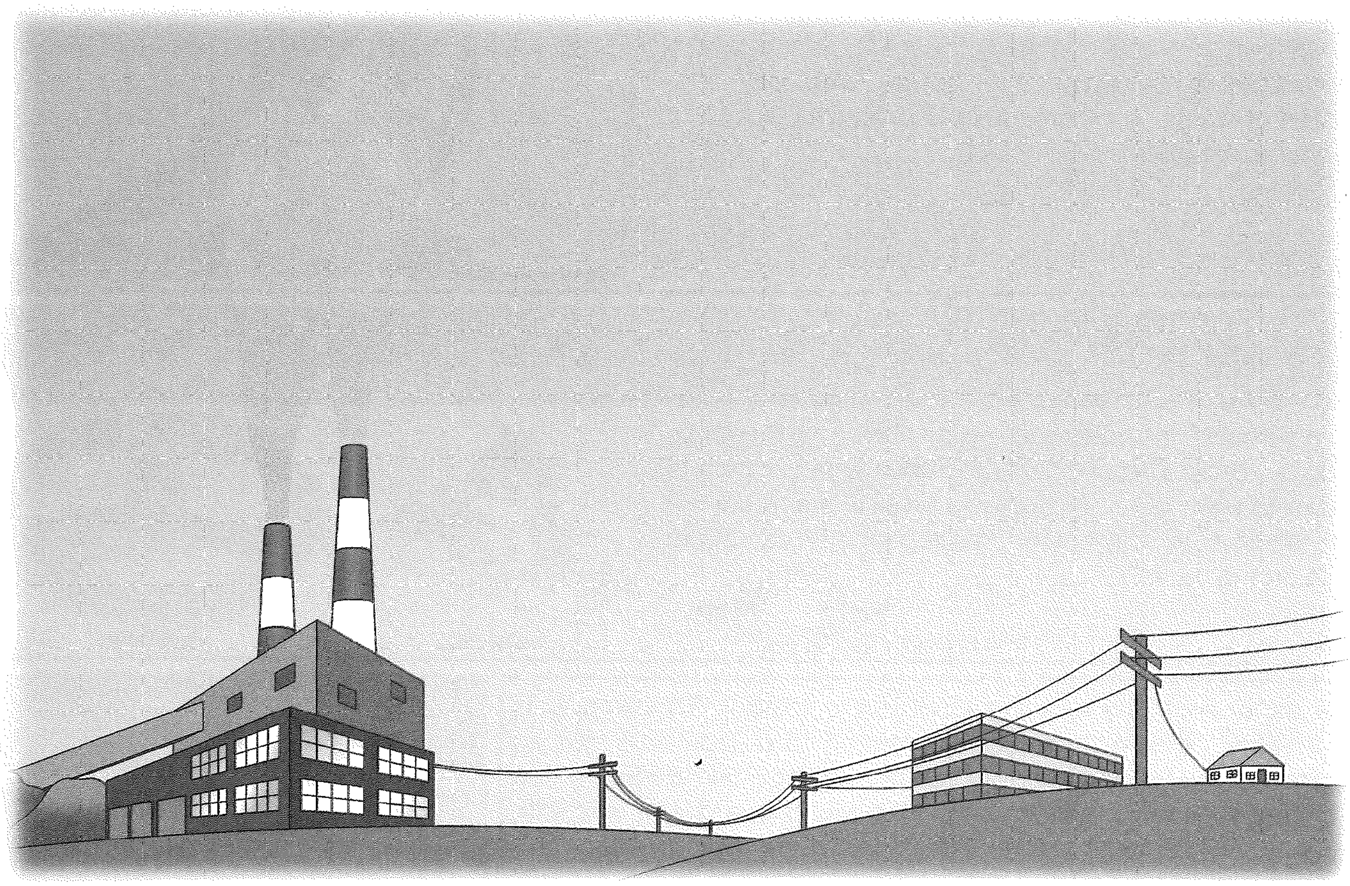
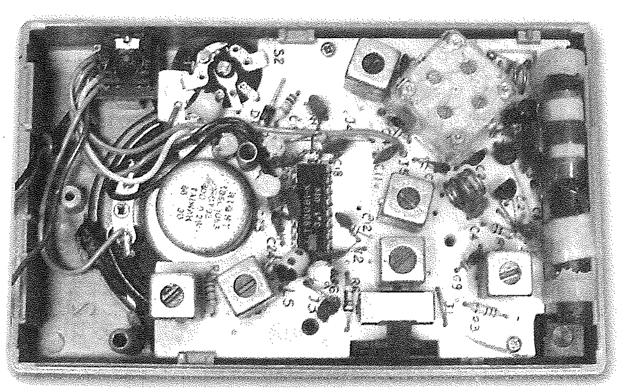
CHAPTER 2: MOTORS & ELECTRICITY

