13

Energy and Power Conversion Devices

Basic Concepts

- List the types of energy and power conversions that can occur.
- Identify devices used to convert various forms of energy or power into other forms of energy or power.

Intermediate Concepts

- Describe the operation of devices used to convert various forms of energy or power into other forms of energy or power.

Advanced Concepts

- Explain new conversion devices not yet routinely used.
- Calculate the efficiency of various energy and power conversion devices.

A converter is simply a device that allows for the changing of one form of energy or power into another form of energy or power. The lightbulbs in your classroom convert electrical power into a form of ***radiant energy,*** or energy in the form of electromagnetic waves, known as visible light. The engine in your car converts the chemical energy stored in gasoline into fluid power and then into mechanical power. Some devices perform a conversion in one step and are known as ***direct converters***. Other devices are considered ***indirect converters*** because it takes several intermediate steps for them to perform conversions. This chapter will examine some of the most commonly used converters and explain how they work.

Types of Conversions

There are four basic types of conversions involving power and energy:

- Power conversion (power to power).
- Energy conversion (energy to power).
- Frequency conversion (energy to energy).
- Energy inversion (power to energy).

Radiant energy: Energy transferred by radiation, including infrared rays, visible light rays, ultraviolet (UV) rays, X rays, radio waves, and gamma rays.

Direct converter: A device that changes one form of energy or power into another form of energy or power in one step.

Indirect converter: A device that changes one form of energy or power into another form of energy or power using several intermediate steps.

Power converter: A conversion device used to change one form of power to another.

Energy converter: A device that changes a form of energy into a useful form of power.

Power converters are used to change one form of power to another and are the most common conversion devices. Because it is so widely used, an electric motor is probably the best example of a power converter. The motor converts one form of power—electricity—into another form of power—mechanical power.

Another type of conversion involves changing a form of energy into a useful form of power. Devices that do this are known as ***energy converters***. A good example of an energy converter is the photovoltaic cell. It converts visible light energy directly into electricity.

Frequency converters change one frequency (wavelength) of radiant energy directly into another frequency of radiant energy. One example is a solar collector. It converts visible light energy into infrared energy.

Sometimes, it is useful to invert a form of power back into a form of energy. One example of an ***energy inverter*** is the electric space heater. It converts electric power into infrared energy.

Power Conversions

The three forms of power are electrical, fluid, and mechanical power. Power conversions involve changing one of these forms of power into another. See **Figure 13-1.**

Electrical to mechanical

Devices that convert electricity into mechanical movement have many practical applications. One of the most widely used electrical-to-mechanical power converters is the ***solenoid***. See **Figure 13-2.**

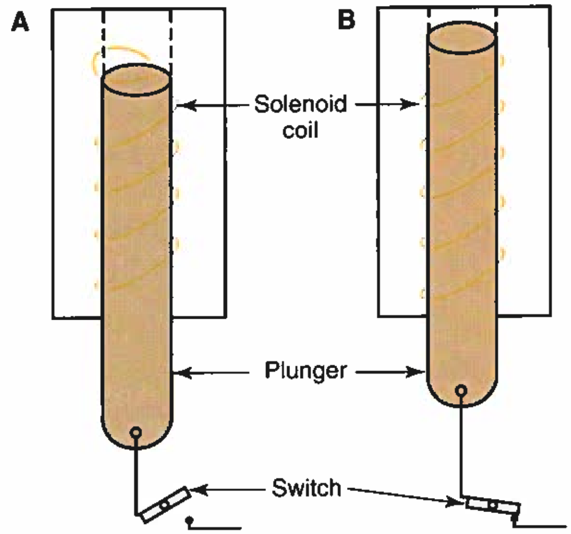
The solenoid consists of a coil of wire with a moveable steel core in the center. When the coil is energized with electricity, it creates a magnetic field and causes linear movement of the steel core. This linear movement can perform many useful purposes. For instance, the moving core could strike a chime or bell and create sound. This is the way many doorbells work. The solenoid's core movement could also be used to trigger a release mechanism. When you push a button at an apartment building for someone to open the entry door and let you in, the button he or she pushes energizes a coil that pulls on a latch, allowing the door to open.

The most common application of this type of electrical energy to linear mechanical movement is to control a relay. A ***relay*** is an electromechanical switching device. When the coil of a relay is energized, the steel core is pushed in one direction. This pushing force is used to open and close switch contacts. Why not just use a manually operated switch to open and close the contacts? Consider this situation: you want to be able to start a conveyor system from one location, but be able to stop it from several locations. Assuming the conveyor is driven by a powerful electric motor, the use of a relay would be more desirable than using manual switches. This is because a relay can be controlled with very little electricity. If you wished to control a powerful motor from many locations by using switches, you would have to

Figure 13-1. The types of power conversions that can occur.

Types of Power Conversions
Electrical ➪ Mechanical
Mechanical ➪ Electrical
Mechanical ➪ Fluid
Fluid ➪ Mechanical
Fluid ➪ Electrical
Electrical ➪ Fluid

Figure 13-2. The operation of a solenoid. A—When no electric current is applied to the solenoid coil, the plunger is at rest, and the switch remains open. B—When the solenoid is energized (current is applied to the coil), the plunger is pulled upward by magnetic force, closing the switch.



Frequency converter: A device that changes one frequency of radiant energy directly into another frequency of radiant energy.

Energy inverter: A device that inverts a form of power back into a form of energy.

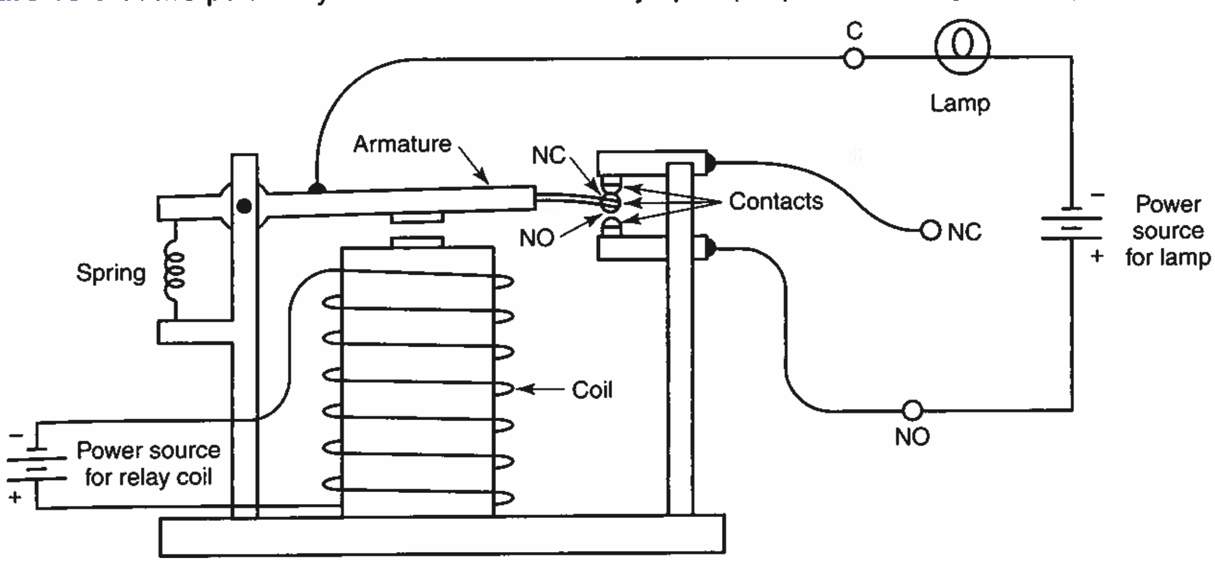
Solenoid: A device that converts electricity into mechanical movement.

Relay: An electromechanical switching device.

run the 120-volt electric current that powers the motor through all those switches before it goes to the motor.

Relays are typically identified by the number of contacts they provide, the number of positions they can offer, and the current ratings for their contacts. For instance, the relay in **Figure 13-3** provides two sets of contacts, so it is known as a two-pole relay. Additionally, this relay offers a normally open (NO) and a normally closed (NC) contact for each pole. The relay can permit electrical flow through the NO contacts when the coil is energized and closes the contacts. In the same way, it can stop electrical flow through the NC contacts when the coil is energized and cause the contacts to open.

Figure 13-3. A two-pole relay that offers both normally open (NO) and normally closed (NC) contacts.



Induced: Made to flow.

Armature: A series of wires around a metal core in which electricity is induced, which is free to rotate.

Brush contactor: The part of a direct current (DC) motor that supplies electricity to the armature.

Commutator: A circular conductive strip connected to the end of an armature loop.

