

Paper Cup Magnetism

By Robert J. Beichner

As part of a unit on electricity, I ask students to construct a simple device that allows them to recognize the presence of an electric current. Students can make a paper cup galvanometer either at home or school using basic materials that they are likely to have on hand. With the galvanometer, students can investigate currents through various combinations of batteries and light bulbs or other circuit elements. This is the best activity I know of for showing that electrical currents generate a magnetic field.

Operation and use in the classroom

The paper cup galvanometer uses the magnetic field produced by an electric current to rotate a permanent magnet. This permanent magnet works in tandem with an attached pointer that moves along a scale as the magnet turns.

As the current moving through the coil increases, the magnetic field it produces around the current-carrying wire also increases. This stronger field has a greater effect on the permanent magnet,

causing it to turn through a larger angle. In commercial galvanometers, the magnet is fixed and a coil of wire turns, but the result is the same. (Also, in commercial models a spring is attached to the pointer in such a way that doubling the current results in twice the pointer deflection.)

To simplify the construction of the paper cup galvanometer, we set the magnetic turning force (called torque) against the force of gravity. Although this arrangement doesn't provide a linear restoring force (as the spring does in a commercial galvanometer), it is very easy to build.

The paper cup galvanometer is surprisingly sensitive. If you would like your students to be able to measure somewhat larger currents, connect a small (approximately 100Ω [ohm] or less) resistor in parallel with the galvanometer's coil. In a commercial ammeter this is called a shunt resistor since it diverts a large part of the current around the coil.

To measure voltages, connect a large resistor (perhaps $50\text{ k}\Omega$) in series with the coil. By changing the amount of resistance attached to the galvanometer coil, you can adjust the range of current or voltage that can be measured. (This is what happens when you turn the knob on commercial ammeters and voltmeters.)

Constructing the galvanometer

For this activity, I divide the class into groups of three or four students each. Before they begin making their paper cup galvanometers, I briefly demonstrate the proper methods of construction.

Materials

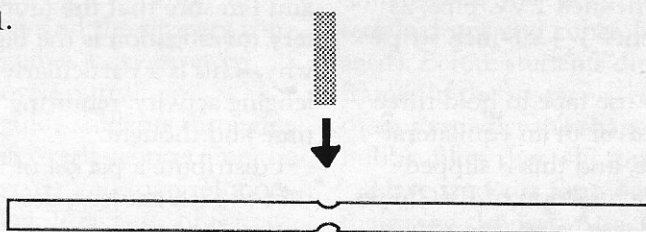
Each group will need:

- Paper cup
- Drinking straw
- Small bar magnet (approximately one inch)
- Ball-headed pin
- Insulated wire
- Dry cell (any size)
- 3 x 5 index card

As mentioned previously, most of these materials are easily obtained. A suitable bar magnet is probably the hardest object to find. This size magnet is often used on magnetic refrigerator decorations.

The trickiest step in construction is the first one, making a hole in the straw for the magnet. Use a paper punch or a pair of scissors to make two side-by-side notches in the center of the straw. Don't make

Figure 1.