In this chapter you will learn about generators and motors. A generator uses mechanical motion to create electricity and a motor uses electricity to create mechanical motion. This statement may not seem important to you but it is actually the foundation of our present society. Nearly all of the electricity used in our world is produced at enormous generators driven by steam or water pressure. Wires are used to efficiently transport this energy to homes and businesses where it is used. Motors convert the electricity back into mechanical form to drive machinery and appliances. **The most important aspect of electricity in our society** - more important than the benefits of the Internet - **is that it allows energy to be easily transported over distances.**



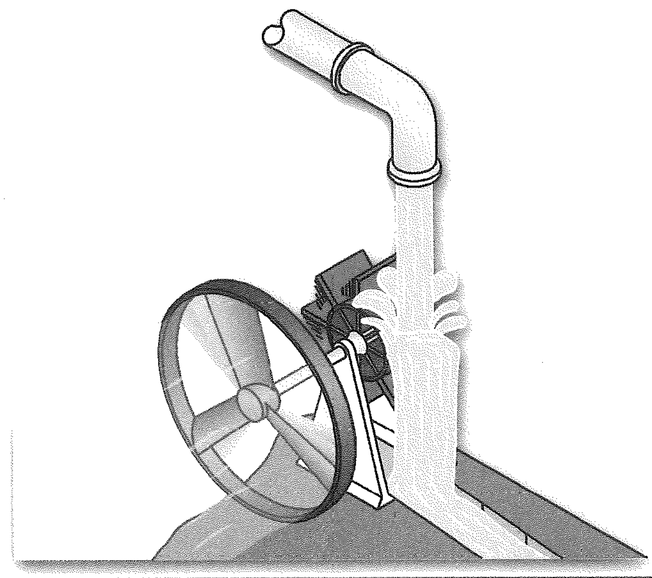
Note that "distances" includes not just large distances but also tiny distances. Try to imagine a plumbing structure of the same complexity as the circuitry inside a portable radio - it would have to be large because we can't make water pipes so small. Electricity allows complex designs to be made very small.



2-1 Motors

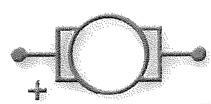
Water flowing under pressure in a pipe or a fast-moving stream can be used to turn a paddlewheel. If the paddlewheel was linked to a fan blade then you could use the water pressure to turn the fan, perhaps to cool yourself on a hot day. If the water was flowing very fast due to high pressure, then you could get the fan moving fast enough it might create a strong airflow like a propeller on a plane.

A similar thing happens in a motor, with electricity instead of water. A motor converts electricity into mechanical motion.

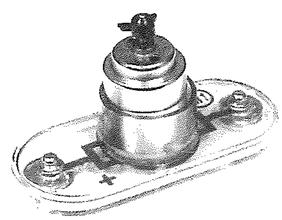


Introducing New Parts

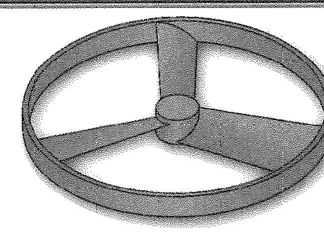
Snap Circuits® includes one motor, shown here with its symbol. Snap Circuits® also includes a fan, which is used with the motor. An electric current in the motor will turn the shaft and the motor blades, and the fan blade if it is on the motor.



Motor Symbol

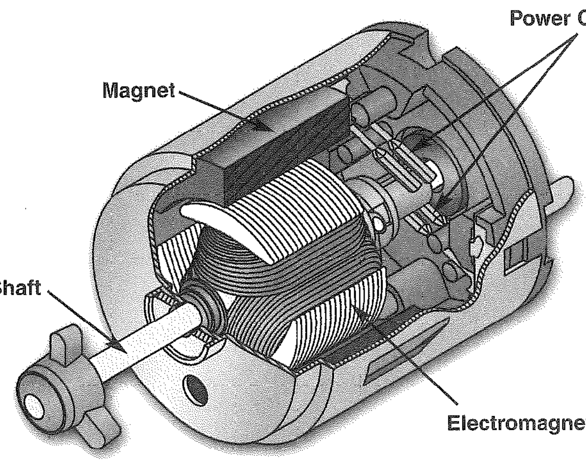


Motor (M1)



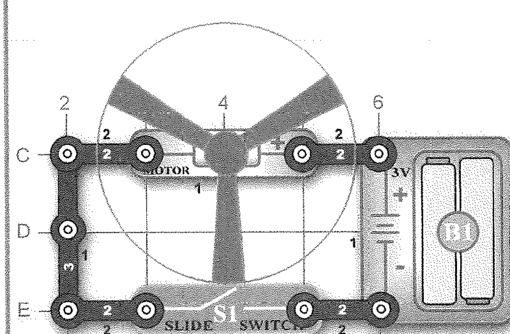
Fan Blade

How does electricity turn the shaft in the motor? The answer is magnetism. Electricity is closely related to magnetism, and an electric current flowing in a wire has a magnetic field similar to that of a very, very tiny magnet. Inside the motor is a coil of wire with many loops, if a large electric current flows through the loops the magnetic effects become concentrated enough to move a small magnet. The motor also has a small magnet, on a shaft. When electricity moves the magnet, the shaft spins. If the fan is on the motor shaft then its blades will create airflow.



