Electric Motors and Generators

Students build model electric motors and investigate how motors and generators are used to meet many of the energy needs of modern society.

Grade Level: 5–8 (9–12)

Subject Areas: English Language Arts, Science, Technology Education

Setting: Classroom

Time:
Preparation: 45 minutes
Activity: three 50-minute periods

Vocabulary: Electricity, Generator, Mechanical energy, Motor, Turbine

Major Concept Areas:

- Natural laws that govern energy
- Development of energy resources

Getting Ready: The materials needed for this activity are available at hardware stores and electronic supply stores, and from science supply catalogs. Build and experiment with ***The Stripped Down Motor*** to familiarize yourself with how this motor works and to troubleshoot problems that may arise when students attempt to build it.

Objectives

Students will be able to:

- build a simple electric motor and describe how it works;
- list some of the ways motors are used at home;
- explain the role generators play in producing electricity;
- describe the energy conversions that take place in a motor and generator; and
- identify the similarities between motors and generators.

Rationale

Understanding how electric motors and generators work and identifying how they are used helps students realize the central role that motors and generators play in producing and using electricity for various purposes.

Materials:

- Common household appliance that uses an electric motor (like a blender)
  - Copies of the following pages:
  - ***Electricity Serves Our Community!***
  - ***The Stripped Down Motor***, (one for each pair of students and the materials listed on the sheet. NOTE: Check science supply companies for kits that contain these items.)
  - ***How the Stripped Down Motor Works*** (optional)
- Find additional resources related to this activity on keepprogram.org > Curriculum & Resources

Background

Make a list of all the devices and appliances in your home that use electricity. When you have finished, cross off items that use electricity exclusively for lighting or heating (for example, you may cross off the television, but not the hair dryer). Read over the remaining items. What do they have in common? Chances are, all of these items use electric motors (see ***Devices and Appliances in the Home That Use Electric Motors***).

A motor is generally defined as a device that converts other forms of energy into mechanical energy, and may range from lawn mowers and automobile engines to rocket engines. Electric motors are a specific member of the motor family—they convert electrical energy into mechanical energy, which usually appears as a spinning or rotating motion. (For information on how an electric motor works, see ***How the Stripped Down Motor Works***).

Electric motors are made in a wide range of sizes and are used to run things ranging from toys to heavy industrial machinery and urban subway trains. The efficiency of electric motors is high; small motors convert electricity into motion with 60 to 75 percent efficiency, while large motors have efficiencies as high as 90 to 97 percent. Motors can be made to use electricity produced by batteries and solar cells (photovoltaic cells) or the electricity produced by an electric utility's power plants and distributed by its transmission lines. These characteristics have led to the widespread use of electric motors for many purposes.

Now make a separate list of the energy resources that an electric utility might use to produce electricity. The list should include coal, oil, natural gas, nuclear energy, wind, falling water, and solar cells. Cross out solar cells and read over the remaining list. What do they all have in common? The energy contained in all of these resources is converted into electricity using an electric generator.

Devices and Appliances in the Home That Use Electric Motors	
Device or Appliance That Uses an Electric Motor	**What the Electric Motor Does**
Refrigerator	Pumps fluid that carries heat out of refrigerator
Air Conditioner	Pumps fluid that carries heat out of air conditioner
Fan (floor fan, table fan, ceiling fan etc.)	Spins propeller or vanes to circulate air
Computer hard drive	Spins hard drive disks
CD player	Spins the compact disk or the record
Clothes washer	Agitates and spins a large drum to wash and remove water from clothes
Clothes dryer	Spins clothes in a large drum
Vacuum cleaner (including hand held models)	Spins fan inside to suck air and dirt into vacuum bag
Mixer	Spins beater to mix food
Food blender, coffee grinder	Spins blade to chop or grind food
Garbage disposal in sink	Spins blade to grind up food wastes
Hair dryer (blow dryer)	Spins small fan to blow hot air out
Electric toothbrush	Moves toothbrush back and forth
Sewing machine	Moves needle and thread up and down
Electric drill	Spins drill bit
Electric circular saw	Spins circular saw blade
Battery-powered toy car or truck	Turns wheel of toy car or truck

An electric generator is a device that converts mechanical energy into electrical energy; it is essentially an electric motor being run in the opposite way. The energy conversions in the motor (electrical energy > mechanical energy) are the reverse of those in the generator (mechanical energy > electrical energy). In fact, many electric motors and generators are built the same way and can be used interchangeably.

