17.3 Electric Motors and Generators

Permanent magnets and electromagnets work together to make electric motors and generators. In this section, you will learn how an electric motor works. The secret is in the ability of an electromagnet to reverse its north and south poles. By changing the direction of electric current, the electromagnet attracts and repels other magnets in the motor, causing the motor to spin. **Electric motors** convert electrical energy into mechanical energy.

VOCABULARY

electric motor - a device that converts electrical energy into mechanical energy.

rotor - the rotating disk of an electric motor or generator.

Using magnets to spin a disk

Imagine a spinning disk with magnets Imagine you have a disk that can spin on an axis at its center. Around the edge of the disk are several magnets. You have cleverly arranged the magnets so they have alternating north and south poles facing out. Figure 17.17 shows a picture of your disk.

Making the disk spin Imagine you also have another magnet which is not attached to the disk. You bring this loose magnet close to the disk's edge. The loose magnet attracts one of the magnets on the disk while at the same time repelling an adjacent magnet on the disk. These attract-and-repel forces make the disk spin a little way around (Figure 17.17).

Reversing the magnet is the key To keep the disk spinning, you need to reverse the magnet in your fingers as soon as the magnet that was attracted passes by. This way, you first attract the magnet on the disk, and then reverse the loose magnet to repel that same magnet on the disk and attract the next one in line on the disk. You make the disk spin by using the loose magnet to alternately attract and repel the magnets on the disk.

Knowing when to reverse the magnet The disk is called a **rotor** because it can rotate. The key to making the rotor spin smoothly is to reverse your magnet when the disk is at just the right place. You want the reversal to happen just as each magnet in the rotor passes by. If you reverse too early, you will repel the magnet on the rotor backward before it reaches the loose magnet. If you reverse too late, you will attract the magnet backward after it has passed. For the best results, you need to change your magnet from north to south just as each magnet on the rotor passes by.

Using a Magnet to Spin a Rotor

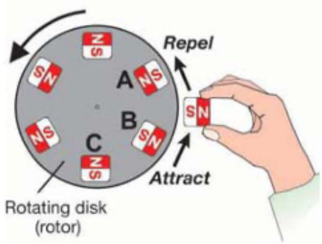


Figure 17.17: *Using a single magnet to spin a disk of magnets. Reversing the magnet in your fingers attracts and repels the magnets in the rotor, making it spin.*

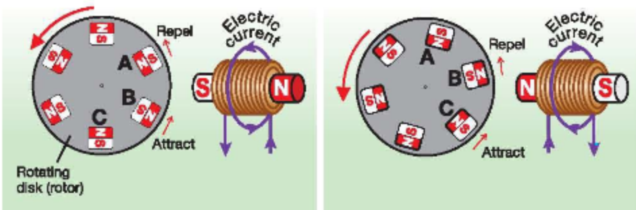
How the electromagnets in a motor operate

How electromagnets are used in electric motors

In a working electric motor, an electromagnet replaces the magnet you reversed with your fingers. The switch from north to south is done by reversing the electric current in the electromagnet. The diagrams below show how an electromagnet switches its poles to make the rotor keep turning.

First the electromagnet repels magnet A and attracts magnet B.

Then the electromagnet switches so it repels magnet B and attracts magnet C.



The commutator is a kind of switch

Just like with the magnet you flipped with your fingers, the electromagnet must switch from north to south as each rotor magnet passes by to keep the rotor turning. The device that makes this happen is called a **commutator**. As the rotor spins, the commutator reverses the direction of the current in the electromagnet. This makes the electromagnet's pole that faces the disk change from north to south, and then back again. The electromagnet attracts and repels the magnets in the rotor, and the motor turns.

Three things you need to make a motor

All types of electric motors must have three parts (Figure 17.18). They are:

- a rotating part (rotor) with magnets that have alternating polarity;
- one or more electromagnets; and,
- a commutator that switches the direction of current in the electromagnets back and forth in the correct sequence to keep the rotor spinning.

VOCABULARY

commutator - a device that switches the direction of electrical current in the electromagnet of an electric motor.

