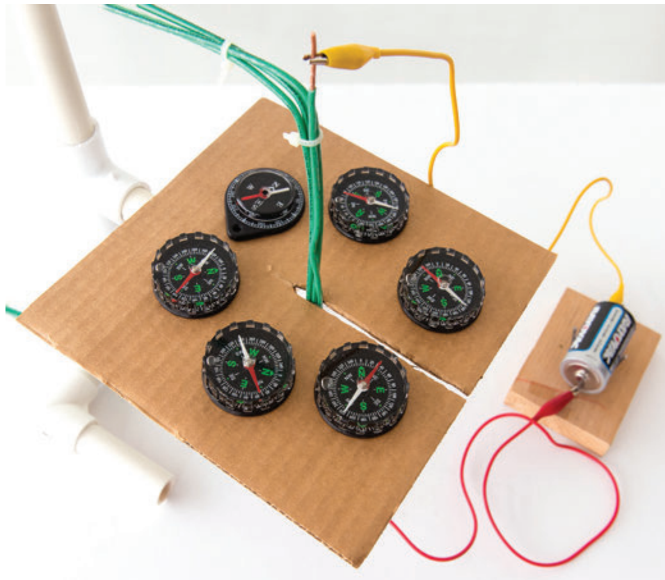


Circles of Magnetism

Make a magnetic field that's stronger than Earth's.

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

Caution! Working with electricity can really heat things up! Always be careful with hot wires. And be sure that you don't leave the clip leads connected too long, because the electric current will rapidly drain the battery and may cause it to overheat. A few seconds should be long enough to make good observations.

Tools and Materials

- PVC pipe and fittings for building the stand shown in the photos above (or one like it using materials and a design of your own choosing)
  - o For the stand shown here, you'll need about 2 feet of 1/2-inch Schedule 40 PVC pipe, cut into the following lengths:
    - One 6-inch piece

        - One 4-inch piece
        - Two 3-inch pieces
        - Three 2-inch pieces
    - You'll also need the following fittings:
        - Two 90-degree elbows
        - Three T-joints
- 12 feet (3.6 meters) of insulated copper wire that is stiff enough to retain the form of the square coil shown in the photo—12-gauge wire was used for this coil
- Six small 4-inch cable ties (regular 8-inch cable ties can be used if small ties are unavailable)
- One regular 8-inch cable tie
- A hot-glue gun and hot glue sticks
- A flat, rigid platform (ordinary cardboard works well) measuring approximately 8 × 8 inches (20 cm × 20 cm), into which you will cut a slit that is large enough to allow the coil of wire to pass through the center
- Four to six small magnetic compasses, each measuring about 1 inch (2.5 cm) in diameter
- Two electrical lead wires with alligator clips at both ends
- One fresh D-cell battery
- A battery holder of some sort to which you can attach the alligator clip leads (we put four nails in a small wooden block to hold the battery; one on each side to hold the battery and one at either end touching the terminals)
- A PVC cutter
- Utility knife (not shown)
- Wire stripper (you can use the utility knife to strip the wire if a wire stripper isn't readily available)

Assembly

Constructing the stand:

Make one of your own design or follow the steps below to build a stand out of PVC. Note that it's not necessary to use PVC cement; friction fit will be ample to hold the stand together.

1. Fit the PVC pieces together as shown in the photos above. Starting from the bottom, insert the 3-inch pieces into the two elbows and connect these to two of the 2-inch pieces and the straight part of a T-joint to form a U-shaped base. Swivel the T-joint so the top part is pointing up and

insert the 4-inch piece. Add a T-joint and the 6-inch piece to complete the vertical part of the stand. Insert the remaining 2-inch piece and T-joint to make the part of the stand that will support your cardboard platform.