Mechanical energy can be transferred to small generators through the use of gears or belts attached to pulleys, much like those connecting a car's engine to its alternator (a type of generator). Large generators used in electricity production are connected to turbines—devices consisting of vanes or blades attached to a wheel or set of wheels mounted on a shaft. A substance such as pressurized steam, water, or air strikes the turbine blades, spinning the turbine and the generator together. Power plants that burn fossil or nuclear fuels heat water to produce pressurized steam to drive the turbine and generator.

Hydroelectric dams use falling water, and wind turbines use wind pushing on propellers for the same purpose.

Like electric motors, generators come in many sizes, ranging from the generators bicycles use to light a small headlamp to the large generators power plants use to produce electricity. Power plant generators are extremely efficient, converting up to 99 percent of mechanical energy into electrical energy. (However, the high efficiency of electric power plant generators should not be confused with the overall power plant efficiency, which is about 33 percent.) Now compare the two lists you made. You should notice that nearly all power plants produce electricity using generators. In turn, much of the electricity produced by generators is used by electric motors. In effect, what the two lists describe are major parts of today's electrical system. Electric generators and motors—two simple, versatile devices that are actually the mirror images of one another—make this system possible.

Procedure

Orientation

Ask students to give examples of motors. They may mention lawn mowers, outboard motors, snowblowers, chainsaws, automobile engines, or rocket engines. Have students list all the motors they know of and record their responses on the chalkboard. If they have not listed electric motors, show them a common appliance that uses an electric motor, such as a blender.

Share with students the definition of a motor, a device that converts other forms of energy into mechanical energy. Have students go through each item listed on the chalkboard and state what type of energy the motor is converting into mechanical energy. For example, if "automobile engine" is listed, then the energy conversion would be "chemical to mechanical." Delete any items on the board that do not fit the definition of a motor.

Tell students that they will be investigating electric motors, devices that convert electrical energy to mechanical energy. Help students understand that electric motors operate many of the appliances in their home. Ask them to identify the items on the list that use electric motors. Students can add items to the list, or as an option, can take an inventory of where motors are used at home and bring their inventory list to class the next day (see ***Devices and Appliances in the Home That Use Electric Motors***).

Steps

1. Divide the class into pairs and give each pair a copy of ***The Stripped Down Motor*** and the accompanying materials. Instruct them to build and demonstrate the motor described in the sheet.

   NOTE: This model uses simple materials and students should carefully follow directions to set up the motor. There is a chance that the motor will not work at first. Encourage students to adjust the pieces and keep trying. This activity can promote cooperative learning when students share what they did to make their motor work. Science supply companies sell kits that often include materials to make a sturdier model.

2. Discuss how the stripped down motor works. You may want to give students copies of ***How the Stripped Down Motor Works*** to review during the discussion. Ask students where the electricity used to run their motor comes from (the batteries). You may want to show students an example of a small motor and have them compare it to the one they built by connecting the motor to a battery or power supply, or by simply passing it around the classroom.

3. Refer to the list of electrical appliances made in the **Orientation**. Ask students where the electricity used to run these motors came from.

4. Display to the students the ***Electricity Serves Our Community!*** page. (As an option, you may give students copies of this diagram.) Have them point out where generators appear on the diagram.

5. Mention that generators convert mechanical energy into electrical energy. Explain what a turbine is. Have students examine ***Electricity Serves Our Community!*** to see if they can identify the substance (steam, water, wind) used to spin the turbine and the generator. Ask if they can tell where the energy in the fluid comes from.

   NOTE: As an option, you may show students an example of a small generator and demonstrate how it converts mechanical energy into electrical energy. An example is lighting a bicycle headlamp using a small generator connected to the bicycle wheel.

Closure

Ask students if the electricity produced by a generator can be used to run an electric motor. Use ***Electricity Serves Our Community!*** to show students how the electricity produced by generators is transported to homes and schools where motor-driven devices and appliances are used.

