Steam locomotives were one of the most important early uses of the steam engine. Prior to the locomotive, steam engines provided power for coal mines and mills. But don’t think that steam engines are only a thing of the past. In fact, most electric power plants today use steam turbines, a very efficient kind of steam engine.

Heat Engines played a key role in the development of the modern industrial world. The two main types of heat engines are the external combustion engine and the internal combustion engine.

External Combustion Engine A steam engine is an external combustion engine—an engine that burns fuel outside the engine. Thomas Newcomen developed the first practical steam engine in 1712. His engine was used to pump water out of coal mines. In 1765, James Watt designed an engine that was more efficient, in part because it operated at a higher temperature.

Figure 11 shows one type of steam engine. Hot steam enters the cylinder on the right side. When the valve slides to the left, hot steam is trapped in the cylinder. The steam expands and cools as it pushes the piston to the left. Thus heat is converted into work. The piston moves back and forth as hot steam enters first on one side and then on the other side.
**Internal Combustion Engine** Most cars use internal combustion engines that burn gasoline. An internal combustion engine is a heat engine in which the fuel burns inside the engine. Most internal combustion engines use pistons that move up and down inside cylinders. Each upward or downward motion of a piston is called a stroke. The linear motion of each stroke is converted into rotary motion by the crankshaft. The crankshaft is connected to the transmission, which is linked to the vehicle’s wheels through the drive shaft.

Figure 12 shows the sequence of events in one cylinder of a four-stroke engine. In the intake stroke, a mixture of air and gasoline vapor enters the cylinder. Next, in the compression stroke, the piston compresses the gas mixture. At the end of compression, the spark plug ignites the mixture, which heats the gas under pressure. In the power stroke, the hot gas expands and drives the piston down. During the exhaust stroke, gas leaves the cylinder, and the cycle repeats.

Recall that a heat engine must discharge some waste energy in order to do work. In an internal combustion engine, the cooling system and exhaust transfer heat from the engine to the environment. A coolant—usually water and antifreeze—absorbs some thermal energy from the engine and then passes through the radiator. A fan blows air through the radiator, transferring thermal energy to the atmosphere. Without a cooling system, an engine would be damaged by thermal expansion. If you are ever in a car that overheats, stop driving and allow the engine to cool. Otherwise, there is a risk of serious damage to the engine.

Gasoline engines are more efficient than old-fashioned steam engines, but they still are not very efficient. Only about one third of the fuel energy in a gasoline engine is converted to work. Auto makers have tried several ways to make engines more efficient. One design, called a hybrid design, uses a heat engine together with an electric motor. This design is explained in the How It Works box on the next page.

**Build Science Skills**

**Applying Concepts** Have students write a short paragraph about how the increased temperature of the gasoline-air mixture allows it to do work during the power stroke in an internal combustion engine. Remind them to use what they know about forms of energy and the relationship between temperature, pressure, and average kinetic energy of particles that make up a substance. *(Answers should indicate that the energy released during ignition of the gasoline-air mixture increases the mixture’s temperature, and thus the average kinetic energy of the gas particles. This greater energy produces an increase in gas pressure, which in turn does work.)*

**Verbal, Logical**

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**Customize for English Language Learners**

**Simplify the Presentation**

The details in the operations of heat engines, heat systems, and cooling systems are rather complex. By simplifying your presentation, the English language learners in your class will have a better comprehension of the material. Speak directly, use simple words and short sentences, and make frequent use of the diagrams to clarify the workings of thermal systems.
Hybrid Automobile

The hybrid automobile is a result of research that was begun initially to develop an efficient electric car. By combining a small gasoline engine with an electric motor, the hybrid automobile is able to travel longer distances, like a gasoline-powered vehicle, but with reduced fuel consumption and emissions. During regenerative braking, kinetic energy that is normally lost to friction is partially recovered for later use. This can be explained to students in simple terms: It takes work to turn a generator. When the spinning wheels do the work of turning the generator, the wheels lose kinetic energy. In other words, the wheels must slow down.

Interpreting Diagrams
Fuel consumption is reduced by using lightweight materials, an aerodynamic design, and high-pressure tires that reduce friction. The use of two engines saves fuel because the small gasoline engine is more efficient than traditional larger engines, and the electric motor is more efficient than a gasoline engine for accelerating at low speeds.

Visual

For Enrichment
Interested students can make a multimedia presentation for the class explaining the hybrid automobile. Numerous articles on the subject can be found on the Internet and in science and engineering periodicals.

