 cm) of bare metal at each end.

Insert the wire through the hole in the flat support surface, and support the wire vertically in the stand, as shown in the photo and diagram.

Arrange the compasses in a circle on the support surface as shown in the diagram.

Attach one clip lead to each battery terminal, but don't attach the other ends of the lead wires to the coat hanger wire yet.

**to do and notice**

Observe the compass needles around the wire as when there is no current passing through the wire. Rotate the support surface. What happens to the compass needles? They will point north, orienting themselves so that they are parallel to the earth's magnetic field. (*Note: a few of your compasses may point south! Inexpensive compasses that are exposed to a strong magnet will sometimes become magnetized in the reverse direction. It's nothing to worry about, though - just keep in mind which end of your compasses points north.*)

Attach the clip leads to the ends of the coat hanger wire where it has been scraped. Watch what happens to the compass needles as current passes through the wire. If the electrical current is large enough, each compass will point in a direction tangent to a circle centered on the wire.
Rotate the support surface again. What happens to the compass needles this time? The compasses will continue to point in a direction tangent to a circle centered on the wire.

Don't leave the clip leads connected too long, because the electric current will rapidly drain the battery. A few seconds should be long enough to make good observations.

Switch the clip leads to the other terminals of the battery. What happens? The compass needles will reverse direction when the electrical current reverses direction.

**what's going on?**

Compass needles line up with magnetic fields. Since the earth is a magnet, a compass will normally line up with the earth's magnetic field. Because opposite magnetic poles attract, the magnetic north pole of the compass points toward the magnetic south pole of the earth. (The magnetic south pole of the earth is located in northern Canada! That is not a misprint. The south pole of the earth magnet is near the geographic north pole.)

The electric current passing through the wire creates a magnetic field that is stronger than the earth's field (in a region close to the wire). You can visualize the shape of this new field as a set of concentric circles surrounding the wire. Each of these circles has its center at the wire.

The closer to the wire you are, the stronger the magnetic field. The compass needles align themselves with the total magnetic field at each point, the sum of the earth's field and that of the wire. Since the magnetic field from the wire is significantly larger than that from the earth, each needle ends up pointing essentially in the direction of the magnetic field of the wire.

When you reverse the current, the direction of the magnetic field also reverses, and the needles dutifully follow it.

**etcetera**

To find the direction of the magnetic field made by an electrical current, use a technique called the *righthand rule*.

Place your right hand with the thumb parallel to the wire carrying the current. Point your thumb in the direction of the electrical current in the wire. (Remember: The electric current flows from the plus side of the battery through the wire to the minus side.) Wrap your fingers around the wire. Your fingers will now point in the direction of the magnetic field around the wire. If there are compasses near the wire, they will point in the same direction as your fingers.
Experiment #5: Circles of Magnetism II

Two parallel, current-carrying wires exert forces on each other. When an electric current flows through a wire, a magnetic field is created around the wire. If you place two current-carrying wires near each other, the magnetic field around each wire exerts a force on the current flowing in the other wire. These forces can push two current-carrying wires apart, or pull them together.

**materials**

- ✔ One 6-volt lantern battery or an equivalent current supply.
- ✔ 2 electrical lead wires with alligator clips at both ends (available at Radio Shack).
- ✔ Tinkertoys™ or wood for a stand.
- ✔ Masking tape or transparent tape.
- ✔ Light aluminum foil.
- ✔ Adult help.

**assembly**

(15 minutes or less)

Make a stand from wood or Tinkertoys™ (see the photo on page 14 and the diagrams below), or build a stand of your own design from available materials.

Cut a strip of aluminum foil measuring about 2 feet (60 cm) long and 1/2 inch (1.3 cm) wide. Tape one end of the foil strip to your support. Run the strip down and back up to the support, making a loop, then tape the other end in place. Be sure the ends of the strip do not touch.

Attach one clip lead to each battery terminal, but do not attach the other ends of the lead wires to the strip yet.