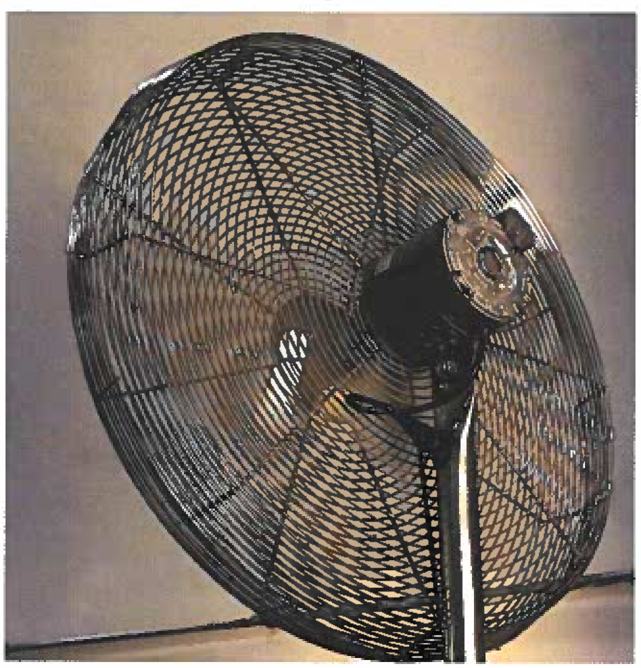
Slip ring: See *Commutator.*

One common relay used for a very different purpose is the solenoid on the starter motor of a car. When you turn the key to start the car, a simple 12-volt control circuit operates the relay, closing heavy contacts that allow electricity to flow from the battery to the powerful starter motor. When you release the key, the coil of the solenoid is no longer energized. A spring attached to the solenoid's steel core pulls the core backward. This opens the contacts that feed the starter motor. Imagine how large and heavy-duty the ignition switch would have to be if all the electricity that flows to the starter motor had to pass through that switch.

Solenoids are also frequently used to open and close valves. This allows for remote control of valves, since the operator does not need to be near the valve to push a lever. Many valves can be controlled from a central location.

When we think of electric motors, we usually do not think of solenoids and relays, but rather of motors that can provide rotary power. See **Figure 13-4.** More than 70% of all electricity generated nationwide is used to operate electric motors. There are many types of motors, but they work on the same basic principles. Simple motor construction begins with the use of magnets that provide a north and south magnetic pole. If a wire is placed between the north and south poles, a current will be ***induced*** (made to flow) in the wire. When current flows in the wire, another magnetic field is generated that spirals around the wire. In some places, the two magnetic fields aid each other, and in other places, they oppose each other. This constant aiding and opposing of magnetic fields creates movement of the wire. If the electricity flowing through the wire is reversed or if the poles of the stationary magnets are quickly reversed, the wire in the center will be continuously pulled and pushed so as to sustain movement.

Figure 13-4. Electrical motors are widely used to provide rotary power. This powerful motor turns the blades of a large industrial fan.



A simple direct current (DC) motor is depicted in **Figure 13-5.** DC motors and generators are almost identical in construction. In fact, if mechanical power is supplied to the rotating shaft of many DC motors, they will act as generators and produce electricity. The most basic motor consists of permanent magnets, mounted with attracting poles facing one another. In between the poles is a single loop ***armature***, a series of wires around a metal core in which electricity is induced, that is free to rotate. An actual working motor consists of many armature loops.

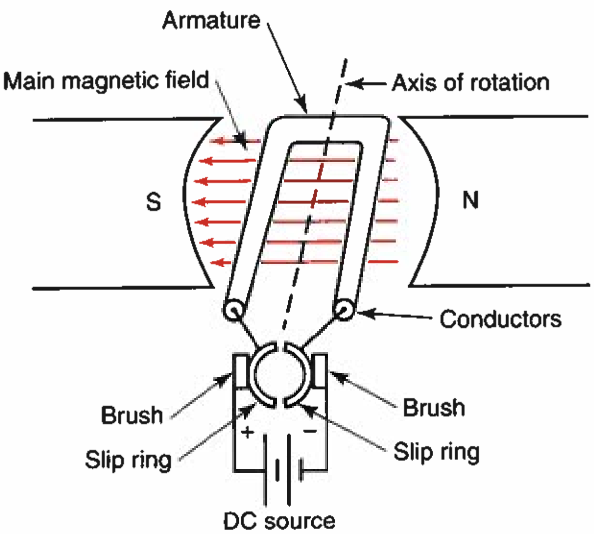
This motor uses ***brush contactors*** to supply electricity to the armature. The brush contactors slide along the ***commutator***, a circular conductive strip connected to the end of the armature loop. A commutator is sometimes known as a ***slip ring*** because of its design and the function it serves. In Figure 13-5, you can see how the commutator reverses the flow of electricity in the armature every half-turn of the coil (in larger motors, this can be done more frequently). When the armature loop is totally vertical, it is being neither attracted nor repelled by magnetic forces. The inertia of the motor in motion, however, carries the armature past the neutral point, where it is again influenced by the magnetic forces.

More powerful motors, like alternating current (AC) induction motors, replace the permanent magnets with electromagnets. The electromagnets are capable of producing much stronger magnetic fields than permanent magnets, and stronger fields result in a more powerful motor. The two primary parts of an AC motor are the rotor and the stator.

Stator windings are so named because they remain stationary and do not rotate. The ***stator*** is typically connected to the housing of the motor and the motor frame. The ***rotor*** is the spinning coil of the motor that is connected to the motor shaft. An induction motor does not require that electricity be provided to the rotor. The motor is built so that, as the stator winding is energized, it induces electricity in the rotor. This causes the rotor to spin. Single-phase induction motors require a special set of ***start windings***. The start windings draw more current than the ***run windings***, which power the motor once it is up to speed. They are needed because a ***single-phase induction motor*** only has one set of run windings. If the rotor is not spinning, the run windings do not create enough magnetic attraction and repulsion to move the rotor past the neutral point of rotation. Once the motor builds up speed, a centrifugal switch opens, taking the start windings out of the circuit. At full operating speed, the inertia of the motor easily carries the rotor past the neutral point, and it can maintain speed. The start windings and their heavy current draw are no longer needed.

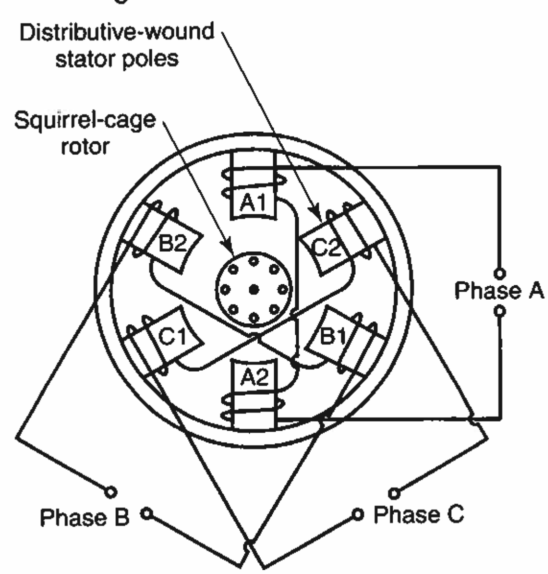
Three-phase induction motors, sometimes called *polyphase motors*, are used for many industrial applications. These motors are constructed using three sets of stator (run) windings, instead of one set. See **Figure 13-6.** The windings are 120° out of phase with one another. The result is that this type of motor does not require separate start windings, since (unlike a single-phase motor) the neutral points are almost nonexistent. This is because if one stator winding is in the neutral position, there are two other windings engaged. The three magnetic fields working in attraction and

Figure 13-5. Components of a simple direct current (DC) motor.



Stator: The part of an alternating current (AC) motor that remains stationary and does not rotate. It is typically connected to the housing of the motor and the motor frame.

Figure 13-6. The stator windings in a three-phase motor are in pairs and are arranged 120° out of phase with each other. No separate start winding is needed.



Rotor: The spinning coil of an alternating current (AC) motor that is connected to the motor shaft.

Start winding: A special winding required by a single-phase induction motor because its single set of run windings do not create enough magnetic attraction and repulsion to move the rotor past the neutral point of rotation.

Run winding: A winding that powers a motor once it is up to speed.

Single-phase induction motor: A type of alternating current (AC) motor that only has one set of run windings.

Three-phase induction motor: An alternating current (AC) motor constructed using three sets of stator windings.

opposition to one another also produce much more power than a single-phase motor of comparable physical size.