Experiments

Consider this circuit (which is project 2):



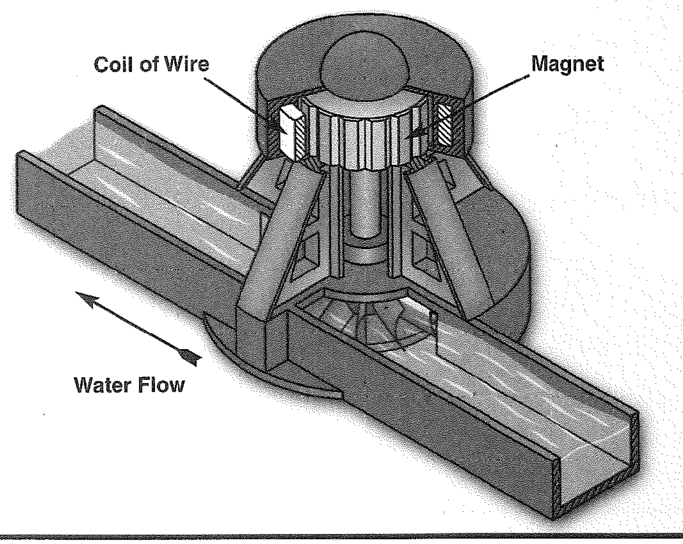
When the switch is on, current flows from the batteries through the motor making it spin. The fan blades will force air to move past the motor. Be careful not to touch the motor or fan when it is spinning at high speed.

Motors are used in all electric powered equipment requiring rotary motion, such as a cordless drill, electric toothbrush, and toy trains. An electric motor is much easier to control than gas or diesel engines.

The electromagnetic effect described above also works in reverse - spinning a magnet next to a coil of wire will produce an electric current in that wire. This is what happens in a **generator**, which uses mechanical motion to create electricity. In an electric power plant, high-pressure water (from a dam) or steam (heated by burning oil or coal) is used to spin a paddlewheel linked to magnets. The magnets create an electric current in a coil of wire, which is used to power our cities.

In theory, you could connect your Snap Circuits® motor directly to the 2.5V lamp and spin the fan blade with your fingers to light the lamp. In reality, it would be impossible for you to spin the motor fast enough to produce enough current to get even a glimmer of light from the lamp.

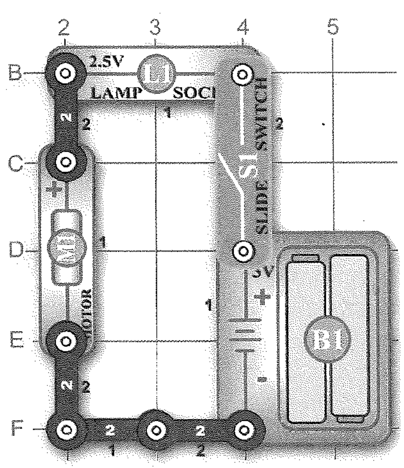
To summarize, **a generator uses mechanical motion to create electricity and a motor uses electricity to create mechanical motion.**



2-2 Motor Circuits

Experiments

Consider this circuit (which is project 5):

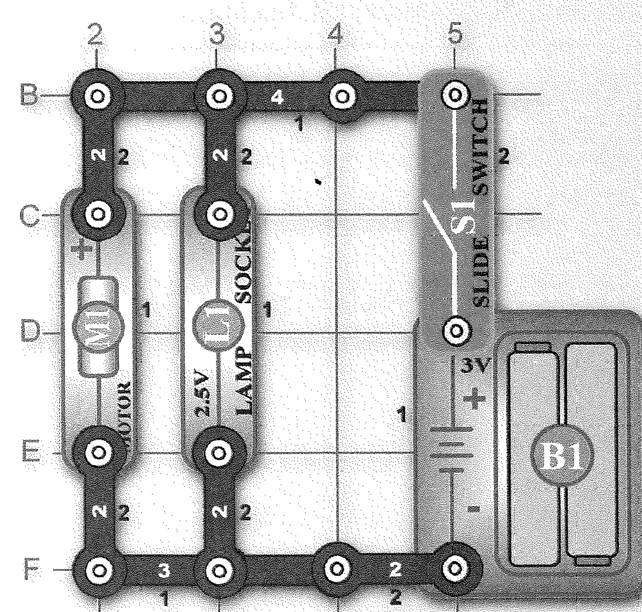


If the switch is on, the lamp will light and the fan will spin.

The lamp and motor are in series, so the voltage from the batteries will get divided between them. In this circuit more of the voltage will be used at the lamp than at the motor.

If the fan was not on the motor then the motor would spin much faster but the lamp would not be as bright. The motor needs more voltage to spin faster, so there is less voltage available to light the lamp.