Point out to students that generators are built the same way as motors and that a motor can be operated as a generator, and vice versa. Have students suggest how the motor they built could be operated as a generator (see ***How the Stripped Down Motor Works***).

Assessment

Formative

- Can students list electric motors used at home?
- How successfully did students build the stripped down motor?
- Can students identify where the electricity used to run motors comes from?
- Can students explain what generators do and the role they play in producing electricity?
- Can students describe similarities between motors and generators in terms of how they are made and how they convert energy?

Summative

- Have students create a version of ***Electricity Serves Our Community!*** for their own home or school. The diagram should include an energy source, a power plant, and a diagram of their home or school containing selected items that use electric motors.
- Challenge students to improve or refine the stripped down motor they built so that it works more efficiently.

Extension

Have students investigate whether solar cells can supply enough electricity to run the motor that they made.

Related KEEP Activities

"Waterwheels, Windmills, and Turbines" orients students to concepts in this activity. Other related concepts are found in "Circuit Circus." Energy sources used in motors and generators are introduced in "Fueling Around." Students can also research energy development over time; see 6–12 Energy Sparks for Theme II: "Energy Production Timeline." Extend this activity by having students look at other motors (6–12 Energy Sparks for Theme II: "Energy Conversions in an Automobile Engine").

Credits

Activity adapted from Doherty, Paul, Don Rathjen, and the Exploratorium Teacher Institute. "Stripped Down Motor" in *The Cool Hot Rod and Other Electrifying Experiments on Energy and Matter*. New York: John Wiley and Sons, 1996. Adapted with permission. ©2005 Exploratorium, exploratorium.edu. Learn more: Exploratorium.edu/snacks

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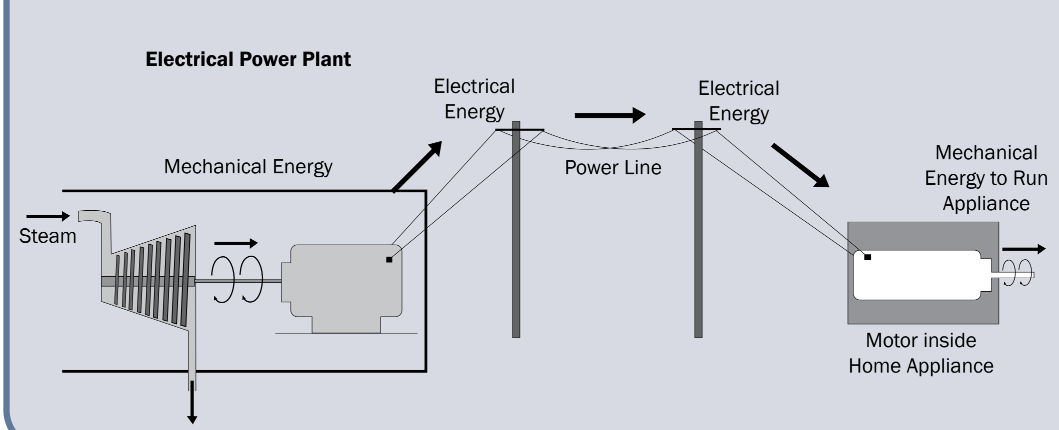
Energy Conversions That Occur in a Generator Connected to a Motor