Mechanical to electrical

A generator is the principal means of producing electricity from rotary mechanical power. The basic theory behind a generator involves moving a wire through a magnetic field. When this happens, a voltage is induced in the wire. See **Figure 13-7.**

If the wire is moved parallel to the magnetic lines of flux, no current or voltage will be generated. A current can be measured if the wire cuts through the magnetic lines of flux. Depending on the direction in which the lines are cut, the current in the wire will flow one way or the other. When magnetism is converted to electricity by this process, the electricity is known as *induced voltage.* Increasing the speed of the wire movement or the magnetic field will produce a stronger induced voltage. In an actual generator, powerful electromagnets are used to produce a tremendous magnetic field, and the armature spins at several thousand revolutions per minute (rpm). The armature may be powered by a steam turbine, a hydroturbine, or even (in the case of a portable generator) a small gas engine. See **Figure 13-8.**

Mechanical to fluid

A pump is used to convert mechanical power to fluid power. Gear and centrifugal pumps are the most common. Reciprocating piston pumps are also sometimes used to pressurize fluids. **Figure 13-9** shows how mechanical power is converted to fluid power in a rotary vane pump. This pump has a circular chamber with a rotor positioned slightly off center. The vanes, or pump paddles, are able to slide in and out of slots in the rotor. As the pump spins, centrifugal force pulls the vanes outward to press against the walls of the pump housing. Since the rotor is slightly off center, the volume of space between each pair of adjoining vanes varies. Fluid enters the pump at a point where a compartment (space between vanes) is at its greatest capacity. As the pump rotates, the compartment becomes progressively smaller, increasing pressure on the fluid until it is forced out of the pump outlet port.

Figure 13-7. When a simple wire armature cuts through the magnetic lines of flux, an electric current is induced in the wire.

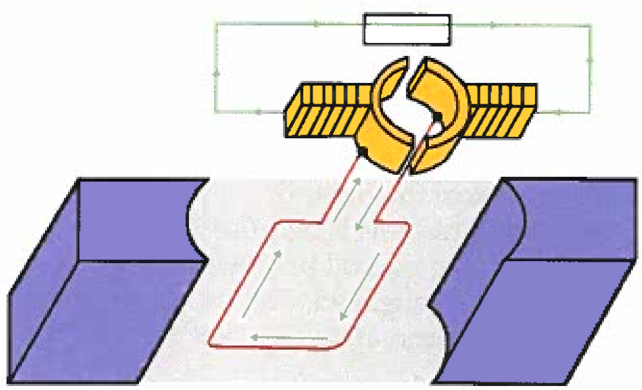
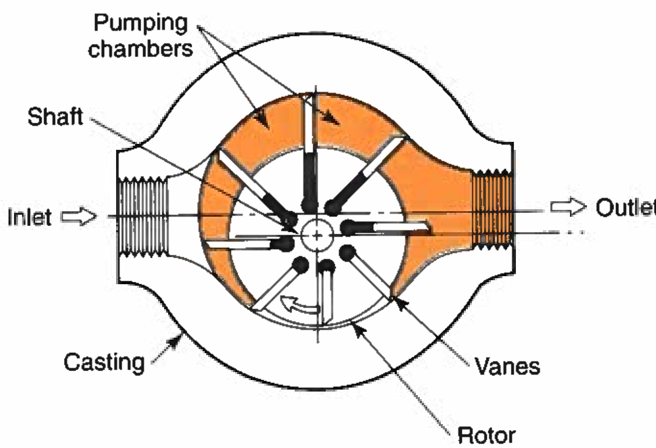


Figure 13-8. A small gasoline engine can power a portable generator. This portable generator can be used on construction projects where electricity is not yet available or for equipment repair in areas far from electrical lines. (Miller Electric Manufacturing Company)

GREEN TECH

You have already learned that solar power can be converted to electrical power. A more environmentally friendly portable generator may be powered by solar power.

Figure 13-9. A rotary vane pump converts mechanical power into fluid power. As the pump rotates, the compartments between vanes become smaller, pressurizing the liquid, until it is expelled through the outlet port.

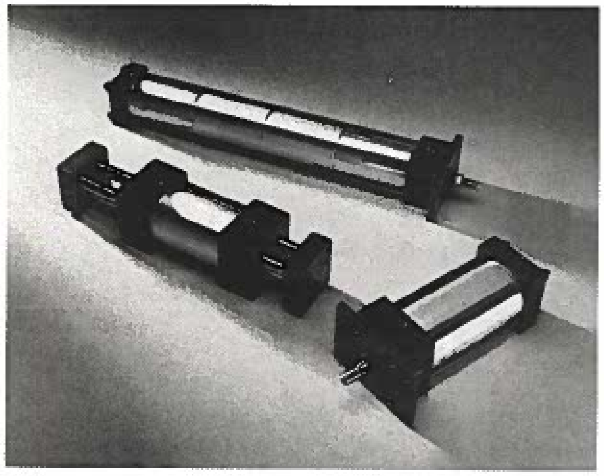


Fluid to mechanical

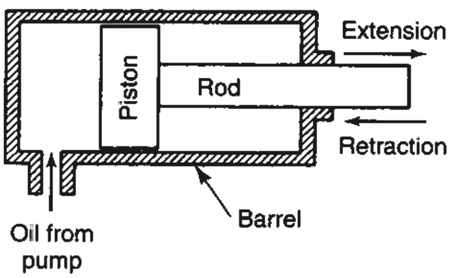
Fluid power is converted back to mechanical power with the use of cylinders, known as *actuators*, that permit linear mechanical movement. See **Figure 13-10.** Fluid motors are also used for converting fluid power into mechanical power. The vane motor in **Figure 13-11** is the reverse of the vane pump described in the preceding paragraph. Fluid enters the inlet port under high pressure and propels the vanes or pump paddles around until it exits the outlet port. The rotor that holds the vanes is coupled to a rotating shaft that provides mechanical power to the load.

Figure 13-10. Linear actuators are a type of hydraulic cylinder. A—Several examples of actuators. (Bimba Manufacturing Company) B—Parts of a typical actuator.

A



B



Fluid to electrical

Converting electricity directly into fluid motion or fluid motion directly back into electricity can be done, but these conversions have far fewer applications than the other power conversions previously described. A ***magnetohydrodynamic (MHD) generator*** is an advanced system for generating electricity from fossil fuels. See **Figure 13-12.** While it is still in the research stage, the appeal of an MHD generator is that it operates at a much higher efficiency than a conventional generating plant. An MHD generator is considered a direct conversion device because it produces electricity directly from the heat source. It does not require a steam generator to spin a turbine, as is the case in conventional power plants. In the MHD process of power generation, fuels are burned at very high temperatures. This permits greater efficiency and causes less pollution. In the MHD process, a very hot ionized gas takes the place of the copper windings of conventional electric generators. Gases from the high temperature ***combustion***, or burning, of fossil fuels are made electrically conductive by seeding them with conductive chemicals. The hot gases then travel at high speed through a magnetic field to produce a DC. Waste heat can be used to produce steam for a conventional turbine generator. This helps to increase the total efficiency of the generating system to one and one-half times that of a conventional power plant.

Magnetohydrodynamic (MHD) generator: An advanced, highly efficient direct conversion device that generates electricity from fossil fuels.

Combustion: The process of burning.

Figure 13-11. A fluid vane motor is similar in construction to a vane pump, but it operates in the opposite manner. Instead of the rotary motion of the device moving the fluid, the fluid movement generates rotary motion.

