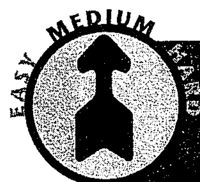
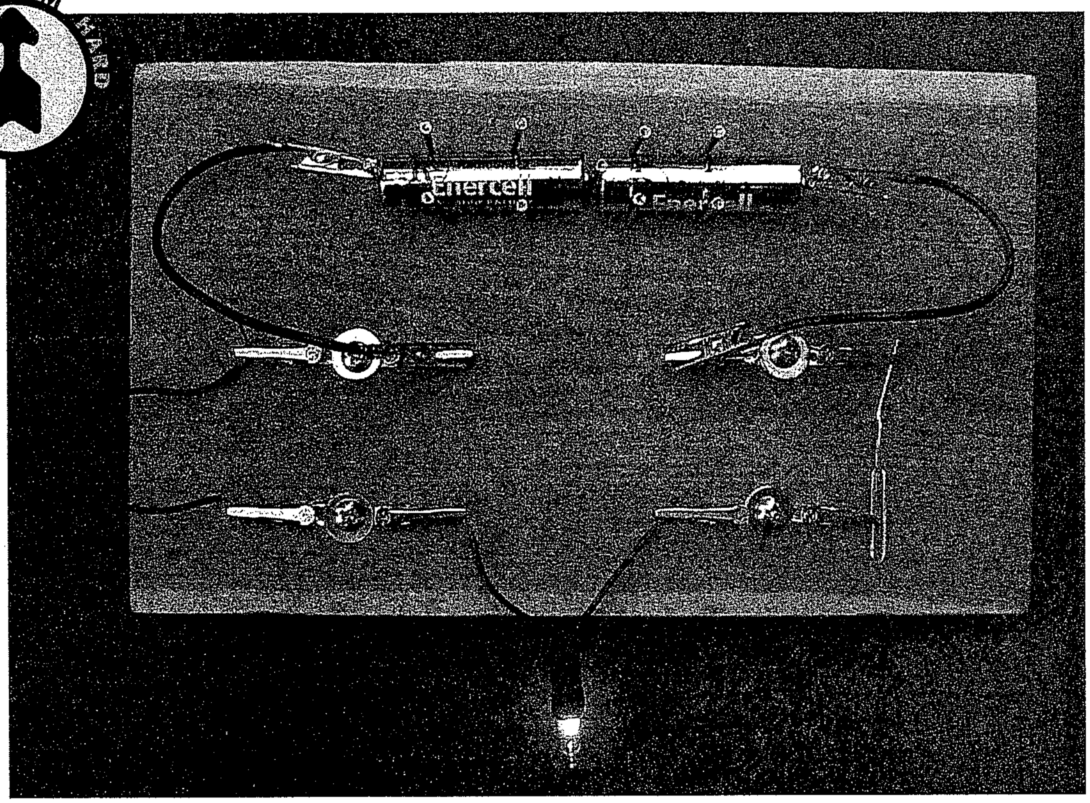
Circuit Workbench

Circuits so interesting you can't possibly get board.

The simple circuit board you build in this snack allows you to easily connect small holiday lights in a variety of ways. By observing the effects of connecting the lights in different ways, you can learn some of the characteristics of series and parallel circuits.





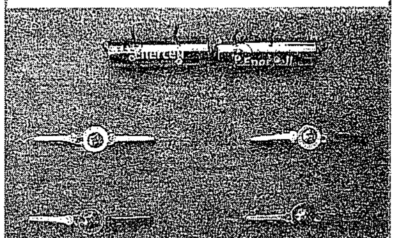
Materials

- hammer
- 11 finishing nails, $1\frac{1}{2}$ in
- wooden board (ordinary 1 in × 6 in pine shelving), about $5\frac{1}{2}$ in × 9 in (14 cm × 23 cm)
- needle-nose pliers
- 12 mini alligator clips (RadioShack #270-380A, pack of 12)
- 4 flat washers (SAE 10)
- 4 sheet-metal screws (#8, $\frac{5}{8}$ in, Phillips pan head)
- Phillips screwdriver
- 2 AA batteries
- short string of miniature Christmas-tree lights
- wire stripper
- 3 pieces of wire, each about 6 in (15 cm) long; you can use extra pieces from the light-bulb string, or #20 or #22 solid or stranded wire
- several metal paper clips

ASSEMBLY

1 Use the hammer and one of the nails to make small pilot holes for screws in the board, at the approximate locations of the four screws in figure 1 (the exact position of the screws is not crucial).