**to do and notice**

(15 minutes or more)

Touch the two clip leads to the ends of the foil strip. The descending and ascending portions of the loop will repel each other. The closer you can hang the descending and ascending portions of the loop to each other - without allowing them to touch - the larger the repulsion.

Now hang the foil strip from the support with the two ends overlapping, so they make a good electrical contact. Connect one of the clip leads to these overlapping ends. Separate the two sides of the loop and briefly touch the other clip to the bottom of the loop. Notice that the sides of the loop are attracted to each other when the current flows. (This step requires a little coordination and a delicate touch to clearly
demonstrate that it is the current flow in the strips that makes them move together and not forces that you create when you touch the clip to the bottom of the loop.)

**what's going on?**

A current-carrying wire generates a magnetic field that circles the wire (See the "Circles of Magnetism II" Snack.)

When a current flows in a magnetic field, the field exerts forces on that current. (See the "Motor Effect" Snack.) So each current-carrying wire in this Snack generates a magnetic field at the position of the other wire and thus exerts a force on the current in the other wire. Two parallel wires will either attract or repel each other, depending on the direction of current flow in each wire. If both currents flow in the same direction, the wires will attract; if they flow in opposite directions, they will repel.

The forces produced on the aluminum foil are small. This is because the electrical current flowing through the foil is small, only a couple of amperes. Larger currents produce larger forces. The Exploratorium exhibit, for example, uses wires carrying 400 amperes, which produces forces that are more than 10,000 times stronger than the forces you produce with this Snack.

**etcetera**

The ampere, the fundamental unit of electrical current, is defined by the force exerted by one wire on another. The definition of the ampere is as follows: A current of 1 ampere flowing in each of two infinitely long parallel wires separated by 1 meter will produce an attractive force of $2 \times 10^{-7}$ newton on each 1-meter length of wire. For comparison, a force of 1 newton is approximately the weight of a quarterpound of hamburger.
Experiment #6: Eddy Currents

A magnet falls more slowly through a metallic tube than it does through a nonmetallic tube. When a magnet is dropped down a metallic tube, the changing magnetic field created by the falling magnet pushes electrons in the metal tube around in circular, eddy-like currents. These eddy currents have their own magnetic field that opposes the fall of the magnet. The magnet falls dramatically slower than it does in ordinary free fall in a nonmetallic tube.

materials

✓ A cow magnet or neodymium magnet.
✓ A nonmagnetic object, such as a pen or a pencil.
✓ One 3 foot (90 cm) length of aluminum, copper, or brass tubing (do not use iron!) with an inner diameter larger than the cow magnet and with walls as thick as possible.
✓ One 3 foot (90 cm) PVC or other nonmetallic tubing.
✓ Optional: 2 thick, flat pieces of aluminum (available at hardware and home-repair stores); a cardboard; masking tape; rubber bands or cord.

assembly

No assembly needed.

to do and notice

Hold the metal tube vertically. Drop the cow magnet through the tube. Then drop a nonmagnetic object, such as a pen or pencil, through the tube. Notice that the magnet takes noticeably more time to fall. Now try dropping both magnetic and nonmagnetic objects through the PVC tube.

In addition to dropping these objects through the tubes, a very simple, visible, and dramatic demonstration can be done by merely dropping the magnet between two thick, flat pieces of aluminum. The aluminum pieces should be spaced just slightly farther apart than the thickness of the magnet. A permanent spacer can easily be made with cardboard and masking tape if you don’t want to hold the pieces apart each time. Rubber bands or cord can hold the pieces all together. The flat surfaces need to be only slightly wider than the width of the magnet itself. Thickness, however, is important. The effect will be seen even with thin pieces of aluminum, but a thickness of about 1/4 inch (6 mm) will produce a remarkably slow rate of fall. Allow at least a 6 inch (15 cm) fall.

what’s going on?