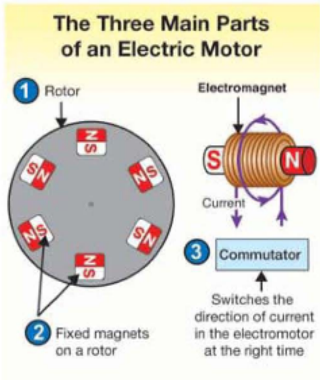


Figure 17.18: *An electric motor has three main parts.*

How a battery-powered electric motor works

Inside a small electric motor If you take apart an electric motor that runs on batteries, it doesn't look like the spinning disk motor illustrated on the previous page. However, the same three mechanisms are still there. The difference is in the arrangement of the electromagnets and permanent magnets. The illustration below shows a small, battery-powered electric motor and what it looks like inside with one end of the motor case removed. The permanent magnets surround the rotor, and they stay fixed in place on the inside surface of the metal housing.

Electromagnets and the armature The electromagnets are in the rotor, and they turn. The rotating part of the motor, including the electromagnet coils, is called the *armature*. The armature in the illustration above has three electromagnets. Figure 17.19 shows the same motor, with the essential parts labeled.

How the switching happens The wires from each of the three coils are attached to three metal plates (the commutator) at the end of the armature. As the rotor spins, the three plates come into contact with positive and negative *brushes*. Electric current flows through the brushes into the coils. As the motor turns, the plates rotate past the brushes, reversing the positive and negative connections to the coils. As you know, when you change the direction of current through a coil, the electromagnet's magnetic poles switch positions. The turning electromagnets with alternating poles are thus attracted and repelled by the permanent magnets, and the motor turns.

AC motors Motors that run on AC electricity are easier to make because the current switches direction all by itself. Almost all household, industrial, and power tool motors are AC motors. These motors use electromagnets for both the rotating and fixed magnets.

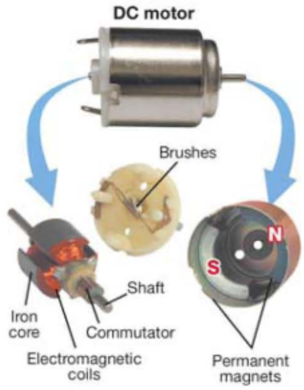


Figure 17.19: *A simple battery-powered motor. Refer to this labeled photograph as you read how the parts work together to make the shaft spin.*

Electromagnetic induction

Motors and generators Motors transform electrical energy into mechanical energy. Electric **generators** do the opposite. They transform mechanical energy into electrical energy. Generators are used to create the electricity that powers all of the appliances in your home.

Magnetism and electricity An electric current in a wire creates a magnetic field. The reverse is also true. If you move a magnet near a coil of wire, an electric current is *induced* in the coil. The word *induce* means "to cause to happen." The process of using a moving magnet to create electric current is called **electromagnetic induction**. A moving magnet *induces* electric current to flow in a circuit.

Symmetry in physics Many laws of physics display *symmetry*. In physics, *symmetry* means a process works in both directions. Earlier in this chapter, you learned that moving electric charges create magnetism. The symmetry is that changing magnetic fields also causes electric charges to move. Nearly all physical laws display symmetry in one form or another.

Making current flow Figure 17.20 shows an experiment demonstrating electromagnetic induction. In the experiment, a magnet can move in and out of a coil of wire. The coil is attached to a meter that measures the electric current. When the magnet moves into the coil of wire, electric current is induced in the coil *as the magnet is moving*, and the meter swings to the left. The current stops if the magnet stops moving.

Reversing the current When the magnet is pulled back out again, current is induced in the opposite direction as the magnet is moving. The meter swings to the right as the magnet moves out. Again, if the magnet stops moving, the current also stops.

Current flows only when the magnet is moving Current is produced only if the magnet is moving, because a *changing* magnetic field is what creates current. Moving magnets induce current because they create changing magnetic fields. If the magnetic field is not changing, such as when the magnet is stationary, the current is zero.

VOCABULARY

generator - a device that converts kinetic energy into electrical energy using the law of induction.

electromagnetic induction - the process of using a moving magnet to create an electric current.

