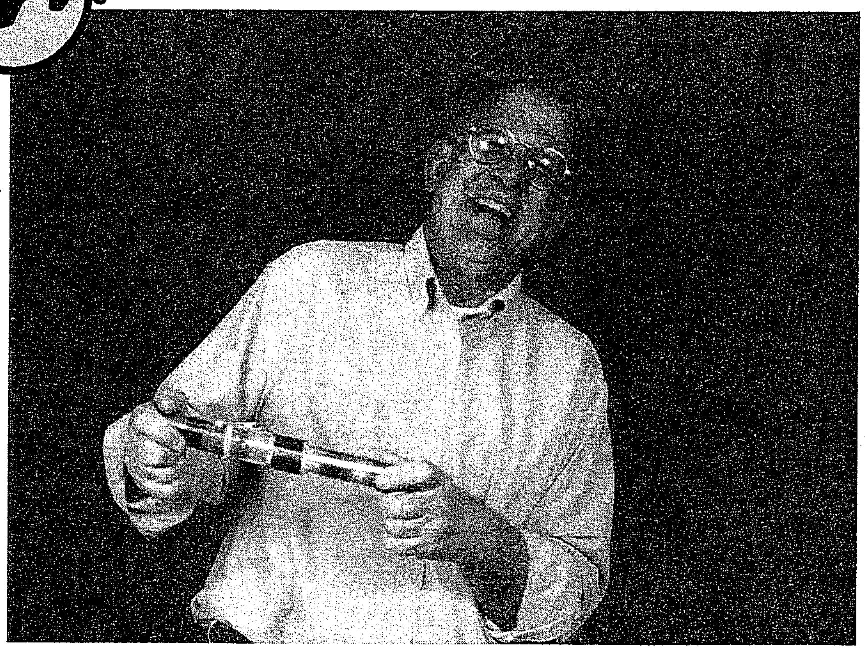
Stripped-Down Generator

If you shake just right, you'll see the light.

In an electric power plant, steam or water power is used to move huge coils of wire past extremely strong electromagnets, generating megawatts of electricity to light whole towns. In this snack, you use your muscles to move ordinary magnets past a small coil of wire, generating milliwatts of electricity—just enough to light an LED. Although the two generators work at very different scales, they're based on the same physics principles.



Materials

- 2 blank overhead transparency sheets, $8\frac{1}{2}$ in × 11 in
- 2 film canisters with lids
- tape (transparent or translucent)
- 3 rubber bands, $\frac{1}{8}$-in (3-mm) wide × $3\frac{1}{2}$-in (9-cm) long (#32 or #33)
- about 200 ft (60 m) of #30 magnet wire (very thin copper wire with enamel insulation); RadioShack sells magnet wire in packages containing one spool each of #22, #26, and #30 wire; the #30 spool has 200 ft of wire on it (RadioShack #278-1345)
- scissors, knife, or wire cutters
- small piece of sandpaper
- 2 mini alligator clips (RadioShack #270-380A, pack of 12 clips)
- light-emitting diode (LED); some LEDs give particularly bright light (e.g., RadioShack Jumbo Super-Bright LED, #276-086, and High Brightness Red LED, #276-066); many ordinary LEDs will also work; RadioShack sells a variety of LEDs, including a 20-pack of assorted LEDs, #276-1622
- 5 ceramic "donut" disk magnets, $1\frac{1}{2}$ in diameter (RadioShack #54-1888, pack of five)
- bipolar (two-color) LED (RadioShack #276-012)
- masking tape

ASSEMBLY

1 Put the two transparency sheets together, one on top of the other, and roll them into a tube, with the long side of the sheets running the length of the tube. Place a film canister (with lid on) in each end of the tube, with the top of the canister facing out. Tighten the tube so that it fits snugly against the canisters at both ends, and tape it at the ends and in the middle so that it stays this diameter. Also tape along the lengthwise seam for added strength. You should now be able to remove the canisters and reinsert them without any trouble.

2 Double two of the rubber bands and place them on the tube so that they are wrapped around the tube near the middle, with about 1 inch (2.5 cm) between them. The rubber bands will help keep the coils of wire you will be wrapping around the tube from spreading.

3 Wrap the magnet wire around the tube between the rubber bands, leaving about 12 inches (30 cm) of wire free on the starting end. Begin as close as you can to one rubber band and proceed toward the other rubber band. When you reach the second rubber band, start another layer and proceed back toward the original rubber band—but keep wrapping in the same direction (i.e., clockwise or counterclockwise, whichever direction you began with). If you reverse the direction of your wraps, you'll cancel the effect of the wire you wrapped initially.