As the magnet falls, the magnetic field around it constantly changes position. As the magnet passes through a given portion of the metal tube, this portion of the tube experiences a changing magnetic field, which induces the flow of eddy currents in an electrical conductor, such as the copper or aluminum tubing. The eddy currents create a magnetic field that exerts a force on the falling magnet. The force opposes the magnet’s fall. As a result of this magnetic repulsion, the magnet falls much more slowly.

etcetera

Eddy currents are often generated in transformers and lead to power losses. To combat this, thin, laminated strips of metal are used in the construction of power transformers, rather than making the transformer out of one solid piece of metal. The thin strips are separated by insulating glue, which confines the eddy currents to the strips. This reduces the eddy currents, thus reducing the power loss.

With the new high-strength neodymium magnets, the effects of eddy currents become even more dramatic. These magnets are now available from many scientific supply companies, and the price has become relatively affordable. (An excellent source is Dowling Miner Magnetics Corp., P.O. Box 1829, Sonoma, CA 95476.)

Eddy currents are also used to dampen unwanted oscillations in many mechanical balances. Examine your school’s balances to see whether they have a thin metal strip that moves between two magnets.
Experiment #7: Magnetic Suction
This experiment shows how your doorbell works.
A coil of wire with current flowing through it forms an electromagnet that acts very much like a bar magnet. The coil will magnetize an iron nail and attract it in a remarkably vigorous way.

materials

✓ 40 feet (12 m) of insulated bell wire.
✓ A plastic or cardboard tube 4 to 6 inches (10 to 15 cm) long and about 1/4 inch (6 mm) in diameter.
✓ A large battery, 6 volts or more. (An ordinary 1.5-volt D battery will work, but may go dead very quickly and will require more coils to get the same effect.)
✓ The largest iron nail that will fit in the tube loosely.
✓ Adult help.

assembly

(15 minutes or less)

Tightly wrap as many coils of wire as possible around the tube, leaving the two ends free so that you can strip the insulation off them and connect them to a battery.

to do and notice

(15 minutes or more)

Insert the nail part of the way into the coil and briefly connect the ends of the wires to the battery. (Leaving the wires connected too long will result in death for your battery and perhaps a burn for you from the hot wires.) The nail should be sucked into the coil. Reverse the leads to the battery and repeat the experiment, after predicting what will happen.

what's going on?

Any moving electric charge creates a magnetic field around it. A loop of wire with a current creates a magnetic field through the loop. You can increase the strength of this field by piling up a lot of loops. The more loops, the stronger the magnet. Like a bar magnet, this coil of wire now has a north pole and a south pole.

Because of the motion of electrons around its nucleus, each iron atom can be thought of as a tiny loop of moving charge. Each atom therefore acts like a small magnet. Ordinarily, all these "loops" point in different directions, so the iron has no overall magnetism. But suppose you bring a nail near the south pole of your electromagnet. The north poles of the iron atoms will be attracted to the south pole of the electromagnet and will line up pointing in the same direction. The nail is now magnetized, with its north poles facing the south pole of the electromagnet. The opposite poles attract each other, and the nail is sucked into the electromagnet.

When the direction of current is reversed, the poles of the electromagnet reverse. Knowing this, you might think that when you bring the nail near the same end of the electromagnet as you did previously, the nail would now be repelled by the electromagnet, rather than attracted and sucked into it again. But when you try it, the nail does the same thing it did before. That's because the nail's iron atoms all reorient so that they line up with their opposite poles pointing toward whatever pole the electromagnet presents. Thus the nail will always be attracted to the electromagnet and will never be repelled.
You can find which end of the coil is the magnetic north pole by wrapping the fingers of your right hand around the coil in the direction the current is flowing; your thumb will point to the north end of the coil. You can also use a magnetic compass.

etcetera

The principle of magnetic suction is used to make a variety of devices, from doorbells (in which an iron rod is sucked into a coil to strike a chime) to pinball machines (in which current goes through a coil, sucking in a rod that is attached to the flipper) to the starter switch on your car.