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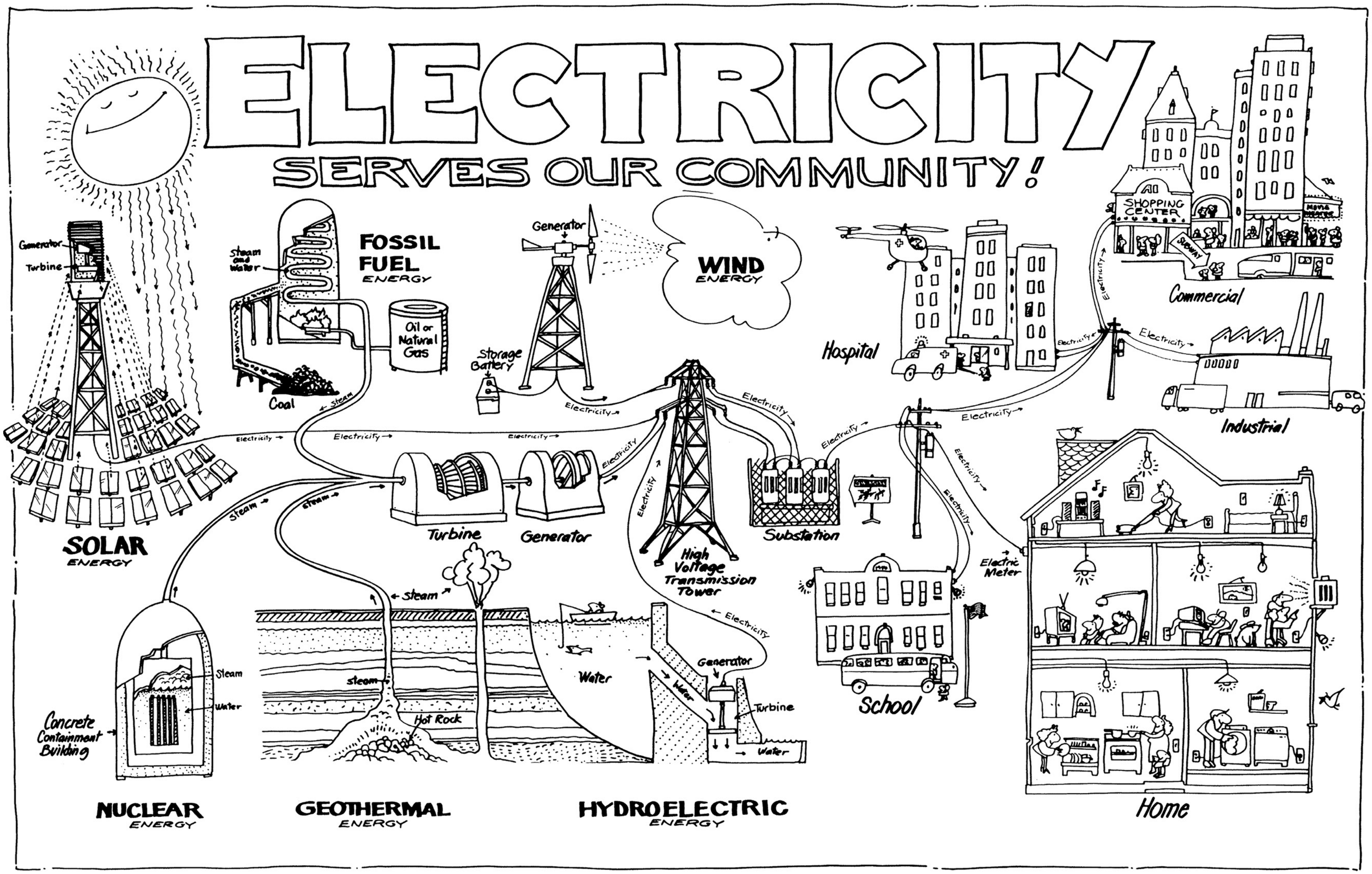


This poster is an artist's representation of the production, transmission and use of electrical energy and not intended to be a technical illustration.

NOTE: The representation of solar energy shown on ***Electricity Serves Our Community!*** is not an example of electricity produced by solar cells. Instead, this representation shows the sun's rays being focused by a set of mirrors onto the top of a tower that contains water or other liquid. The water or other liquid is heated into steam, which then spins the turbine and the generator. Solar cells, on the other hand, produce electricity directly from sunlight without using generators.

The Stripped Down Motor

Adapted from Doherty, Paul, Don Rathjen, and the Exploratorium Teacher Institute. “Stripped Down Motor” in The Cool Hot Rod and Other Electrifying Experiments on Energy and Matter. New York: John Wiley and Sons, 1996. Used with permission.

Introduction

A coil of wire becomes an electromagnet when current passes through it. The electromagnet interacts with a permanent magnet, causing the coil to spin. Voila! You have created an electric motor.