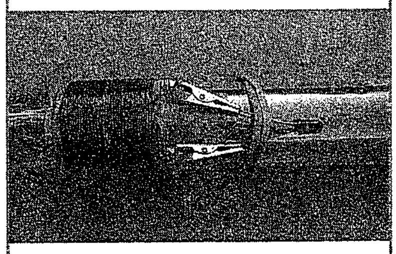
Keep wrapping the wire around the tube, building up multiple layers, until you have about 500 wraps. (If you use the #30 magnet wire from RadioShack, you'll get about 450 to 500 wraps if you use the whole spool—anything close to this will be enough.) Wrap the wire as tightly as you can without squashing the tube. Be sure you don't scrape the insulation off the wire as you wrap it. Try to keep all the wire between the rubber bands. (If the coil starts to come apart, use tape to hold it in place.) Make sure to leave another 12 inches (30 cm) of wire free.

4 You should now have a coil with two 12-inch pieces of wire coming from it. Tape the base of each free wire end to the tube near the coil to hold it in place. Then cut both of these wires so that they extend about 3 inches (8 cm) from the coil.

5 Use a knife or sandpaper to remove about $1\frac{1}{2}$ inches (4 cm) of the insulation from each of the two ends of wire. Make sure that you remove the insulation thoroughly. Put the stripped end of one of the wires through the hole in the shank of an alligator clip, and then wind the wire tightly around the shank of the clip. Be sure that the stripped wire makes good contact with the clip. Repeat for the other wire and alligator clip.

6 Clip each alligator clip to one of the legs of the LED. Lay the alligator clips alongside each other on the tube, but be sure that they don't touch each other. Use the third rubber band to hold them in place. The completed coil and LED assembly should look like figure 1.

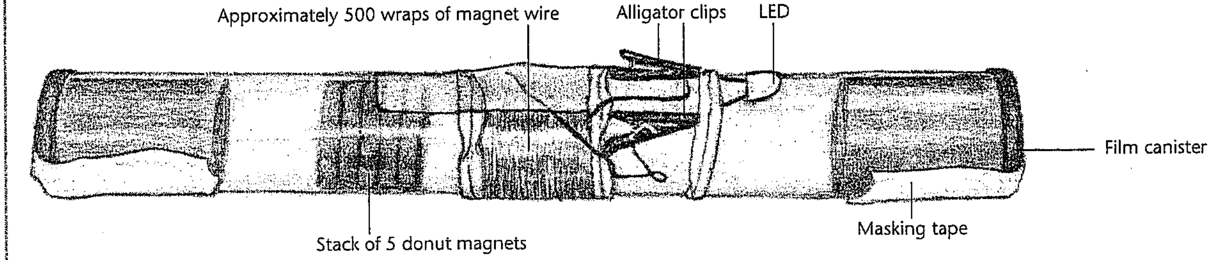
Figure 1



Here is a close-up view of the coil, alligator clips, and LED assembly.

7 Put the donut magnets together to form a stack. Remove one of the film canisters from the tube, put the magnets in the tube, and replace the canister in the end of the tube. (Be sure the lid is still on the canister, so that squeezing the canister won't easily deform its circular cross-section.) Tape the film canisters in place with masking tape. Figure 2 shows the completed Stripped-Down Generator.

Figure 2



When completed, the Stripped-Down Generator will look like this.

To Do and Notice

Grasp the tube at both ends to hold the film canisters in place. Shake the tube back and forth horizontally so that the magnet stack slides back and forth inside the tube. Shake the tube as rapidly as you can.

Each time the magnet stack passes through the coil of wire, the LED should flash. The flashes are more dramatic in a darkened room.

Remove the original LED and hook up the bipolar LED. Shake the tube again so that the magnet stack slides back and forth. What happens now?

What's Going On?

Whenever a wire and a magnetic field move perpendicular to each other, a voltage is induced in the wire. If the wire is part of a complete electric circuit, the voltage will cause a current to flow in the circuit. If a coil of wire is used instead of a single wire, the voltage obtained is the single-wire voltage multiplied by the number of turns in the coil.

In the Stripped-Down Generator, every time the magnet stack moves through the coil of wire, the coil experiences a changing magnetic field, which induces a voltage in the coil. Since the coil is part of a complete circuit that includes the LED, current flows in the LED and it lights. Note, however, that this depends on your shaking the generator rapidly. If you shake it too slowly, you may not produce the voltage needed to light the LED.