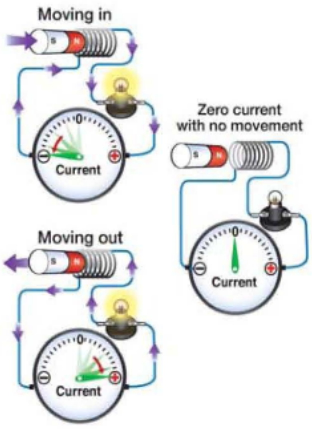
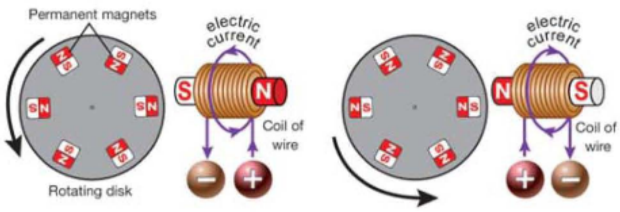


Figure 17.20: *A moving magnet produces an electric current in a coil of wire.*

Generating electricity

A simple generator A generator converts mechanical energy into electrical energy using the law of induction. Most large generators use some form of rotating coil in a magnetic field (Figure 17.21). You can also make a generator by rotating magnets past a stationary coil (see the diagram below). As the disk rotates, first a north pole and then a south pole passes the coil. When a north pole is approaching, the current is in one direction. After the north pole passes and a south pole approaches, the current is in the other direction. As long as the disk is spinning, there is a changing magnetic field through the coil and electric current is created.



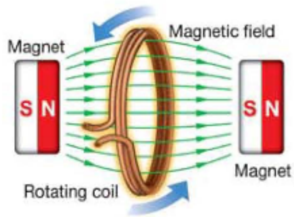


Figure 17.21: *Current is created when a coil rotates in a magnetic field.*

Alternating current The generator shown above makes *alternating current* or AC electricity. The direction of current is one way when the magnetic field is becoming "more north" and the opposite way when the field is becoming "less north." It is impossible to make a situation where the magnetic field keeps increasing (becoming more north) forever. Eventually the field must stop increasing and start decreasing. Therefore, the current always alternates. The electricity in your home is produced by AC generators. The current from a battery, on the other hand, is always in the same direction, from the positive to the negative end of the battery. This type of current is called *direct current* or DC.

Energy for generators The electrical energy produced by a generator must have a source. Energy must continually be supplied to keep the rotating coil (or magnetic disk) turning. In the next section, you will explore energy sources that can be used to produce electricity (Figure 17.22).

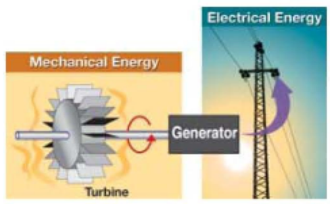
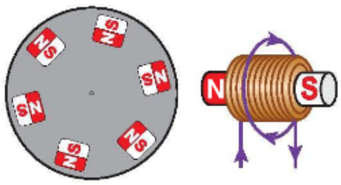


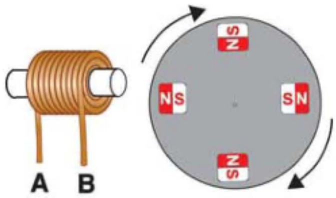
Figure 17.22: *A power plant generator contains a turbine that turns magnets inside loops of wire, generating electricity. Some other form of energy must be continually supplied to turn the turbine.*

Section 17.3 Review

1. A(n) _____ is used to convert mechanical energy into electrical energy.
2. A(n)_____ is used to convert electrical energy into mechanical energy.
3. Using a magnet to create electric current in a wire is called _____.
4. Why is it necessary to use at least one electromagnet in a motor instead of only permanent magnets?
5. At the instant shown below, the electromagnet in the motor has its north pole facing the rotor that holds the permanent magnets. In which direction is the rotor spinning?



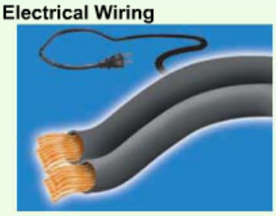
6. The rotor in the motor below is spinning clockwise. Is the direction of the current in the electromagnet from A to B or from B to A?



7. In most electric power plants, the energy stored in gas, coal, oil, or nuclear energy is transformed into the movement of a turning turbine. Why is the turning turbine necessary in a power plant?

TECHNOLOGY

Electrical Wiring



There is a magnetic field around all the wires that carry current, but you don't notice magnetic fields created by electrical wiring in your house. Why not?

the wires in your home are actually made of two parallel wires. If you look at an appliance cord, you will notice the two wires inside the plastic covering. At any instant, the current in one wire is opposite the other. Each creates a magnetic field, but the fields are in opposite directions so they mostly cancel each other out.

Because the wires are not at exactly the same location, and field strength depends on distance, the fields do not completely cancel each other right at the wire, but quickly fall off to nothing a short distance away.