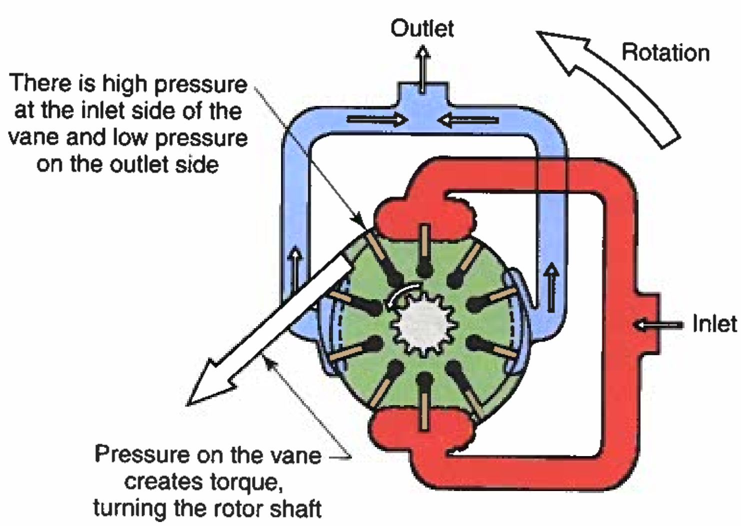
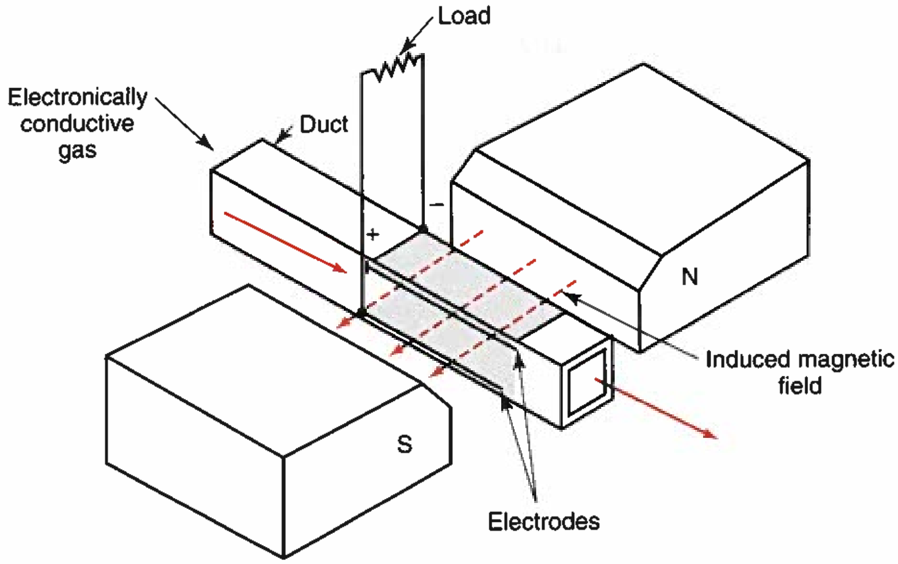


Figure 13-12. In a magnetohydrodynamic (MHD) generator, an electrically conductive heated gas flows inside an insulated duct through an induced magnetic field. As the gas moves through the magnetic field, an electric current is induced and collected by a pair of electrodes on opposite sides of the duct.



Electrical to fluid

An electromagnetic induction pump without any moving parts can propel a liquid, as long as the liquid can be polarized. Liquid metals, such as mercury, can be easily polarized. The essential principle of the electromagnetic induction pump can be visualized by moving mercury around on a tabletop using a permanent magnet.

Energy Conversions

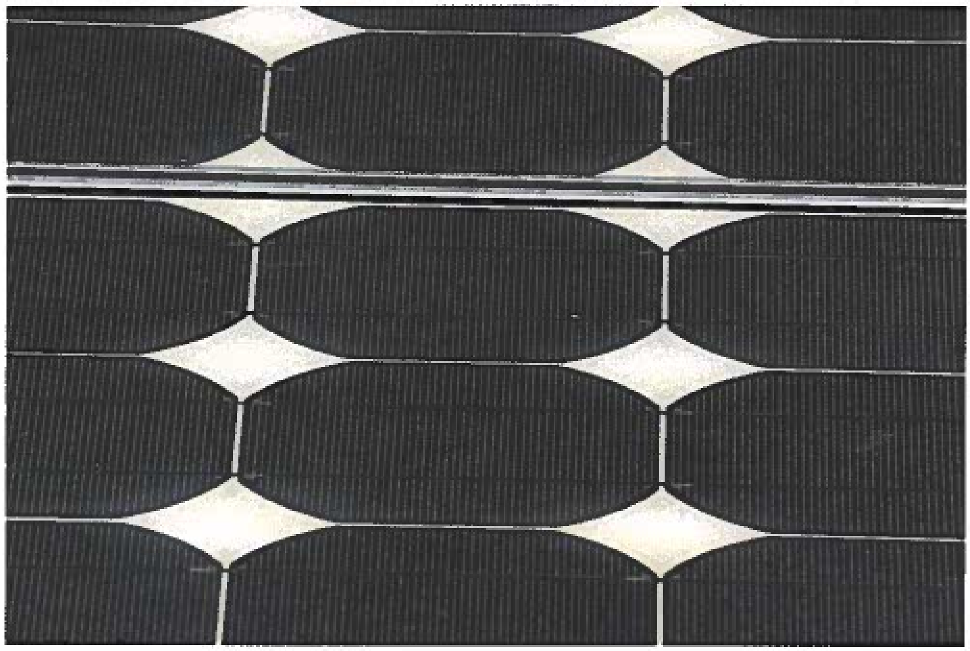
Energy converters are responsible for changing a form of energy into a form of power. Some practical examples of energy converters include the photovoltaic cell, which converts sunlight directly into electricity, and the internal combustion engine, which converts chemical energy into heat, then into fluid power in the form of expanding gases, and ultimately into mechanical power. Some energy converters are direct converters. Others are indirect converters.

Visible light energy to electrical power

Photovoltaic cells have the ability to convert sunlight directly into electricity. An array of cells can be used to produce enough electricity to power a load. See **Figure 13-13.** Photoelectric "eyes" (sensors) also make use of the photovoltaic effect. In these devices, photons striking the sensor generate a small current. This current triggers a ***transistor*** (solid-state switching device) to open or close a circuit. In the case of a photoelectric eye used for streetlights or security floodlights, the lights will remain off as long as the eye is generating enough current to influence or bias the transistor. When the sun sets or light levels fall to a selected point, the current weakens, and the transistor switches to turn the lights on. The lights will remain on until the morning light becomes strong enough to produce enough current to bias the transistor again.

Transistor: A solid-state switching device.

Figure 13-13. Photovoltaic cells convert light energy from the sun into electricity. This view shows part of a large solar array made up of many thousands of photovoltaic cells.



Infrared energy to mechanical power

Bimetallic coil: The part of a thermostat formed from strips of two metals with differing coefficients of expansion.

Coefficient of expansion: The rate at which a metal expands and contracts as temperature rises or falls.

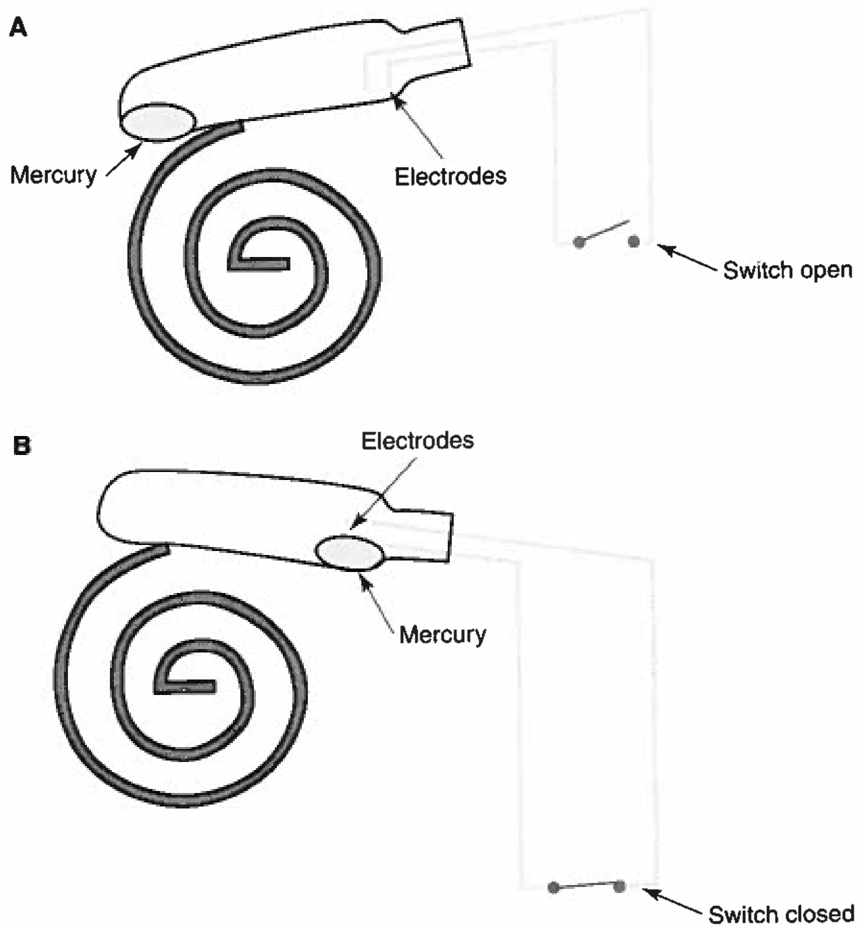
A thermostat is a device that can detect temperature and convert changes in temperature into mechanical movement. This movement is often used to open or close electrical switch contacts to turn a furnace or air conditioner on or off. At the heart of the thermostat is a ***bimetallic coil***. The coil is formed from strips of two metals with differing ***coefficients of expansion***. This means that the metals will expand and contract at differing rates as the temperature rises or falls. This expansion and contraction can be calibrated. If a needle is attached to the bimetallic coil, a thermometer is created. This will indicate temperature, but that is all. To make the bimetallic coil perform switching functions, a little glass bulb of mercury is attached to it. Mercury is a highly conductive liquid metal. The mercury bulb sits between two wires and acts as a switch. If the temperature decreases, the bimetallic coil will contract (coil more tightly). This movement will cause the ball of mercury to move to one end of the glass bulb, closing switch contacts that send a signal to the furnace calling for heat. As the room temperature rises, the coil expands (coils more loosely) and moves the mercury bulb the other way, opening the switch contacts and causing the furnace to shut down. See **Figure 13-14.**

Sound waves to electrical power

Sound: Vibration traveling through matter in the form of a wave motion.