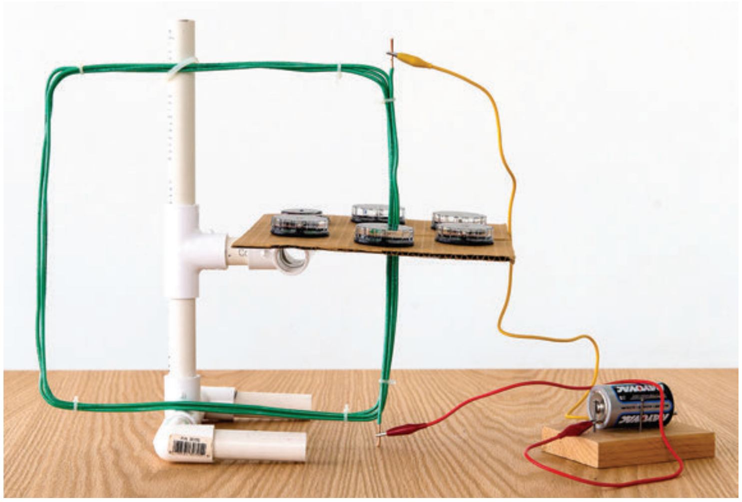
2. Cut a 1/8- to 1/4-inch-wide slit from the center of one edge to the center of the cardboard piece.
3. Glue the opposite edge of the cardboard to the part of the PVC stand (the T-joint attached to the 2-inch piece) that sticks out horizontally.

Making a square coil:

1. Strip about 1 inch of insulation from one end of the copper wire.
2. Leave about 1 1/2 inches of the stripped end, then measure another 10 inches and bend the wire 90 degrees. Measure about 10 more inches and bend 90 degrees again. Continue the process until you have formed a square "coil" with 10-inch-long sides—you should have three complete 4-sided square loops plus one additional side. Let this last, or thirteenth, side extend an additional 1½ inches and then cut the wire (you should have about a foot of wire left over, which you can discard or save for another use). Strip the insulation from the last inch of wire. The completed coil is shown in the photo below.
3. Use the small cable ties to hold the wire together in the square coil shape.

Putting the whole thing together:

1. Turn the square coil on its side, and orient it so the side with the two stripped ends runs vertically through the platform (see photo). Use the large cable tie to attach the coil to your PVC stand.
2. Arrange the compasses in a circle on the cardboard as shown.
3. Attach one end of a clip lead to each of the stripped ends, but do not attach the other ends of the clip leads to the battery yet.



To Do and Notice

Observe the compass needles when there is no current passing through the wire. Rotate the cardboard platform. What happens to the compass needles? They will point north, orienting themselves so that they are parallel to 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 each compass points north.)

Now attach the clip leads to the battery terminals. Watch what happens to the compass needles as current passes through the coil. *(CAUTION: Don't leave the battery connected for more than several seconds at a time—the electric current can rapidly drain the battery and may cause it to overheat.)* If the electrical current is large enough, each compass will point in a direction tangent to a circle centered on the vertical coil wires that they surround.

Rotate the cardboard platform 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 vertical coil wires.

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 Earth is a magnet, a compass will normally line up with 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. Indeed, the magnetic south pole of the Earth is near the geographic north pole. To make things even more confusing, mapmakers call this the north magnetic pole.)

Electric current passing through a wire creates a magnetic field. In the vertical side of the coil, there are four wires and the current is the same size and moving in the same direction in all of them. Thus the compasses are sensing the magnetic field produced by a current four times larger than if they were surrounded by just one of the wires. This allows the use of a D-cell battery rather than a larger and more expensive battery that would be necessary to produce an equivalent current in a single wire.

The electric current passing through the vertical side of the coil creates a magnetic field that is stronger than Earth's field (in a region close to the wires). You can visualize the shape of this new field as a set of concentric circles surrounding the vertical coil wires. The closer to the vertical coil wires you are, the stronger the magnetic field. The compass needles align themselves with the total magnetic field at each point, the sum of Earth's field and that of the wire. Since the magnetic field from the vertical coil wires is significantly larger than that from 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.

Going Further

To find the direction of the magnetic field made by an electrical current, you can use a technique called the right-hand 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.

Note that what actually moves in the wire are electrons flowing from the negative side of the battery to the positive side. Electrical engineers and scientists think of "current" as a flow of positive charges that produces the same effect as that produced by the flow of negative charges in the opposite direction.