That's the simple explanation. What's actually going on is a little more complicated. The stack of magnets has two poles, and the lines of magnetic force are oriented differently at each pole. When the north pole of the stack passes through the coil, a voltage is created. Then when the south pole passes through, the voltage is reversed. Therefore, each time the magnet passes through the coil, two pulses of voltage are produced, and they are opposite each other in sign.

The normal LED lights up once each time the magnet stack passes through the coil, regardless of which way the stack is traveling, even though two pulses of voltage are produced. There is only one flash because the LED is a diode, and a diode only allows current to flow in one direction. When the magnet stack passes by the coil in one direction, the first pulse of current lights the LED, and when it passes by in the other direction, the second pulse of current does the job.

The bipolar LED is actually two LEDs in one casing. When current flows in one direction, one of the LEDs emits red light; when current flows in the opposite direction, the other LED emits green light. When you hook up this LED, you see two flashes of light each time the magnet passes through the coil—one of them when the north pole of the magnet stack passes through the coil, and the other when the south pole passes through.

More About the Two Pulses

When the magnet stack passes through the coil, two pulses of voltage of opposite sign are produced. This happens because the direction of the voltage induced in a coil is related to both the *orientation* of the magnetic field lines relative to the coil, and their *direction of movement* relative to the coil. When the north pole of the magnet stack, for example, is moving to the left through the coil, as shown in figure 3a, the magnetic field lines are

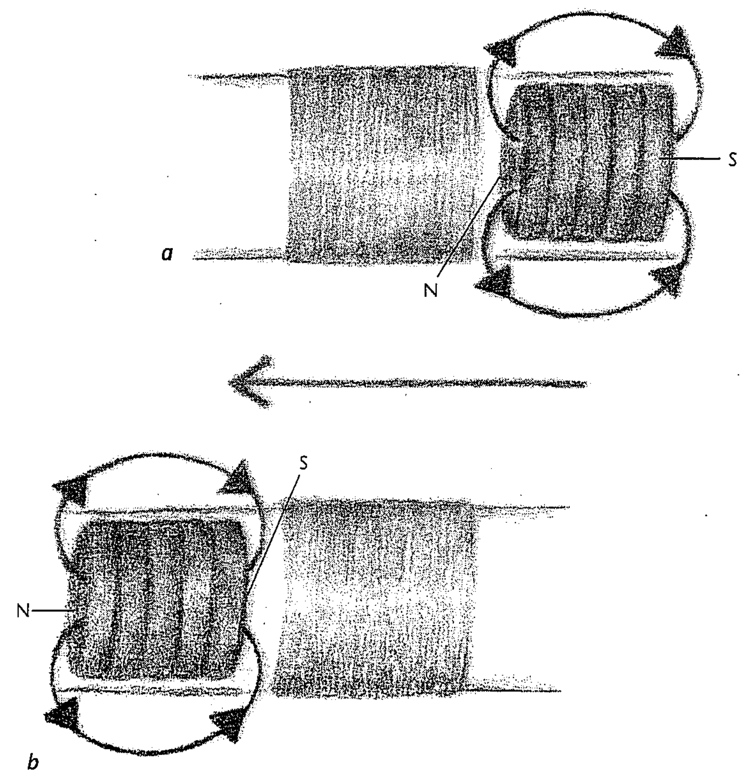
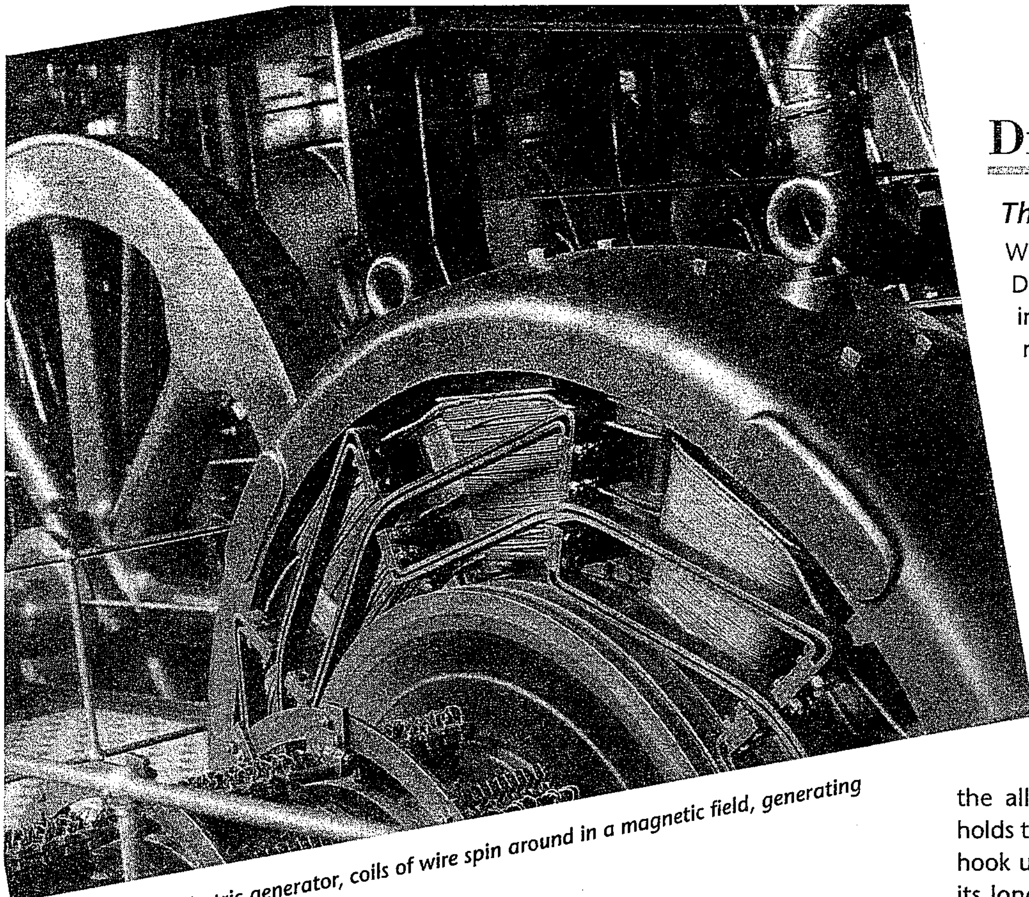