Sound is vibration traveling through matter in the form of a wave motion. The vibrations we hear as sound are movements in a gas, liquid, or solid. Sound can travel through any form of matter, but it cannot travel though a vacuum because it would not have any medium in which to generate a wave motion. Air is perhaps the most important medium through which sound travels, since it brings the sound to our ears. It is

Figure 13-14. Operation of a thermostat in a home heating system. A—While temperature in the room remains above the set point, the bimetallic coil holds the bulb in the position shown. The mercury in the tube remains at the end opposite the electrodes. The switch used to operate the furnace remains open. B—When the room temperature drops below the set point, the bimetallic coil moves the bulb, allowing the mercury to flow to the electrode end. Since mercury is a conductive material, it completes a circuit with the electrodes and closes a switch that operates the furnace.



GREEN TECH
Scientists have been using sound waves in recent experiments as a green alternative to chemicals. For example, it may be possible to use sound waves to create hydrogen gas out of crystals under certain circumstances.

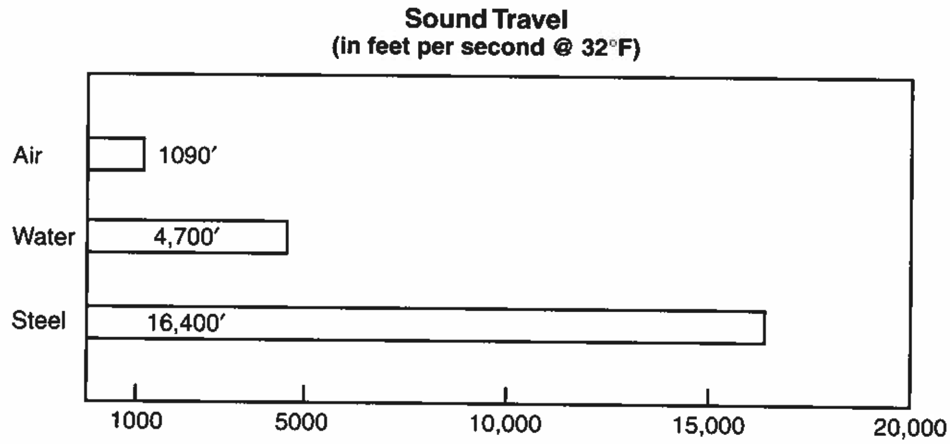
not, however, the fastest medium for sound travel. Sound travels much more quickly through water, for example. See **Figure 13-15.** The speed of sound can be calculated using the velocity formula:

$$\text{velocity} = \frac{\text{distance}}{\text{time}}$$

It is important to remember there are variables that affect the actual speed at which sound is transmitted.

The speed sound can travel through substances such as steel may appear impressive in comparison to sound traveling through air. Steel is, however, not a very useful means of transmitting sound over distance. Assuming 100% efficiency, a conversation transmitted through a solid piece of steel could only travel a little more than 3 miles per second. This means, if grandma lives about 35 miles away, you could expect a 10-second delay when speaking to her by telephone. This delay would

Figure 13-15. The speed of sound through air, water, and steel.



make it quite hard to carry on a conversation. Some means for speeding up sound transmission would be needed. This can be done if the sound waves are converted into a form of energy that travels much faster than sound. Both visible light and electricity can travel at 186,000 miles per second, approximately more than 10 times faster than the speed of sound through steel.

The simplest explanation for how sound is converted to electricity or light is the operation of a microphone. A microphone is a device that converts mechanical movement (created by changes in air pressure caused by sound waves) into electrical impulses of equivalent strength and duration. There are many types of microphones, but all of them convert the mechanical vibrations into equivalent electrical waves that can travel much faster than sound itself.

STEM Connection

Science: The Speed of Light and Sound

During a thunderstorm, the lightning and sound of thunder actually occur close together. Yet, lightning is always seen before the thunder can be heard. If you are close to the location of the strike, you will hear the thunder before others who are farther away. You can tell how far you are from the actual strike by the amount of time between seeing the flash of lightning and hearing the thunder. This delay is caused by the difference between the speed of light and the speed of sound.

Sound and light both travel in wave form. While air is the fastest medium for light waves, the same is not true of sound waves. Sound travels more quickly through materials with more density, such as water. The speed of sound traveling through air is about 0.2 miles per second, but the speed of light traveling through air is 186,000 miles per second. When lightning strikes, therefore, it can be seen before the thunder can be heard.

One common type of microphone is a ***dynamic coil microphone***. See **Figure 13-16.** Like most microphones, the dynamic microphone has a ***diaphragm***—a thin membrane that will receive the sound waves in the air and vibrate accordingly. If you shout, it will vibrate vigorously. It will hardly vibrate at all, if you whisper. A ***voice coil*** is a wire attached to the diaphragm that moves back and forth as the diaphragm vibrates. It is surrounded by a magnetic field. As vibrations move the voice coil back and forth in the magnetic field, voltages are induced in the voice coil. These voltages are an electrical reproduction of the sound waves that struck the diaphragm. The electrical waves are then transmitted to a speaker that is the reverse of the microphone, converting the electrical waves back into sound with the use of a voice coil and diaphragm. If the electrical waves must travel a long distance or if the sound needs to be significantly increased, they may be amplified. An ***amplifier*** receives the electrical waves and increases the power of the signal, so it has greater strength, before sending it on to the speaker. The telephone system uses a specialized amplifier known as a ***repeater***, which receives electronic communication signals and sends out corresponding amplified signals.

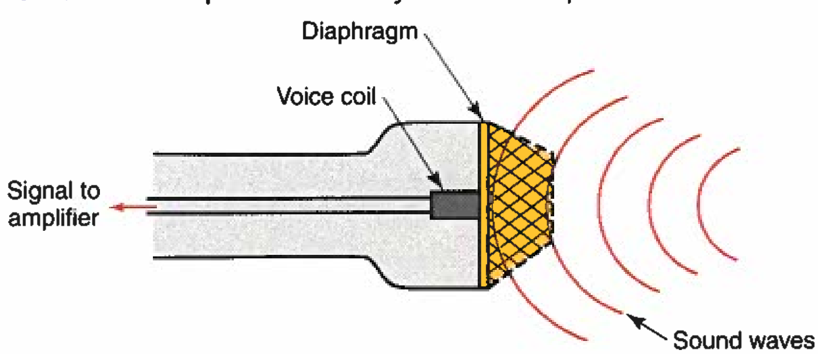
Chemical energy to mechanical power

The internal combustion engine is a good example of an energy converter. It could not, however, be considered a direct converter by any means. The engine consumes gasoline, a form of chemical energy with plenty of potential in it, and converts it first to heat and then to fluid power in the form of expanding gases. Finally, the expanding gases are converted into mechanical power through the piston, connecting rod, and crankshaft assembly. This mechanical power can be used to perform useful work. See **Figure 13-17.**

Frequency Conversions

Frequency conversions occur when one ***frequency*** (wavelength) of radiant energy is directly converted to another frequency of radiant energy. The electromagnetic spectrum is made up of radiant energies with varying frequencies, including infrared rays, visible light rays, UV rays, X rays, radio waves, and even gamma rays. The term *frequency* describes the number of cycles in a given time interval, such as one second. The number of ***cycles*** per second can be measured. It is usually measured in a unit known as ***Hertz***. A complete ***wavelength*** from start to finish is one Hertz.

Figure 13-16. The components of a dynamic microphone.



Dynamic coil microphone: A common type of microphone with a voice coil attached to the diaphragm.

Diaphragm: The part of a dynamic microphone that is a thin membrane designed to receive sound waves in the air and vibrate accordingly.

Voice coil: The wire in a dynamic coil microphone that is attached to the diaphragm and moves back and forth as the diaphragm vibrates.