To extend the original activity, hold the coil vertically and repeat the experiment. Try smaller nails and straightened paper clips in the coil. Remove the nail from the coil and test its magnetic properties by seeing if you can pick up some paper clips with it. If the electromagnet is not strong enough, the nail will not stay magnetized after the battery is disconnected, so to see this effect use as large a current source as possible. If the electromagnet is strong enough, the nail may stay magnetized for a while, until the random jiggling of the iron atoms eventually moves them out of alignment again. To demagnetize the nail rapidly, drop it onto a solid surface, such as a cement floor, a couple of times. This knocks the iron atoms out of alignment. Try to pick up paper clips with the demagnetized nail.
Experiment #8: Motor Effect

A magnet exerts a force on current-carrying wire. This simple device shows that when an electrical current flows through a magnetic field, a force is exerted on the current. This force can be used to make an electric motor.

Materials

- 4 to 6 small disk magnets. (Radio Shack sells inexpensive 1-inch (2.5 cm) diameter disk magnets.)
- One or two 1.5 volt flashlight batteries.
- Approximately 2 feet (60 cm) of flexible wire, such as solid or multistranded hookup wire, or magnet wire (available at Radio Shack).
- Masking tape.
- A wooden board approximately 2 x 4 x 6 inches (5 x 10 x 15 cm).
- A knife or sandpaper.
- Adult help.

Assembly

(15 minutes or less)

Group the disk magnets into a single cylindrical pile. Place the pile on the board so that it can be rolled along the board. Split the pile in the middle, leaving a gap of about 1/2 inch (1.3 cm) between the faces of the two groups. Tape the two groups to the board. A north pole will face a south pole across the gap.

Tape the battery onto the board as shown in the photo. Remove the insulation from the ends of the wire. (Use a knife for stranded wire, or use sandpaper to remove the nearly invisible insulating enamel from magnet wire.) Loop the wire through the gap between the magnets, with the ends of the wire close enough to the battery to touch it.

to do and notice

(5 minutes or more)

Touch one end of the wire to the positive side of the battery and simultaneously touch the other end of the wire to the negative side. The wire loop will jump either up or down.

If you reverse the direction of current flow, the wire will jump in the opposite direction. To reverse the current, attach the lead that was connected to the positive end of the battery to the negative end and vice versa.

What's going on?

The magnetic field of the disk magnets exerts a force on the electric current flowing in the wire. The wire will move up or down, depending on the direction of the current and the direction of the disks' magnetic field.
To predict the direction of movement, you can use a mathematical tool called the right-hand rule. Put your right hand near the section of wire that goes between the disk magnets. Make your hand flat, with your thumb sticking out to the side. (Your thumb should be at a right angle to your fingers.) Place your hand so that your thumb points along the wire in the direction that the electric current is flowing (current flows from the positive terminal of the battery to the negative terminal) and so that your fingers point from the north pole of the disk magnets toward their south pole. (You can find the north pole of the magnets by using a compass; the south end of a compass will point toward the north pole of a magnet.) Your palm will then naturally “push” in the direction of the magnetic force on the wire.

The deflecting force that a magnet exerts on a current-carrying wire is the mechanism behind the operation of most electric motors. Curiously (and happily for our sense of symmetry!), the reverse effect is also true: Move a loop of wire across the pole of a magnet, and a current will begin to flow in the wire. This, of course, is the principle of the electric generator. The electric current you generate by moving this single loop of wire through the weak magnetic field of the disk magnets is too weak to detect with all but the most sensitive of microammmeters.

etcetera

This experiment creates just a short pulse of motion. A motor requires continuous motion. This problem was solved originally in the early 1800s by the invention of commutators. A commutator is a sliding contact that not only makes electrical contact with a rotating loop of wire but also allows the current direction to reverse every half-cycle of rotation.