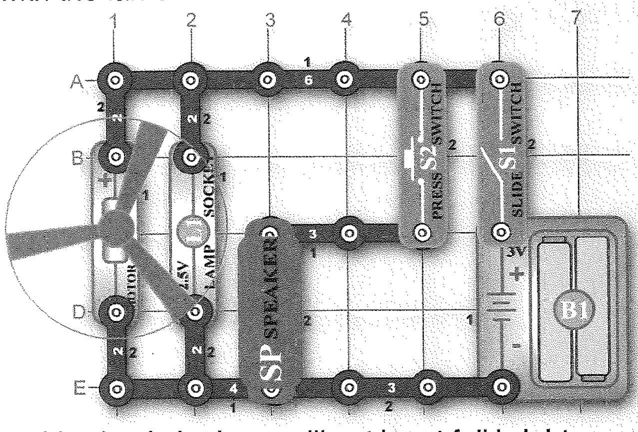
Consider this circuit (which is project 6):



If the switch is on, the lamp will light and the fan will spin. This circuit has the lamp and motor in parallel, so the full voltage from the batteries would be applied to both. So the fan would spin faster than for the circuit in project 5, which divided the battery voltage between the lamp and motor.

Experiments

Now consider this circuit (which is project 80), with the fan on the motor:



In this circuit the lamp will not be at full brightness, even though the full battery voltage is applied to it. Do you know why?

Remember that as the circuit current increases the voltage produced by a battery is reduced. The motor draws a high current, very high when it first starts up with the fan on. The chemical reaction in the batteries can't supply such a high current, so the battery voltage (electrical pressure) drops.

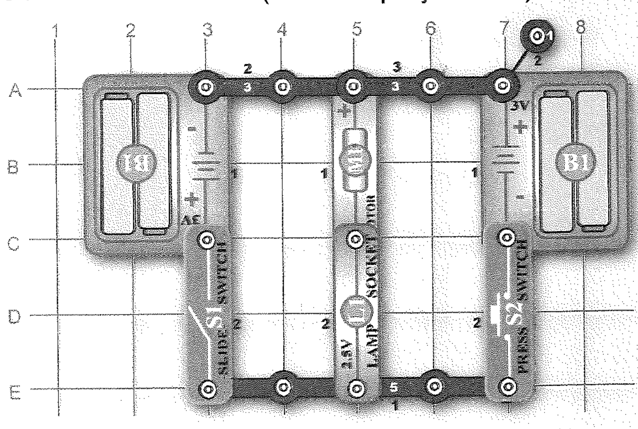
If your instructor has a meter to measure voltage, ask him to measure the battery voltage with the slide switch on and off. You would see the voltage drop to under 2.5V when the switch is on.

Push the press switch to add the speaker to the circuit and increase the circuit current even more. This will make the lamp less bright. Take the fan off the motor and turn on the switch again. The lamp will be brighter now. It doesn't take as much current to spin the motor without the fan, so the battery voltage doesn't drop much.

You know that the AA batteries used to power your snap circuits have + and – markings on them, called **polarity** markings. The chemical reaction in the batteries only makes the electric current flow in one direction. To make the current flow in the other direction you just reverse the batteries (all batteries in the same circuit must be reversed). The motor also has + and – markings, because if the direction of current flow through is reversed than the motor will spin in the opposite direction (reversing the electric current reverses the magnetic field generated, which reverses the direction the shaft spins). The lamp, switch, and wires have no such + and – markings on them because they work the same regardless of which way the current is flowing.

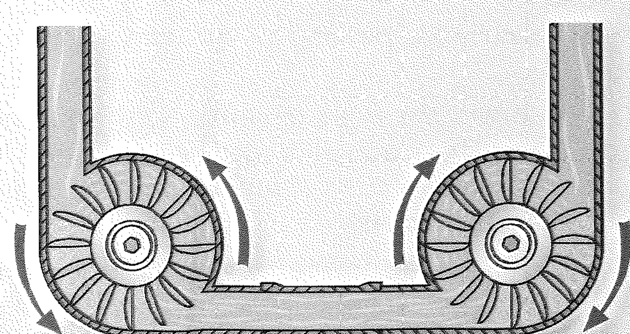
Experiments

Consider this circuit (which is project 262):



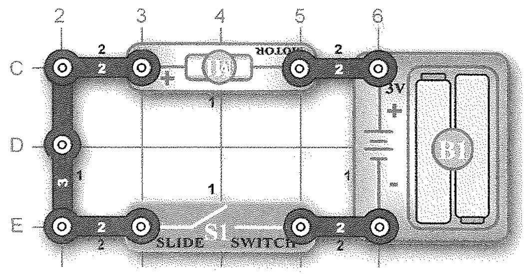
If the slide switch is on, the fan will spin to the left. If the press switch is on, the fan will spin to the right. The slide and press switches apply opposite voltages to the circuit. The lamp lights in either case, since it is not affected by the direction of current flow.

What happens if both switches are on? Nothing happens, just as if both were off. The opposite voltages from the batteries cancel each other out. Think of this as two pumps trying to pump water through a pipe in opposite directions.