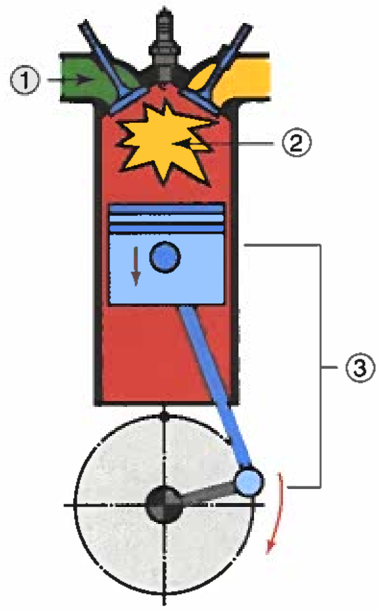
Amplifier: A device that receives electrical waves and increases the power of the signal, so it has greater strength, before sending it on to the speaker.

Repeater: A specialized amplifier used in a telephone system. It receives electronic communication signals and sends out corresponding amplified signals.

Frequency: The number of cycles in a given time interval.

Cycle: One complete performance of a periodic process.

Figure 13-17. An internal combustion engine converts chemical energy from gasoline into mechanical power. Gasoline vapor is drawn into the engine cylinder (1). It is compressed and then changed to heat by combustion (2). Fluid power of the expanding gases drives the piston downward. The piston, connecting rod, and crankshaft assembly transmit mechanical motion (3).



See **Figure 13-18.** For example, AC electricity has a wavelength of 60 cycles per second, which is also referred to as 60 Hertz.

Radiant energy to chemical energy

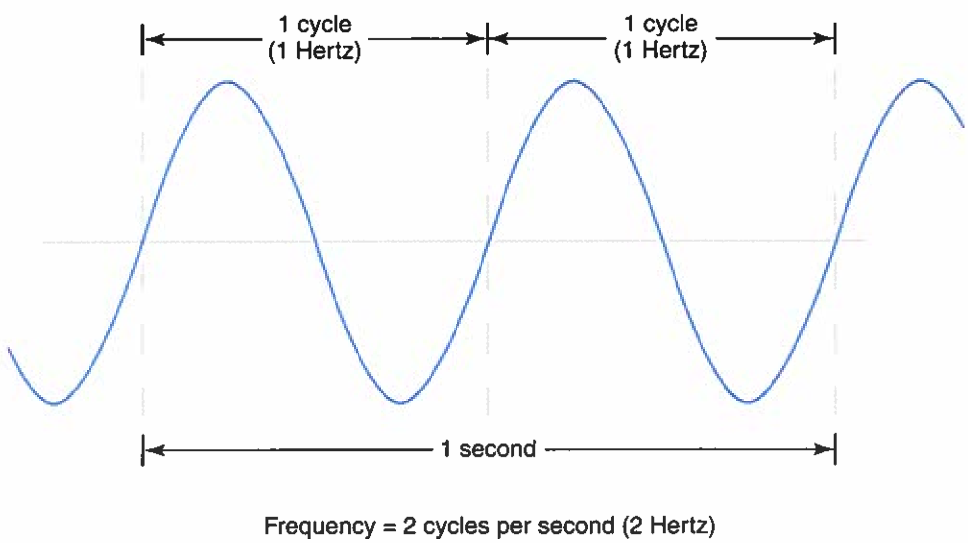
Radiant energy is converted into chemical energy all the time. The type of change is a purely scientific conversion, not a technological conversion. In other words, this conversion occurs naturally and is not the result of a human-made product. The process known as photosynthesis is essential to life. Without it, all the hydrocarbon fuels we use and all the food we eat would not exist. ***Photosynthesis*** is the process by which carbohydrates are compounded from carbon dioxide (CO_2) and water in the presence of sunlight and chlorophyll. From a practical standpoint, photosynthesis is the primary method for bioconversion of solar energy into forms of energy such as hydrocarbon fuel sources and agricultural crops. Photosynthesis occurs when organisms convert CO_2 to organic material by reducing these gases to carbohydrates. The carbohydrates are compounds of hydrogen, oxygen, and carbon (such as sugars, starches, and celluloses), which are formed by green plants. Energy for this process is provided by light, some of which is absorbed by the pigments of chlorophyll, the green matter that comprises many plants. See **Figure 13-19.**

Hertz: A unit of frequency equal to one cycle per second.

Wavelength: One frequency of radiant energy.

Photosynthesis: The process by which carbohydrates are compounded from carbon dioxide (CO_2) and water in the presence of sunlight and chlorophyll.

Figure 13-18. A waveform—in this case, 2 Hertz, or 2 cycles per second.



Chemical energy to radiant energy

Chemical energy is converted to radiant energy through the process known as *combustion*. Scientifically, it is described as a rapid chemical reaction in which heat and light are produced. Combustion requires ***oxidation***, a union between fuel and oxygen, in order to occur.

Visible light to infrared energy

The most common frequency conversion occurs when visible light is converted to infrared energy upon striking something. Solar collectors are designed to maximize this conversion and capture the energy from the heat. See **Figure 13-20.**

Ultraviolet (UV) radiation to visible light

When electricity is passed through a fluorescent lightbulb, electrodes are heated by the current flowing through them. These electrodes emit free electrons, which strike atoms of mercury vapor stored in the bulb. The mercury vapor emits radiant energy when it is stimulated by the free electrons. This radiant energy is not in the form of visible light, however, but in the form of UV ***radiation***. The UV energy strikes a phosphor coating on the

Figure 13-19. Plants, such as this cactus, convert sunlight into organic matter through the process known as photosynthesis.

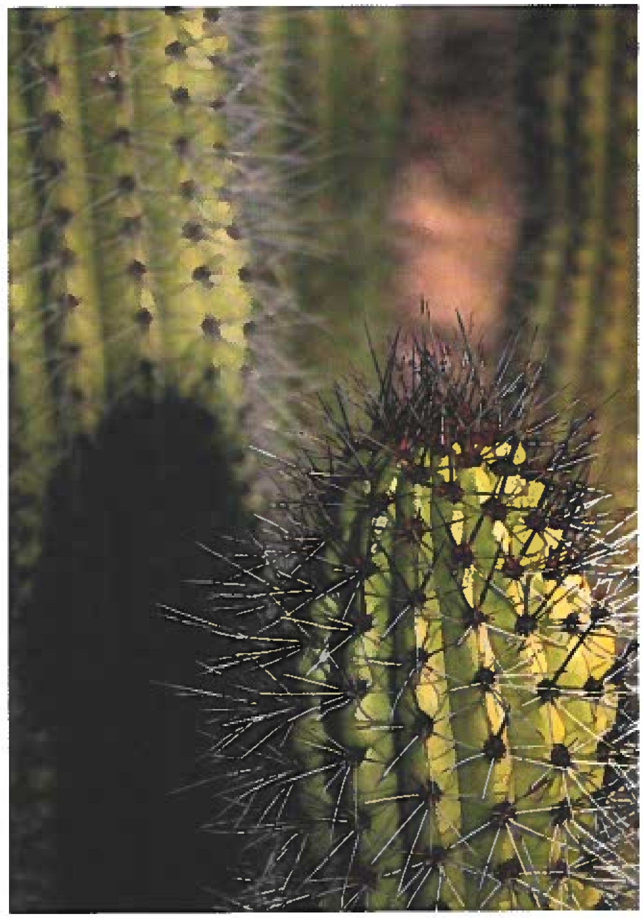


Figure 13-20. An active solar energy collector system performs a frequency conversion, changing visible light into infrared energy.

Oxidation: A union between fuel and oxygen.

Radiation: Energy radiated in the form of waves or particles.

tube, and a frequency conversion to visible light occurs. More specifically, the UV energy stimulates the electrons in the phosphorous atoms, and the atoms emit visible ("white") light. This process of converting one form of light to another is known as ***fluorescence***, providing the name of the fluorescent lightbulb. See **Figure 13-21.**

Fluorescence: The process of converting one form of light to another.

Energy Inverters

Energy inversions involve converting a form of power back into a form of energy. An example of an energy inverter is a lightbulb that changes electricity into visible light. Among the most useful inversion devices are those that provide the ability to convert electricity into heat, light, and sound.

GREEN TECH

Because incandescent bulbs use heat to make filaments glow, a great deal of energy is wasted to light these bulbs. Compact fluorescent lamps (CFLs) use up to 75% less energy to create light.

Electrical power to visible light energy

There are two basic methods of producing artificial light with the use of electricity. One is to heat something to the point where it gives off a glow. In a standard incandescent lightbulb, the filament is made of tungsten, a conductive metal element. See **Figure 13-22.** Tungsten can be heated to the point that it becomes white-hot, but does not melt. The second method of producing artificial light is to pass electricity through a gas or vapor, causing the tiny charged particles within the atoms to emit radiation. The color that such lights emit is specific to the gas within them. Halogen lights work in this manner.