Figure 1



Board without lights

2 Use the needle-nose pliers to bend the two small tabs on the ends of eight of the alligator clips outward, so that the entire end of each clip is flattened as shown in figure 2.

Figure 2

Clip with tabs flattened outward

3 Put a washer on each of the screws, and screw the screws about halfway into the pilot holes.

4 Put the flattened ends of two alligator clips under one of the washers. Position the clips so that they point in opposite directions, parallel to the length of the board, as shown in figure 1. Tighten all the screws until the clips are held firmly in place between the washers and the board.

5 Create a holder for the two batteries, like the one shown in figure 1, by hammering the 11 nails about a half inch (1.2 cm) into the board to surround the batteries. Don't forget the nail between the two batteries; this will allow you to use either one or two batteries to power the light bulbs. Point the negative ends of the batteries (the flat ends) toward the left.

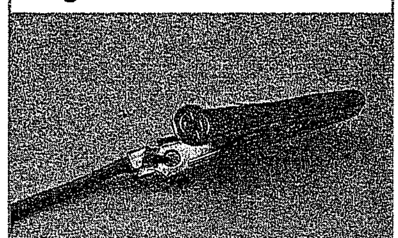
6 Cut three individual bulbs from the string. Cut the wire halfway between adjacent bulbs so that each bulb ends up with two wire leads that are equal in length.

7 Use the wire stripper to strip about a half inch (1.2 cm) of insulation from the ends of the wires coming from each of the light bulbs.

8 Strip the insulation from the ends of each of the three additional pieces of wire.

9 Use the needle-nose pliers to attach alligator clips firmly to both ends of two of the pieces of wire (leave the other piece alone). A good way to attach the clips is to poke the stripped part of the wire down through the hole near the end of the clip so that the insulated part lies in the curved part of the clip between the two tabs. Then bring the stripped part up around the clip and lay it on top of the insulated part. Finally, bend the two tabs down on top of both the bare and the insulated parts to hold them tightly in place. This should ensure both a good electrical connection and a good physical connection (see figure 3).

Figure 3



Clip with tabs flattened against both the bare and insulated wire

To Do and Notice

Making Connections

Refer to figure 4 (on page 11) for clip numbers, then connect a single bulb to clips 6 and 7. Use the alligator-clip leads you made to connect the nails at the ends of the batteries to clips 2 and 3. Connect clips 4 and 8 with a straightened-out paper clip, and use the plain piece of wire to connect clips 1 and 5. What happens to the bulb when you make the final connection? Your completed circuit should look like the opening photo. (**Note:** If the bulb doesn't light, see Helpful Hints on page 11.)

Connecting Bulbs in Series

Replace the wire between clips 1 and 5 with a bulb, and replace the paper clip between clips 4 and 8 with the third bulb. All three bulbs should light and glow with approximately the same brightness. (If one of the bulbs is very much brighter or dimmer than the other two, remove it and replace it with another bulb.) How does the brightness of these bulbs compare to the brightness of the single bulb in the initial setup?

Remove one of the bulbs from the circuit, and don't replace it with a wire or paper clip. What happens to the other two bulbs? Try replacing the bulb you removed, and removing another one instead. Does it matter which one of the bulbs you remove?

Helpful Hints

If the bulb doesn't light, check to see that the nails are in firm contact with the ends of the batteries, and that all the connections are made properly. The most common problem in a circuit is a bad connection. Also, be sure that the batteries are not dead!

While you try to figure out what's wrong, unhook one of the leads from the batteries. It's possible that you've hooked things up in a way that will cause the batteries to go dead quickly if left connected. (If this is the case, the batteries may get noticeably hot in the process.)

Both the wire and a paper clip act as good electrical conductors, and you can use whichever is most convenient whenever you want to connect two clips.