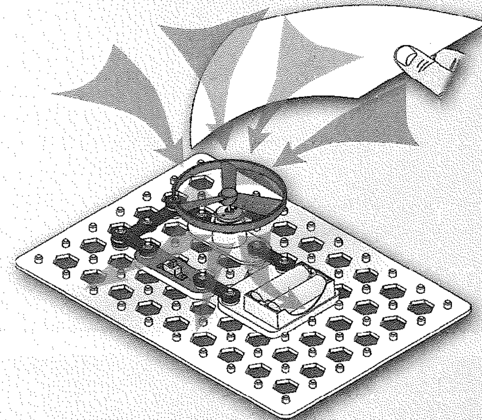
Experiments

Consider this circuit (which is project 11):



If the switch is turned off when the motor is spinning at full speed, the fan will rise into the air. Be careful not to touch the motor or fan while it is spinning at high speed. In this circuit the fan blades suck in air and push it down to the table.

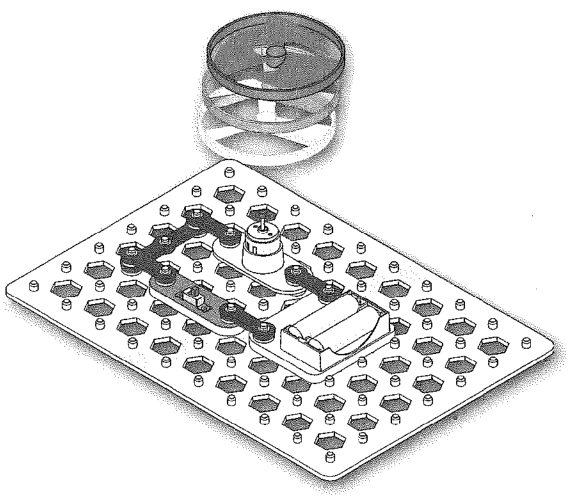
If you hold a sheet of paper above the fan, you will see it get sucked toward the fan.



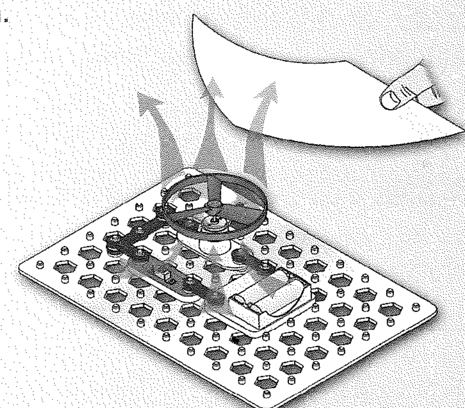
How does the fan rise? Think first about how you swim. When your arms or legs push water behind you, your body moves ahead. A similar effect occurs in a helicopter - the spinning blades push air down, and create an upward force on the blades. If the blades are spinning fast enough, the upward force will be strong enough to lift the helicopter off the ground.

While the switch is on, the motor rotation locks the fan on the motor shaft. The fan does not spin fast enough to lift the entire circuit off the ground. Sometimes there may be enough lift to make the base grid hover around the table like a puck on an air hockey table.

When the motor is turned off, the fan unlocks from the shaft. The fan rises into the air like a helicopter, since it is no longer held down by the weight of the full circuit.

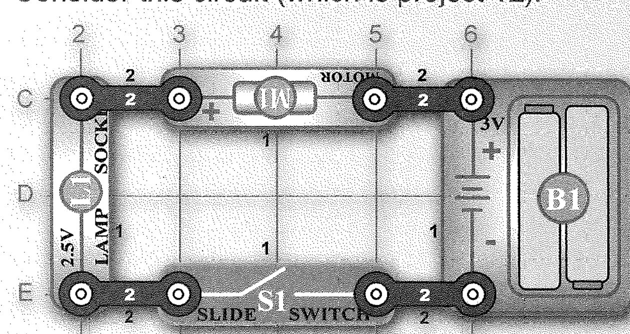


If the motor polarity were reversed (+ on the right), the fan would never fly. The fan blades are sucking in air around the motor and pushing it straight up. If you hold a sheet of paper above the fan, you will see it get pushed up and away from the fan.



Experiments

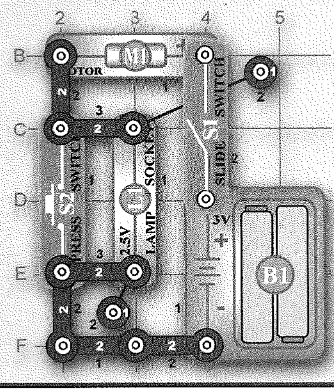
Consider this circuit (which is project 12):



By placing the lamp in series with the motor, the voltage at the motor is reduced. The motor speed will be reduced, so the fan will probably not fly off.

Experiments

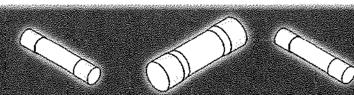
Consider this circuit (which is project 13):



If the slide switch (S1) is on, the fan spins and the lamp lights. If the press switch (S2) is also on, then the fan will spin faster but the lamp will be off. In this case, the full battery voltage is applied to the motor, instead of being divided between the motor and lamp.