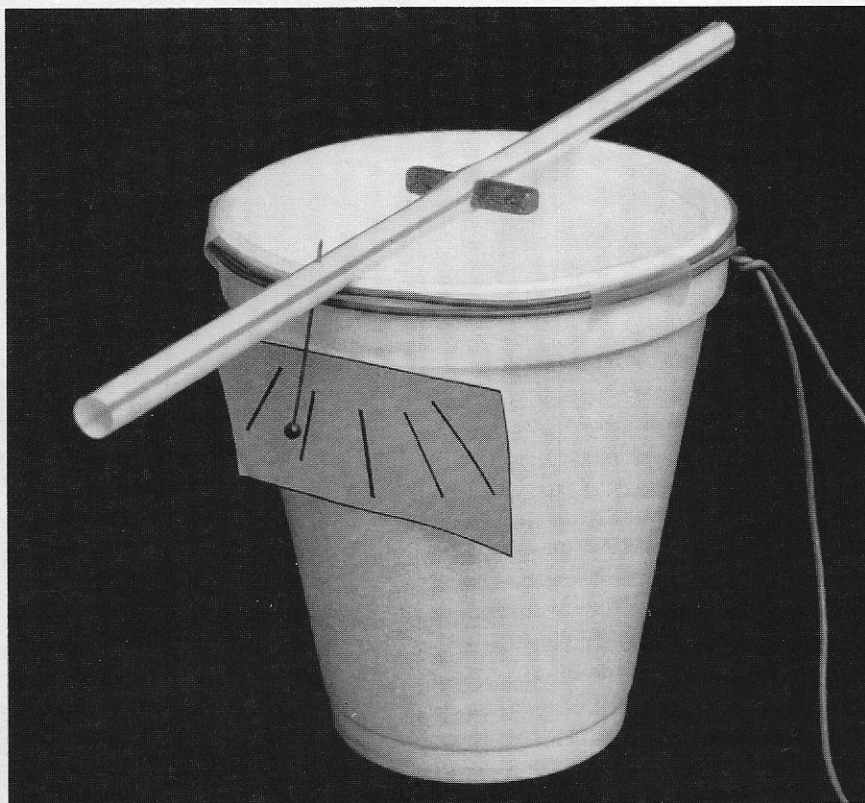
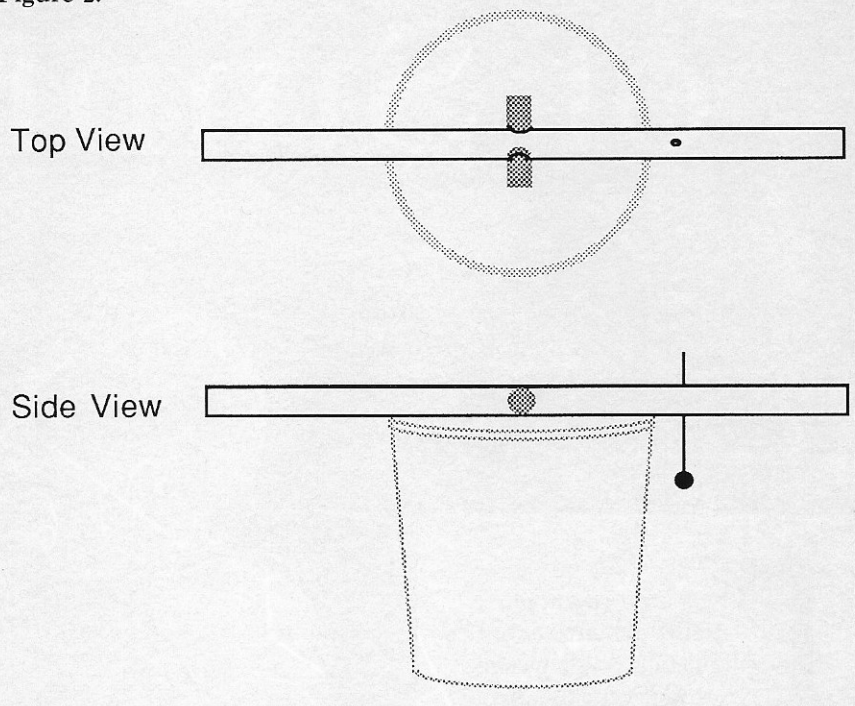
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them too large—the magnet should fit snugly in the hole. (See Figure 1.)

Next, insert the ball-headed pin in the straw. The pin should be set perpendicular to the magnet. When the straw is placed on top of the paper cup, with the magnet over the center of the opening, the pin should dangle just outside the cup. The pin acts as a pointer and stabilizes the galvanometer. Adjust the position of the straw and magnet until the straw balances on the center of the cup, with the pin hanging head-down. By adjusting the distance between the head of the pin and the straw, you can roughly control the sensitivity of the galvanometer. (See Figure 2.)

Now make a scale from an index card. Place the card against the side of the cup and sketch five or six short lines, each pointing toward

Figure 2.



the center of rotation of the pin. Trace over your lines with a thin marker and securely tape the scale to the side of the cup. (See photo.)

Finally, wrap a few loops of wire around the top of the cup and tape them in place. Be sure to leave enough wire so that you can connect the ends to your dry cell. (When I assembled my first paper cup galvanometer, I wrapped 15 or 20 turns of wire around the cup, expecting a small turning force on the straw. After blasting the straw off the cup several times, I realized just how sensitive the galvanometer is. Amazingly, it only takes one or two turns of wire to produce a measurable deflection of the straw.)

It is sometimes necessary to place a small weight in the bottom of the cup to keep it from tipping over. Once you've done this, you're finished. The completed galvanometer should look like Figure 3.

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A setup sampler

Your class can carry out various investigations with their galvanometers. Ask students to try different orientations for the magnet to see if they can maximize the sensitivity of the galvanometer. Advanced students get a real mental

workout trying to apply the "right-hand rule" to this simple device. The right-hand rule allows you to determine the direction of a magnetic field by observing the direction of the electric current creating the field. If students know which end of the bar magnet is north, they can predict which way it should turn.

After we have done various experiments with the galvanometer, I ask students if they can think of any practical applications for the

"newly discovered" force of magnetic fields. I show the class a simple electric motor—it really isn't much different from their galvanometers. I also point out that electrical generators function in a way that is similar to our homemade galvanometer.

You might also want to bring a commercial galvanometer to class. A comparison of the commercial model with the paper cup galvanometers can provide important insights into engineering. Ask students to think how the components of a commercial galvanometer differ from those of the homemade ones.

The possibilities for experimentation are nearly boundless. Teach students a simple method for detecting electricity and you'll soon feel the electricity of intellectual stimulation in your classroom. Try not to appear too shocked. □

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