Changing the Voltage

Set up the circuit in its original form, with just one bulb. Move one of the alligator clips from a nail at the end of the battery holder to the nail between the batteries. What happens?

Connecting Bulbs in Parallel

Remove all bulbs, wires, and paper clips. Connect one of the alligator-clip leads from the end of the battery holder to clip 1, and the other lead from the other end of the battery holder to clip 6. Connect bulbs between clips 1 and 5 and between clips 2 and 6. What happens? Remove one of the bulbs. What happens now?

Replace the bulb you removed, and remove the other one. What happens? Does it make any difference if you remove one bulb or the other? How does the brightness of the single bulb compare with the brightness of each of the two bulbs? How does the behavior of the two bulbs differ from that of the three bulbs that were connected differently?

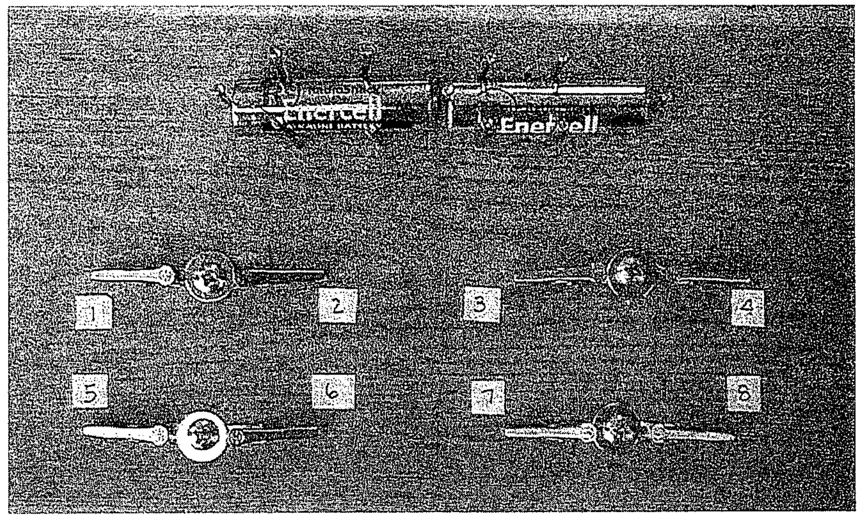


Figure 4 *Board with clips numbered*

What's Going On?

Connecting Bulbs in Series

In the initial setup with one bulb, electrons come out of the negative end of the left battery to begin their journey through the circuit. They travel through clips 2 and 1, the wire, clips 5 and 6, the bulb, clips 7 and 8, the paper clip, clips 4 and 3, and back into the positive end of the right battery. This path is called a complete electrical circuit. The flow of electrons in a complete circuit is often referred to as electrical current, although this is not technically correct—see the Current Versus Electron Flow discussion in the Did You Know? section.

In the batteries, the electrons gain energy. Batteries are rated in volts, and volts are a measure of the energy that electrons have when they leave the battery. We'll assume that the only place the electrons lose energy is in the bulb, where their energy is transformed to the light and heat given off by the bulb. The process of energy transformation resists the electron flow through the bulb, and the bulb is said to have electrical resistance. (If the battery voltage stays the same, changing the resistance does not change the energy of individual electrons, it just changes the number of electrons that flow. That is, it changes the current.) It's very important to realize that while an electron loses energy on its trip around the circuit, the electron itself doesn't leak out of the circuit or disappear. For every electron leaving the battery to enter the circuit, another enters the battery from the circuit.

When two or more bulbs are connected so that electrons have no choice but to pass through all the bulbs to get back to the battery, the bulbs are said to be connected in series. When three bulbs are connected in series, each bulb glows less brightly than one bulb alone. This is because three bulbs provide more total resistance than one bulb, decreasing the current and resulting in a smaller amount of energy being transformed to light and heat. Additionally, each bulb only gets one-third of this reduced amount of energy.

When you remove one bulb in a series circuit, the others go out. It doesn't matter which one you remove; as long as you create a gap in the circuit, the electrons can no longer flow.

Changing the Voltage

When you move one of the battery clips to the nail between the batteries, the circuit is powered by one battery instead of two. This decreases the voltage by half, so the bulb gets dimmer.