Materials

Make sure that you have all the parts needed to build the motor by checking off each item in the materials list:

- ☐ 5 small disk or rectangular ceramic magnets
- ☐ 2 large paper clips
- ☐ 1 plastic, paper, or Styrofoam cup or small piece of wood
- ☐ V-nails and hammer (if you are using a piece of wood instead of a cup)
- ☐ Solid (not stranded or braided) enameled or insulated 20-gauge copper wire, about 2 feet (60 cm) long
- ☐ Masking tape
- ☐ Batteries or a power supply

  NOTE: Motors have been successfully run on one 1.5-volt D cell; additional batteries seem to make it easier to get the motor to run. You may want to try 6-volt lantern batteries. Using a power supply (battery eliminator) set to about 4 volts also yields excellent results. The advantage of the power supply is that it will supply a substantial current over a period of time. Unlike batteries, it doesn’t have to be replaced. Experiment with what you have and use whatever works!
- ☐ Battery holders or a small piece of wood and 4 nails per battery (if batteries are used)
- ☐ 2 alligator clip leads
- ☐ Wire strippers (if you are using insulated wire)
- ☐ Sandpaper (if you are using enameled wire)
- ☐ Black, waterproof, felt-tipped marker
- ☐ Ruler with 1/16-inch markings on it

Assembly

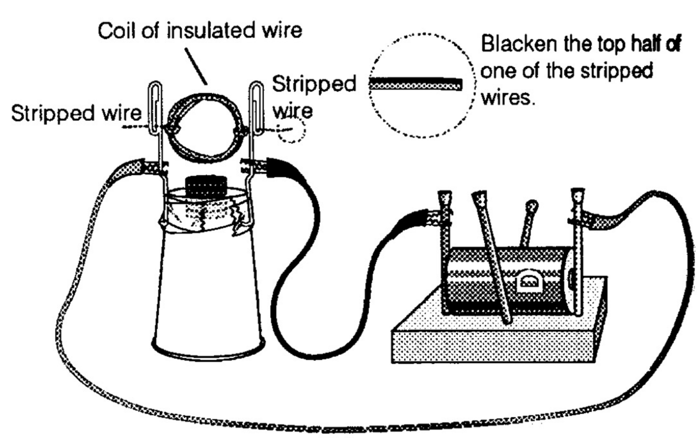
Refer to the diagram below right when assembling the motor.

1. Wind the copper wire into a coil about 1 inch (2.5 cm) in diameter. Make four or five loops. Wrap the ends of the wire around the coil a couple of times on opposite sides to hold the coil together. Leave 2 inches (5 cm) projecting from each side of the coil and cut off any extra wire.

2. If you are using insulated wire, use the wire strippers to strip the insulation off the ends of the wire projecting from the coil. If you are using enameled wire, use the sandpaper to remove the enamel.

3. Color one side of one of the projecting ends black with the felt-tipped pen.

   NOTE: It is very important that the orientation of the painted side corresponds to the orientation shown



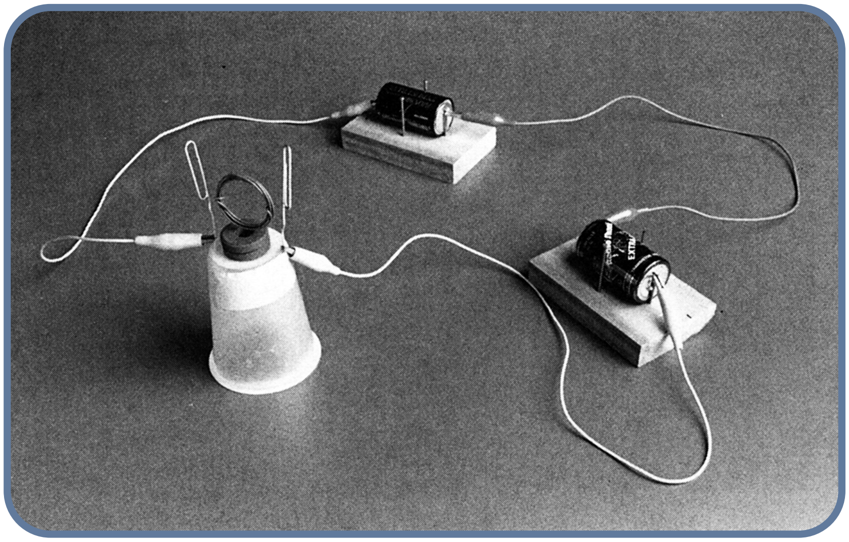
The Stripped Down Motor

in the drawing. If the coil is held in the vertical plane, paint the top half of one of the wires black.