Figure 13-21. In a fluorescent lightbulb, ultraviolet (UV) radiation strikes a phosphor coating, generating visible light.

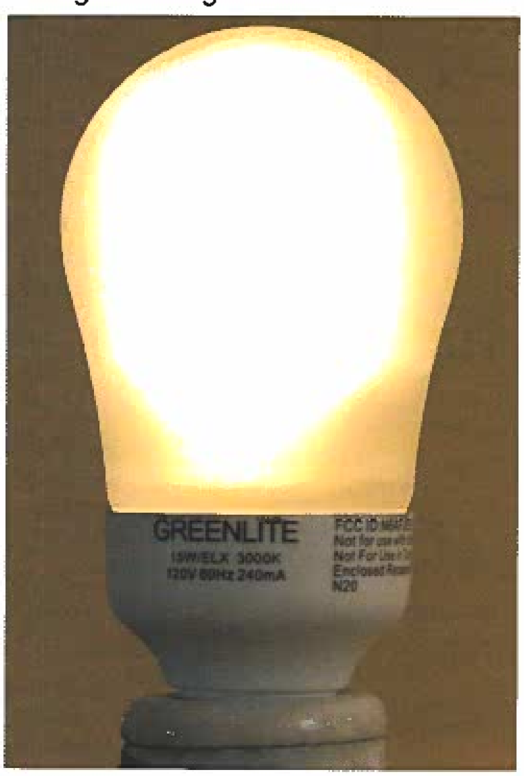
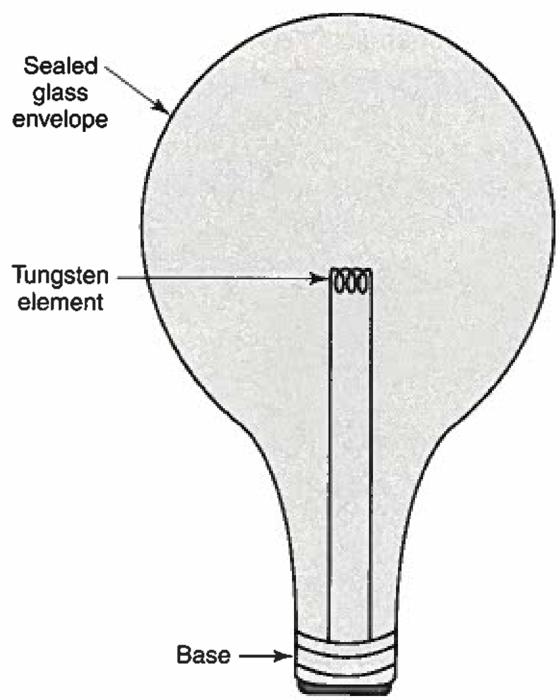


Figure 13-22. The components of an incandescent lightbulb, which is an energy inverter. Electrical energy flowing through the high-resistance tungsten element causes it to heat up and glow, emitting visible light.



Technology Link

Communication: Radio Detecting and Ranging (Radar) Guns

Police typically use radio detecting and ranging (radar) guns to identify speeding vehicles in order to protect the public and help keep our roadways safe. A radar gun consists of both a transmitter and a receiver. The transmitter converts electricity into radio waves and broadcasts or aims them toward a moving object, such as a vehicle. The radio waves strike the vehicle and bounce back to the radar gun. The receiver picks up the radio signal and converts it back into electricity. The analog electrical signal is converted into a digital electrical signal, and ultimately a visual readout in miles per hour is provided.

Radar guns measure so accurately because radio waves travel at a constant 186,000 miles per second, or the speed of light, and with a certain frequency, or number of oscillations per second. If the radio waves strike a stationary object, they will return at the same rate of speed and with the exact same wavelength. The distance it takes for them to return can be used to accurately calculate how far they have traveled.

If the radar gun is aimed at an object that is moving rather than stationary, however, the speed at which the radio waves return will be different from the rate at which the signal was sent. The frequency will also vary based on the speed of the object. This is because the radio wave is oscillating. Even though the signal is traveling very fast, because the car is moving, the signal will not reflect from the vehicle as the exact same waveform. This variation in waveform is known as a *Doppler Shift*. If a car is moving away from the radar, the wavelength is stretched. It has to travel a greater distance to return to the receiver. If the vehicle is moving toward the radar gun, the signal is compressed and returns to the receiver more quickly than the rate at which it was transmitted. These signals are calibrated and can measure speed with great accuracy.

Electrical power to infrared energy

Another very common inversion is that of electricity to heat. The way electricity is used to generate heat is easily explained. When electricity flows through a wire, it excites the molecules within the wire. This increased agitation causes the molecules to move, and this movement generates excessive energy, given off in the form of heat. See **Figure 13-23.**

In some homes, resistance heating is the primary heating system. It is used to supplement other heating methods in other homes. Small electrical resistance ("space") heaters may be used to warm specific rooms or such spaces as garages and workshops.

Electrical power to x-radiation

The *X-ray tube* is a wonderful device that can convert electricity into x-radiation. X rays have a higher frequency than visible light or even UV light. The X-ray tube produces a stream of negatively charged electrons that strike a tungsten filament, similar to that within a lightbulb. This bombardment of electrons causes the tungsten to emit X rays. The X rays are focused out through a window and aimed at a piece of film or an

X-ray tube: A device that converts electricity into x-radiation. It produces a stream of negatively charged electrons that strike a tungsten filament, causing the tungsten to emit X rays.

Career Connection

Administrative Assistants

Business, Management & Administration

Utility companies have the responsibility of providing electricity to the public. As a result of this, these businesses must also have a reliable record-keeping system. Administrative assistants have the task of organizing the paperwork of utility companies.

The duties of an administrative assistant vary from answering phones and opening mail to attending board meetings and performing research for executives. Assistants may be in charge of other clerical staff, which requires them to train their subordinates. Administrative assistants keep track of all incoming and outgoing paperwork and files. They are qualified to answer many questions from customers and other individuals.

Administrative assistants must be skilled in using multiple word processing and spreadsheet systems. They must understand business and management procedures in order to better aid executives. Administrative assistants must also possess a knowledge of grammar and communication skills. They typically receive on-the-job training. The yearly salary for this profession can range from $25,000 to $56,000.

Figure 13-23. The heating element in this toaster is an example of energy inversion. Electricity flowing through the high-resistance heating element is converted to heat.

array of photodiodes to produce an image. See **Figure 13-24.** The radiation is such that it can pass through lighter atoms, such as those that make up flesh, cloth, or canvas. The rays are absorbed, however, by more dense materials, such as metals. Since the calcium in your teeth and bones is a form of metal, X rays will not pass through these areas. This is why bones, teeth, and fillings will appear as negative images on a piece of developed X-ray film. All other areas of the film are exposed to the radiation and appear black.

An airport baggage scanner works in a way similar to the X-ray machine. Instead of exposing a piece of film, however, the scan displays a continuous "live" image. The X rays radiate through more porous substances, such as the luggage, and are received by photodiodes that convert the x-radiation to a displayed image. Denser items within the luggage do not allow X rays to pass through, and the result is that a strong image of such items appears on the screen.

Electrical power to sound waves

A number of different types of speakers are available for converting electricity back into sound. Electrodynamic speakers work on the

principle of magnetism, which states that like forces repel one another and opposing magnetic forces are attracted to one another. See **Figure 13-25.**

Principle of magnetism: Like forces repel one another, and opposing magnetic forces are attracted to one another.

This type of speaker contains both a permanent magnet and an electromagnet (a device that can become magnetic only when electricity is flowing through it). As the electromagnet receives its signal from the microphone or amplifier, it will change its polarity and intensity continuously, based on the sine wave it is receiving. The electromagnet is sometimes referred to as a *voice coil*, because it is attached to the cone of the speaker. The cone acts much like the diaphragm of a microphone, except in reverse. Based on the electrical signal it receives, the voice coil is continuously attracted and repelled by the permanent magnet mounted behind the cone. The cone moves in and out accordingly, producing vibrations in the air that cause sound to be created. See **Figure 13-26.**

Figure 13-24. An X-ray tube emits electrons that are converted to x-radiation. If an object (such as the human knee shown here, is placed between the radiation source and a piece of film, a negative image will be formed}. More dense materials (such as the bones and the screw used for a medical repair) block the rays in part or in full. They show up darker on the film than less dense substances, such as muscle. (Siemens)

Transducers

A device for converting one form of energy to another or one form of power to another is called a ***transducer***. Transducers can be frequency converters or power converters. They are often used to measure quantities in a system (such as pressure, current, or voltage) and convert them to a proportional unit displayed on a meter or scale. A thermometer is one such device. Other transducers are used as switching mechanisms. An example of a common transducer is a ***thermocouple***. See **Figure 13-27.** A thermocouple consists of two different metals joined end-to-end to produce a loop. When there is a difference in temperature between the two junctions (points in the loop where the metals are joined), a small electric current will flow between the two junctions. This electricity can be used to send a signal to turn something on or off.