Verbal, Portfolio
Heating Systems

At the start of the industrial revolution, wood-burning fireplaces were the principal method of heating buildings. Rumford was keenly aware of the drawbacks of fireplaces. They were smoky and not very efficient. Too much heat went up the chimney. In 1796, Rumford designed a fireplace that now bears his name. His fireplace was not as deep as standard fireplaces, and it had slanted walls to reflect heat into the room. His improvements were quickly accepted and used throughout England.

Today, fireplaces are often used to supplement central heating systems. A central heating system heats many rooms from one central location. The central location of a heating system often is in the basement. The most commonly used energy sources for central heating systems are electrical energy, natural gas, oil, and coal. Heating systems differ in how they transfer thermal energy to the rest of the building. Most heating systems use convection to distribute thermal energy.

Hot-Water Heating Figure 13 shows the main components of a hot-water heating system. At the boiler, heating oil or natural gas burns and heats the water. The circulating pump carries the hot water to radiators in each room. The hot water transfers thermal energy to the radiator by conduction. As the pipes heat up, they heat the room air by conduction and radiation. Hot air rises and sets up a convection current in each room. After transferring much of its thermal energy to the room, the cooled water returns to the boiler and the cycle begins again.

Temperature is controlled by a thermostat. One kind of thermostat is like a thermometer, with a strip of brass and steel wound up in a coil. When the heating system is on, the coil heats up. The two metals in the coil expand at different rates, and the coil rotates. This trips a switch to turn off the heat. As the room cools, the coil rotates in the opposite direction, until it trips the switch to turn the heat back on.

Steam Heating Steam heating is very similar to hot-water heating except that steam is used instead of hot water. The transfer of heat from the steam-heated radiator to the room still occurs by conduction and radiation. Steam heating often is used in older buildings or when many buildings are heated from one central location.

How are fireplaces often used today?

Facts and Figures

Heat of Vaporization Although hot-water heating and steam heating systems are similar in structure, steam systems convey more energy for each kilogram of water used. This difference occurs because the phase change that takes place during the boiling process, when liquid water is vaporized to steam, requires a much greater input of energy than is necessary to heat water in a hot-water system. The energy required for this phase change, called the heat of vaporization, is equal to $2.26 \times 10^6$ J/kg. This amount is more than 500 times as great as the energy required to raise the temperature of a kilogram of liquid water by 1°C (about 4180 J/kg). When steam completely condenses to liquid water, an amount of energy equal to the heat of vaporization is given up. This is why steam heating is effective, and also why steam is so hazardous.

Answer to . . .

Figure 13 Water returning to the boiler has cooled because it has lost thermal energy in the radiator.

Today, fireplaces are often used to supplement central heating systems.
Electric Baseboard Heating
An electric baseboard heater uses electrical energy to heat a room. A conductor similar to the heating element in an electric stove is used to convert electrical energy to thermal energy. The hot coil heats the air near it by conduction and radiation. Then convection circulates the warm air to heat the room.

Radiant heaters are similar to electric baseboard heating. They are often sold as small portable units, and are used to supplement a central heating system. These “space heaters” are easy to turn on and off and to direct onto cold toes or other areas where heat is needed most. Sometimes these heaters have a fan that helps to circulate heat.

Forced-Air Heating
To maintain even room temperatures, forced-air heating systems use fans to circulate warm air through ducts to the rooms of a building. In a forced-air heating system, shown in Figure 15, convection circulates air in each room. Because the warm air entering the room rises toward the ceiling, the warm-air vents are located near the floor. Cool room air returns to the furnace through floor vents on the other side of the room. One advantage of forced-air heating is that the air is cleaned as it passes through filters located near the furnace.

Cooling Systems
Most cooling systems, such as refrigerators and air conditioners, are heat pumps. A heat pump is a device that reverses the normal flow of thermal energy. Heat pumps do this by circulating a refrigerant through tubing. A refrigerant is a fluid that vaporizes and condenses inside the tubing of a heat pump. When the refrigerant absorbs heat, it vaporizes, or turns into a gas. When the refrigerant gives off heat, it condenses, or turns back into a liquid.