This is one way of controlling the speed of a fan. Commercial fans do not use this method because the lamp produces heat and wastes energy. Commercial fans change the amount of voltage applied to the motor using other methods.

2-3 Fuses

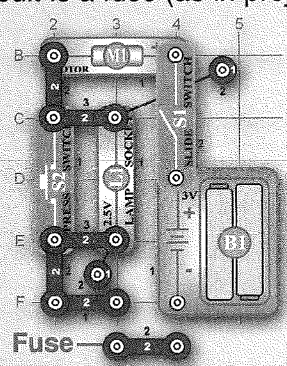


Occasionally electronic products/components break due to people using them incorrectly, accidents, natural storms, bad design, or component failures. Often the problem is a short circuit, which results in an excessively high current flow. This high current can overheat components in the product enough to damage them, make them explode, or start a fire.

A **fuse** is usually a special wire that breaks ("blows") when too much current flows through it. A "blown fuse" shuts down the product before anything can overheat or cause a fire. Although a "**blown fuse**" prevents the product from working, fuses are easy to replace.

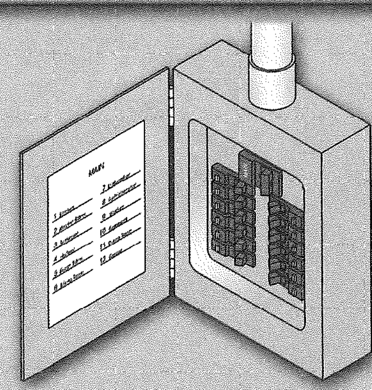
Experiments

Imagine that one of the 2-snap wires in the previous circuit is a fuse (as in project 14):



If the circuit is operating properly then the "fuse" acts as a 2-snap wire. However if the motor breaks and suddenly becomes a short circuit while both switches are on, then there will be nothing to limit the current in the circuit. A very high current will flow from the batteries, and would damage them if it continues. This excessively high current will "blow" the fuse, creating an open circuit just like turning off the slide switch would do. This will protect the batteries from damage. The motor can then be repaired and the fuse replaced.

Fuses are very important and most electronic products have one. Products using electricity supplied by the electric company are usually required to have them because the high voltages and currents available here can cause severe damage and fires. Small battery-powered products usually do not have fuses because the batteries in them are not powerful enough to cause harm.



While many fuses must be replaced when blown, flipping a switch can reset some types. Every home has an electrical box of such fuses, to isolate any problems in one room from the rest of the house and your neighbors. But these fuses protecting your home take a much higher current to "blow" them than a fuse used in a radio.

2-4 Your Electric Company

Batteries are widely used because they are easy-to-use, safe, and portable. For example, Snap Circuits® can be used on a camping trip in a remote wilderness as long as you have batteries. You can even take along spare batteries because they are small and easy to carry.

What if you wanted to take a microwave oven on the camping trip? A microwave oven uses a lot of electricity, so the batteries for it would be large, heavy, expensive, and wouldn't last long. Heavy, high-power products like microwave ovens are not moved often.

Only a tiny portion of the electricity used in our world comes from batteries. The rest is produced at enormous electric power plants, operated by your local electric company. The electricity from these power plants is available at the electrical outlets in the walls of your home.

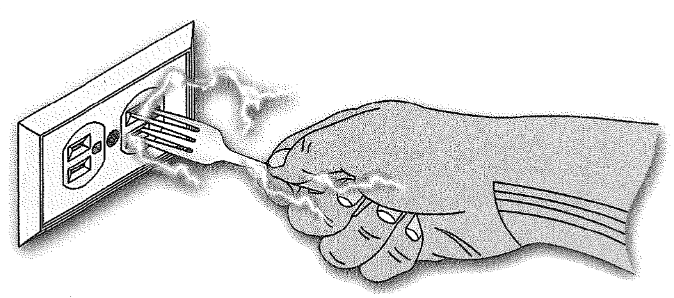
The cost of electricity from the electric company is much less than the cost of electricity from batteries.

The voltage of the electricity supplied by the electric company is 120V, much higher than the voltage of the batteries in Snap Circuits®. This is available at each of the electrical outlets in your home. The current available is very large, since it must power products like dishwashers and TVs.

A "**blackout**" occurs when part of a city is cut off from the power plants supplying it with electricity. The city will appear "black" from the air at night, since there are no electric lights on. This is usually due to accidents or storms, but is also done to confuse attacking bombers in war.

A "**brownout**" occurs when power plants cannot supply enough current to a city during high demand, and must reduce the voltage below 120V. This sometimes occurs on hot days in summer when everyone is using their air conditioners.

Our lives are much easier and more fun by having such power available by simply plugging into an electrical outlet. This amount of electricity is also very dangerous, and it will kill anyone who abuses it. While accidents involving electricity are rare, they kill people every year. **Never put anything into an electrical outlet except an electrical plug.** Battery-powered products are safe, since small batteries are too weak to hurt people.