4. Turn the cup upside down and place two magnets on top in the center. Attach three more magnets inside the cup directly beneath the original two magnets. This will create a stronger magnetic field as well as hold the top magnets in place. You might find using a piece of wood sturdier than the cup. If you use the wood, place two magnets on top of the wood. Hammer the paper clips in place using v-nails.
5. Unfold one end of both paper clips and tape them to opposite sides of the cup with their unfolded ends down (see diagram). Rest the ends of the coil in the cradles formed by the paper clips. Adjust the height of the paper clips so that when the coil spins, it clears the magnets by about 1/16 inch (.16 cm). Adjust the coil and the clips until the coil stays balanced and centered while spinning on the clips. Good balance is important in getting the motor to operate well.
6. Once you have determined how long the projecting ends of the coil must be to rest in the paper-clip cradles, you may trim off any excess wire. (The length of the projecting ends depends on the separation of the paper-clip cradles, which in turn depends on the width of the base of the cup you are using. See diagram.)
7. If you are not using a power supply or battery holders for the batteries, you may want to build a simple but effective battery holder to hold the batteries. All you need is a small piece of wood and four nails for each battery (see diagram).
8. Use the alligator clip leads to connect the battery or power supply to the paper clips, connecting one terminal of the battery to one paper clip and the other terminal to the other paper clip.

Operating the Motor

1. Give the coil a spin to start it turning. If it doesn't keep spinning on its own, check to make sure that:
   • the coil assembly is well balanced when spinning;
   • the enamel has been thoroughly scraped off if enameled wire has been used;
   • one projecting end has been painted with felt pen as noted; and
   • the coil and the magnet are close to but do not hit each other.
   You might also try adjusting the distance separating the cradles: this may affect the quality of the contact between the coil and the cradles.
2. If the motor will still not spin, check to make sure that good contacts have been made with the alligator clips, battery holder and battery, or power supply.
3. Keep making adjustments until the motor works. Have patience! The success rate with this design has been exceptionally good.



How the Stripped Down Motor Works

Current flows through the wire coil of the stripped down motor and creates an electromagnet. One face of the coil becomes a north pole and the other becomes a south pole. The permanent magnet attracts its opposite pole on the coil and repels its like pole, causing the coil to spin.

Another way to describe the operation of the motor is to say that the permanent magnets exert forces on the electrical currents flowing through the loop of wire. When the loop of wire is in a vertical plane, the forces on the top and bottom wires of the loop will be in opposite directions. These oppositely directed forces produce a twisting force, or torque, on the loop of wire that will make it turn.

Why is it so important to paint half of one of the wires projecting from the coil black? Suppose that the permanent magnets are mounted with their north poles facing upward. The north pole of the permanent magnet will repel the north pole of the loop-electromagnet and attract the south pole. But once the south pole of the loop-electromagnet was next to the north pole of the permanent magnet, it would stay there. Any push on the loop would merely set it rocking about this equilibrium position.

By painting half of one end of the projecting wire black, you prevent current from flowing for half of each spin. As the south pole of the loop-electromagnet comes closest to the permanent magnet, the paint turns off the electric current. The magnetic field of the loop-electromagnet is then turned off for that half-spin. The inertia of the rotating coil carries it through half of a turn, past the insulating paint. When the electric current starts to flow again, the twisting force is in the same direction as it was before. The coil continues to rotate in the same direction.

In this motor, the sliding electrical contact between the ends of the coil of wire and the paper clips turns off the current for half of each cycle. Such sliding contacts are known as commutators. Most direct-current (DC) electric motors use more complicated commutators that reverse the direction of current flow through the loop every half cycle. The more complicated motors are twice as powerful as the motor described here.
The stripped down motor can also be used to demonstrate how a generator works. Try hooking up the ends of the paper clips to a sensitive galvanometer instead of the battery or power supply. Spin the coil and see if any current registers on the galvanometer.