Entropy and Efficiency of Converters

In any conversion, entropy will occur when the conversion takes place. Entropy is a measure of energy lost upon conversion. Simply stated, total system efficiency will decrease every time an energy or power form undergoes a conversion. As described in Chapter 7, efficiency can be calculated using the following formula:

$$\frac{\text{output}}{\text{input}} \times 100 = \%\text{ of efficiency}$$

Figure 13-25. The principle of magnetism. A—Unlike magnetic poles are attracted to each other. B—Like magnetic poles repel each other.

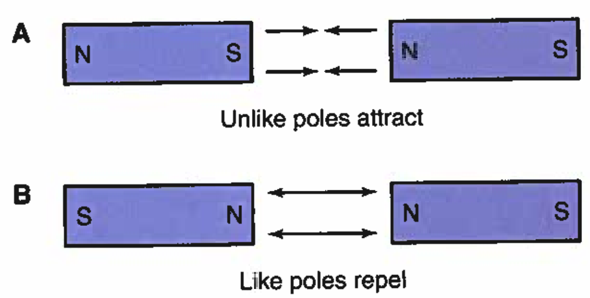
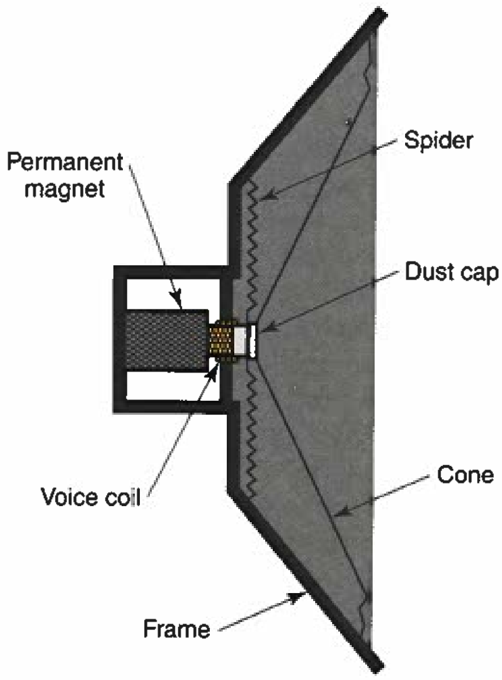


Figure 13-26. The components of an electrodynamic speaker.



The output and input units must always be the same. For instance, watts can be divided by watts, but watts cannot be divided by horsepower (hp) when using this formula. Units commonly used for calculating efficiency of energy and power devices include hp and British thermal units per minute (Btu/min). When calculating efficiency, sometimes it may be necessary to use a constant to convert some other unit to hp or Btu/min, in order to be able to perform the efficiency calculation. Some constants discussed in Chapter 7 include the following:

$$1 \text{ hp} = 746 \text{ watts} \qquad 1 \text{ hp} = \frac{550 \text{ ft.-lbs.}}{\text{sec}}$$

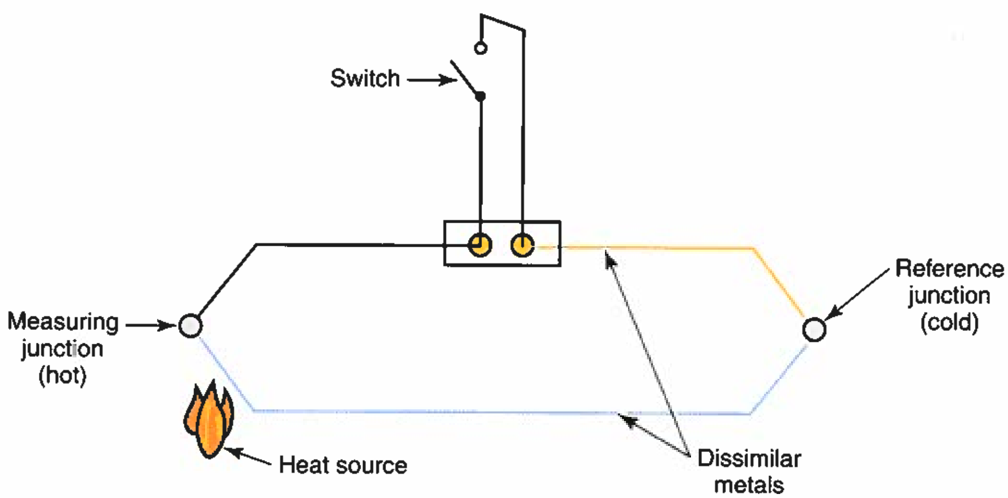
The following constant is useful because it allows for the comparison of thermal systems to electrical, fluid, or mechanical systems:

$$1 \text{ hp} \times 42.44 = \frac{1 \text{ Btu}}{\text{min}} \quad \text{or} \quad \frac{1 \text{ Btu/min}}{42.44} = 1 \text{ hp}$$

Transducer: A device for converting one form of energy into another. It is often used to measure quantities in a system and convert them to a proportional unit displayed on a meter or scale.

Thermocouple: A transducer consisting of two different metals joined end-to-end to produce a loop.

Figure 13-27. A thermocouple in operation. A temperature difference between the two junctions causes a current to flow. This current can be used to operate a switch.



Summary

The ability to convert energy into power and one form of power into another form of power is essential to many of the modern conveniences we take for granted. Some conversions occur naturally, but most conversions are the result of technological innovation. Conversions can be classified as either direct, meaning they take only one step, or indirect, meaning they take two or more steps. Transducers convert one form of power into another. They are typically used for sensing equipment and can also perform switching duties. Some of the most popular conversions are actually termed inversions because a form of power is converted back into a form of energy. Every time a conversion occurs, some energy or power is lost due to entropy.

Key Words

All the following words have been used in this chapter. Do you know their meanings?

amplifier
armature
bimetallic coil
brush contactor
coefficient of expansion
combustion
commutator
cycle
diaphragm
direct converter
dynamic coil microphone
energy converter
energy inverter
fluorescence
frequency
frequency converter
Hertz
indirect converter
induced
magnetohydrodynamic (MHD) generator
oxidation
photosynthesis
power converter
principle of magnetism
radiant energy
radiation
relay
repeater
rotor
run winding
single-phase induction motor
slip ring
solenoid
sound
start winding
stator
thermocouple
three-phase induction motor
transducer
transistor
voice coil
wavelength
X-ray tube

Test Your Knowledge

Write your answers on a separate sheet of paper. Do not write in this book.

1. Explain the difference between a direct converter and an indirect converter.
2. When one form of radiant energy is converted into another form of radiant energy, this is known as a(n) _____ conversion.
3. List the four types of power conversions that can occur, and describe each type of conversion.

4. *True or False?* Power conversion devices are technological, as opposed to natural.
5. *True or False?* Energy converters change one form of energy into another form of energy.
6. Describe at least three uses for a solenoid.
7. Spinning the shaft of a direct current (DC) motor will _____.
8. The windings in a motor that do not move are known as the _____ windings.
9. Induction motors are typically _____-phase or _____-phase.
10. *True or False?* Magnetohydrodynamic (MHD) generators are extensively used to produce power throughout the United States.
11. *True or False?* One advantage of an MHD generator is its increased efficiency over conventional steam turbine power generation.
12. List the sequence of conversions that occur within an internal combustion engine in order to produce rotary mechanical power.
13. *True or False?* A transistor is a solid-state switching device.
14. Sound is converted to electricity using a(n) _____.
15. The signal strength of sound is boosted by a(n) _____.
16. The frequency of a wavelength can be determined by dividing the _____ by the _____.
17. *True or False?* The phosphor coating on a fluorescent lightbulb converts ultraviolet (UV) energy into visible light energy.
18. *True or False?* Electricity generates heat by exciting the molecules in the wire of a heating element.
19. The law of magnetism states that opposite forces attract and like forces _____ each other.
20. In a speaker, the _____ converts electrical signals into movement of the cone to produce sound.
21. A device often used to convert a form of energy or power into another form for measurement or switching purposes is known as a(n) _____.

STEM Activities

1. Construct a simple electric motor from a set of plans.
2. Design and construct a model of simple relay.
3. Disassemble a small electric motor and identify its components.
4. Locate and photograph devices that are examples of each of the four types of energy conversion. Write a paragraph describing each device and how it functions.