The protective plastic around the wires to plug in a lamp are all that protects you from the full power of electricity. Damaged electrical cords should always be unplugged and repaired. Remember that electricity travels through water, so don't use electric products while taking a bath (battery-powered products are fine).

Your home has fuses that automatically turn off the electricity in your home if there is an electrical problem, such as a short circuit. These fuses prevent electrical problems in your home from affecting your neighbors, but they do not protect you.

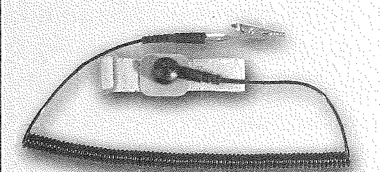
2-5 Static Electricity

You may have noticed that sometimes you can get an electric "zap" in your home or school, how clothes stick together when you take them out of the dryer, or when taking off a wool sweater on a dry day. Occasionally differences in electrical charge build up between things, called static electricity. The things, which might include your body, are storing electrical charge. They might store a very small amount of electrical charge at high voltage. This is just like a cloud storing electrical charge before a thunderstorm.

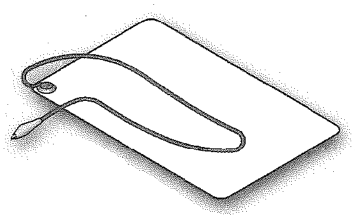
The name "static" is used to describe the electrical charge build-up because the charge is not moving around to disperse. "Static cling" refers to how clothes sometimes cling to each other in the dryer, due to static electricity. Static electricity in the atmosphere causes the "static" (erratic noises) you hear on your AM radio when reception is poor.

Static "zaps" occur when an electrical current flows to equalize the charge difference. Though the voltage might be high, the current is small and the duration is short. The actual "zap" occurs because the voltage is high enough to "jump" across a high-resistance material (usually air), making a small spark as it happens.

Though the "zap" might sting you briefly, these effects do not harm people. However, these static zaps can damage some types of sensitive electronic components and electronics manufacturers have to protect against it. Such protection includes static wrist straps, conductive floor matting, and humidity control. The parts in Snap Circuits® will not be damaged by static.



Anti-Static Wrist Strap



Anti-Static Floor Mat

Anti-Static Ankle Strap

In the same way, clouds can build up a static electrical charge. This charge might become very large, and it is spread out over the enormous volume of the clouds. Lightning occurs when this electrical charge discharges into the ground, and can be very destructive. Lightning is looking for the lowest-resistance path from the clouds to the ground.

Do you know why you often "see" lightning before you "hear" it? It is because light travels faster than sound.

Since people have less resistance than air, standing in an open field during a thunderstorm is very dangerous. Houses and other buildings have "**lightning rods**" to protect them, which are metal bars from the roof into the ground. Their purpose is to encourage lightning to go through the rods to the ground, instead of going through the house to the ground.

Large aircraft can build up a large electrical charge during a long flight. A wire similar to a lightning rod is usually connected to an aircraft shortly after landing, as a precaution against static zap.

Static Electricity Example:

Comb your hair vigorously with a plastic comb and hold the comb near some little (1cm x 1cm) scraps of paper to pick them up OR tilt the comb near a slow, steady stream of water from a faucet and see how the water bends towards it.

Quick Quiz

1. List all the products in your home that use an electric motor.
2. Name some examples of static electricity.

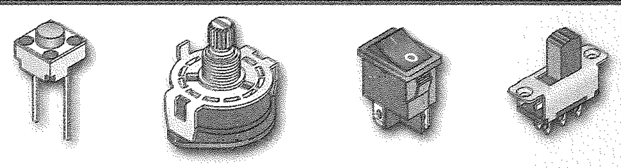
2-6 Types of Lamps

The lamps in Snap Circuits® are **incandescent** type, the same as the larger lamps in your home. The bulbs contain a special high-resistance wire, called the **filament**. When an electric current passes through it the wire gets so hot that it glows. Heat is also produced, and the glass bulb prevents the filament from reacting with oxygen in the air and burning. When the voltage rating of an incandescent bulb is exceeded, the filament gets so hot it burns out. Filaments are usually made of tungsten, since ordinary copper would melt.

The **fluorescent** light bulbs that come in white 4 ft. tubes are the standard room lights for offices and schools. They pass electric current through a gas, usually neon. This gas emits light as the electricity passes through it, similar to how a tungsten wire does. Although larger and more expensive than ordinary incandescent lamps, they are more efficient at converting electricity into light.

The difference in heat produced between incandescent and fluorescent light bulbs might surprise you. Find a fluorescent bulb and feel the heat coming off it; you won't feel much. Find an incandescent lamp THAT HAS BEEN OFF FOR A WHILE and turn it on. Feel the heat it produces; it soon becomes too hot to touch. Only about 5% of the electricity used by incandescent bulbs is converted into light. Without the more efficient fluorescent bulbs, our society of office buildings might have been much different.