Figure 3 *As the north pole of the magnet stack enters the coil (a), a voltage pulse is created in the coil. As the south pole of the magnet stack leaves the other end of the coil (b), a second voltage pulse, of the opposite sign, is produced in the coil.*

The difference in sign of the voltage pulses is due to the different direction of the magnetic field lines in each case. At the north pole of the magnet stack, the magnetic field lines are pointing outward, and at the south pole they are pointing inward. When the LED is connected in the proper direction relative to the sign of the voltage pulse, current flows in the LED, causing it to light.



In this large electric generator, coils of wire spin around in a magnetic field, generating voltage and currents.

pointing *away* from the center of the coil, and the resulting voltage forces the current to flow in one direction in the coil. Then when the south pole of the magnet stack passes through the coil, as shown in figure 3b, the magnetic field lines are pointing *toward* the center of the coil, and the resulting voltage forces the current to flow in the opposite direction.

So What?

Current that always flows in the same direction is called direct current (DC). Current that flows first in one direction and then the other is called alternating current (AC). The generators that provide the electricity you use every day operate on the same general principle as the Stripped-Down Generator, and they produce AC current just like the Stripped-Down Generator.

Most of the appliances and lights in your home can use AC current straight from the outlets. Some electrical devices, however, require DC rather than AC for their operation, and they either have a built-in electrical circuit that converts the AC to DC, or they use an adapter that accomplishes this task. These devices include portable phones, answering machines, stereos, and computers. Many devices that can be run on batteries, such as laptop computers and tape recorders, also come equipped with AC adapters, which convert the AC from the wall outlet into DC for the device.

Did You Know?

The Motion Is Relative

When you shake the Stripped-Down Generator, the coil is moving back and forth over the magnet at least as much as the magnet is moving back and forth through the coil. In any case, it's the relative motion of coil and magnet that's important in generating electricity.

Going Further

Dual LEDs

Attach an ordinary LED to the alligator clips. Note which clip holds the longest leg of the LED. Then hook up a second ordinary LED, with its longest leg in the other clip. The two LEDs now have opposite polarities. Predict what will happen when you shake the tube.

Measure It

Hook the generator up to a voltmeter (not digital) and see what the needle does.

Picture It

Hook the generator up to an oscilloscope and see if you can display the entire signal.

Credits & References

Curt Gabrielson developed this snack based on an idea proposed by a sixth grade student named Van in an afterschool workshop.

Macaulay, David. *The Way Things Work.* Boston: Houghton Mifflin, 1988. See LED, page 293, and Electric Generator, pages 304–305.