Recall that thermal energy flows spontaneously from hot objects to cold objects. Heat pumps must do work on a refrigerant in order to reverse the normal flow of thermal energy. In this process, a cold area, such as the inside of a refrigerator, becomes even colder.
Refrigerators A refrigerator is a heat pump—it transfers thermal energy from the cold food compartment to the warm room. To move heat from a colder to a warmer location, a motor must do work to move refrigerant through tubing inside the refrigerator walls. Could you cool your kitchen on a hot day by leaving the refrigerator door open? It might seem so, but an open refrigerator would actually heat the kitchen! You may have noticed the hot coils underneath or behind the refrigerator. The coils not only release heat absorbed from the food compartment; they also release thermal energy produced by the work the motor does. That is why a refrigerator with an open door adds more heat to the room than it removes.

**Reading Checkpoint**

**What is a heat pump?**

**Figure 15** When a refrigerator door is open, some thermal energy from the room enters the refrigerator. But more thermal energy leaves the refrigerator through the coils underneath the food compartment.

**Interpreting Photos** Why can't you cool a room by leaving the refrigerator door open?

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**Facts and Figures**

**Water Cooling** Although refrigerants are used to reach temperatures below the freezing point of water, water itself has been used for cooling for centuries. Because of its specific heat and heat of vaporization, water can greatly reduce the temperature of hot dry air. Fountains helped to cool the air in courtyards in places like Spain and Italy. In many desert cities, evaporative coolers, in which hot air is drawn through water-soaked pads into houses, are still widely used for air conditioning.
Section 16.3 (continued)

Use Visuals

Figure 16 Stress that evaporation is the key process for cooling in an air conditioner and refrigerator. Most of the work done by the air conditioner motor involves changing the pressure of the refrigerant so that it will evaporate (and so absorb thermal energy) and condense (to give up thermal energy) easily. Ask, What is the direction of the net flow of thermal energy in an air conditioner? (Looking at the red arrows only, thermal energy is transferred from the air inside the room to the outdoor air.) Visual

3 ASSESS

Evaluate Understanding

Ask students to write two questions each about heating systems and cooling systems. Review the questions for accuracy, and then have students form groups and ask each other their approved questions.

Reteach

Use Figure 12 to review how an internal combustion engine operates during one cycle.

Writing in Science

Student flyers should clearly compare four heating systems. Students may choose to show the comparisons using a chart. Possible columns in the chart are efficiency, physical space used per room, environmental concerns, and local climate. Students may choose to compare systems in different climates. In southern states, a benefit of a forced-air heating system is that it combines easily with central air conditioning. Electric baseboard heating is advantageous in regions where electric power is inexpensive.

If your class subscribes to iText, use it to review key concepts in Section 16.3.

Answer to . . .

Figure 16 The compressor does work by pushing particles of vapor closer together to form a high-pressure vapor. It also does work as it pushes refrigerant through the tubing.

Section 16.3 Assessment

Reviewing Concepts

1. List the two main types of heat engines.
2. How is thermal energy distributed in most heating systems?
3. How does a heat pump move thermal energy from a cold area to a warm area?
4. If the efficiency of a gasoline engine is 25 percent, what happens to the missing 75 percent of the energy in the fuel?

Critical Thinking

5. Predicting A diesel engine runs at a higher temperature than a gasoline engine. Predict which engine would be more efficient. Explain your answer.

6. Applying Concepts Why would it be a mistake to locate a wood-burning stove on the second floor of a two-story house?

Air Conditioners Have you ever been outside on a hot day and stood near a room air conditioner? The air conditioner is actually heating the outdoor air. Near the air conditioner is the last place you’d want to be on a hot day!

Where does the hot air come from? It must come from inside the house. But as you know from the second law of thermodynamics, heat only flows from a lower temperature (indoors) to a higher temperature (outdoors) if work is done on the system.

Figure 16 shows how a room air conditioner operates. The compressor raises the temperature and pressure of the refrigerant, turning it into a hot, high-pressure gas. The temperature of the condenser coil is higher than the outside air temperature, so heat flows spontaneously from the coil to the outside air. A fan increases the rate at which heat flows. As thermal energy is removed from the coil, the refrigerant cools and condenses into a liquid.

The liquid refrigerant then flows through the expansion valve and decreases in temperature. As the cold refrigerant flows through the evaporator coil, it absorbs thermal energy from the warm room air. The fan sends cold air back into the room. The refrigerant becomes a vapor, and the process starts all over again. 

The maximum efficiency of a heat engine increases with a greater difference between the temperature inside and the temperature outside the engine. A diesel engine is likely to be more efficient, assuming both engines discharge thermal energy into an environment at the same temperature.

6. Convection will carry cool air to the lower level so the lower level will be cooler than the upper level. This is inefficient because if the lower level is comfortable, the upper level will be warmer than necessary.