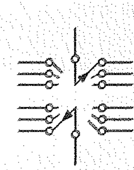
2-7 Types of Switches



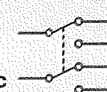
Push Button **Rotary** **Rocker** **Slide**

The slide and press switches included in Snap Circuits® are simple switches, more complex types are also available. Switches come in almost every shape and size imaginable. There are membrane, rocker, rotary, DIP, locking, and non-locking types just to name a few.

Very often, a single switch is used to make many different connections. The combinations of connections for a switch are indicated in the symbol for it. Here are some examples:



Rotary Switch Schematic



Slide Switch Schematic

2-8 Electricians

There are many different ways of using electricity, so there are many types of people who work directly with it. The main categories are electricians and engineers/technicians. Although many people think of these as being the same career, they are actually very different. They attend different schools, use different tools, and work in different places.

Electricians are the people who install electrical wiring into homes and businesses. Electricians deliver the electricity to your home to be used. It takes a lot more electricity to operate everything in a building than to operate a computer or radio, so safety is very important and the equipment they use can handle high levels of voltage and current. Buildings are not easy to re-wire, so the wiring must be reliable and safe for many years. Electricians are trained in union and trade schools. Local government licenses them because buildings must be wired as per strict local building codes to be sure they will be safe even after many years.

Electrical/electronics engineers and technicians design and develop products that will use the electricity that electricians have brought to them. Voltages and currents are much lower and safer, but circuits can be much more complex (like computers) and technologies change quickly. Electronic products are mass-produced in factories, unlike building wiring which must be installed in the building. Engineers are trained in colleges and technicians are trained in trade schools. Government does not regulate them but products must meet industry safety standards.

Summary

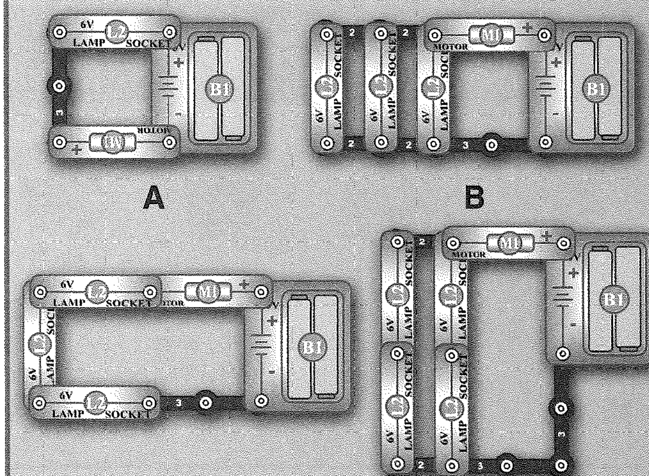
Summary of Chapter 2:

1. An electric current flowing in a wire has a magnetic field.
2. A generator uses mechanical motion to create electricity and a motor uses electricity to create mechanical motion.
3. A fuse is a special wire that breaks when an excessively high current flows through it, used for safety.
4. Electrical outlets are 120V, and can supply enough current to kill people.
5. Static electricity can cause clothes to stick together. Lightning occurs when static electricity in clouds discharges into the ground.
6. Only a small amount of the electricity used by light bulbs is converted into light, the rest becomes heat.

Quiz

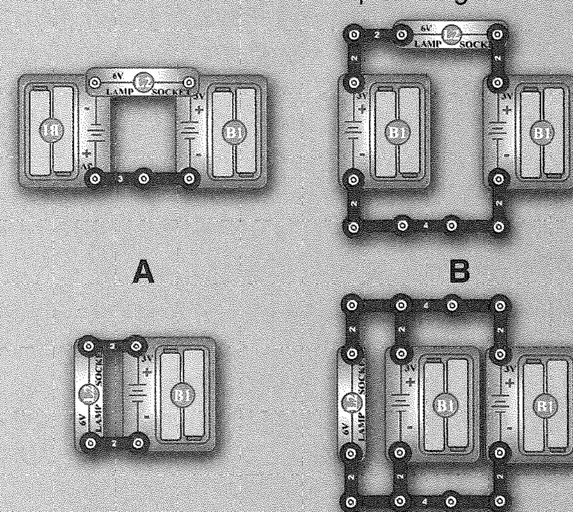
Chapter 2 Practice Problems

1. Fuses are needed for all of the following reasons except:
   A. They improve circuit performance.
   B. To prevent an electrical problem from starting a fire.
   C. To limit the current in a circuit.
   D. People don't always use products correctly.
2. All of the following are caused by static electricity except:
   A. Lightning
   B. Erratic noises interrupting music on your AM radio.
   C. Clothes sticking together in the dryer.
   D. Blackouts
3. Which circuit will spin the fan the fastest? Which will spin fan the slowest?



A B C D

4. Which circuit will make the lamp the brightest?



A B C D

Answers: 1. A, 2. D, 3. B/C, 4. A