Connecting Bulbs in Parallel

When you connect bulbs between clips 1 and 5 and between clips 2 and 6, the electrons arriving at clip 1 now have two alternative paths to get to clip 6. If the two light bulbs are identical, half the electrons will go through one bulb and half through the other. The electrons will then recombine into one flow at clip 6, and return to the battery. Bulbs connected in this fashion are said to be connected in parallel.

When two or more identical bulbs are connected in parallel, all the bulbs will be as bright as a single bulb. This is because each additional bulb provides another path for electron flow, allowing the battery to send more electrons through the circuit and giving each bulb the same amount of current as a single bulb. The alternative paths actually reduce the total resistance in the circuit. In fact, the resistance of two identical bulbs in parallel is half the resistance of a single bulb, allowing twice as much current to flow in the circuit. When one of the bulbs in the parallel circuit is removed, current still flows through the other bulb and it stays lit.

Summary

After you completed the experiments, you probably noticed the following differences between series and parallel circuits: Removing any one of the bulbs in a series circuit makes all the bulbs go out, but removing one or more of the bulbs in a parallel circuit has no effect on the remaining bulbs. Also, the more bulbs you place in series, the dimmer each one gets, whereas adding more bulbs in parallel has no effect on the brightness of any of the bulbs. (This last statement is true as long as the battery you are using can supply the electron flow required to light all the bulbs at their normal brightness. Although AA, C, and D batteries all have the same voltage [1.5 volts]—meaning that an electron leaving any one of them has the same energy—a AA battery is not capable of supplying as large a flow of these electrons as a D battery.)

So What?

Do you think the circuits in your house are wired in series or in parallel? If you have a toaster and a radio plugged into the same outlet, does the radio go off when the toast is done? The fact that you can turn electrical items in your house on and off individually tells you that your circuits are wired in parallel. If this were not the case, when a light bulb burned out, all other devices on the same circuit would go off.

It's obviously practical to have household appliances wired in parallel. But remember that with each additional device wired into a parallel circuit, the overall resistance of the circuit is decreased, allowing more current to flow. A sufficiently large amount of current can generate enough heat to melt the insulation on electrical wires and start a fire. To safeguard against this potential danger, we use circuit breakers or fuses. Circuit breakers are designed so that when the current exceeds a certain level, a switch opens to stop the flow. Fuses accomplish the same interruption of current flow by "blowing" (actually melting), which breaks the circuit.

Did You Know?

Current Versus Electron Flow

In some high school physics textbooks, and in most college physics and engineering texts, the direction of flow of electric current is defined as the direction positive charge would flow, which would be through the circuit from the positive terminal of the battery to the negative terminal. In reality, however, positive charges do not move in wires. It's the negatively charged electrons that move, and they flow through a circuit from the negative terminal of the battery to the positive terminal. The definition of current as movement of positive charge has historical roots, and continues in use; current defined in this way is often called conventional current. In some situations (e.g., movement of charged particles in semiconductors, solutions, and gases) positive charges do actually move and contribute to electric current. For beginning work with simple circuits, it's easier to deal with electron flow; in this snack we've used current and electron flow interchangeably.

Going Further

A Series of Connections

Think of a way to connect a third bulb in the circuit so that all three bulbs will retain their maximum brightness, and any one or two of them can be removed without the third one going out.

Experiment further with your circuit board. How many bulbs can you connect in series? How many in parallel? Try putting a bulb in series with two bulbs that are in parallel; this is called a series-parallel circuit.

Try some arrangements of your own design. Notice the paths that the electrons can take in the circuits that you set up, and see if you can understand the behavior of the bulbs in these circuits.

Measure It

Obtain a voltmeter and ammeter, and measure the voltage and current in the various circuits you set up. (You can buy an inexpensive multimeter, part number 990177, from Kelvin, 800-535-8469, www.kelvin.com.)

Circuit Equations

Look up Ohm's Law and Kirchoff's Rules for voltage and current in a physics text or other reference source, and see if you can apply them to your circuits.

Credits & References

This snack is based on the Exploratorium exhibit of the same name.

Mims, Forrest M. III. *Getting Started in Electronics.* RadioShack, 2000. (RadioShack #62-5004)