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Grade 7 Science: Heat

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Contents

CONCEPT 1

Thermal Energy

Learning Objectives

- Define thermal energy.
- Relate thermal energy to temperature and mass.

This unusual landscape is found in the hottest place in the U.S.: Death Valley, California. The temperature of the air near the ground can be as high as 57 °C (134 °F)—and that's in the shade (if you can find any)! The temperature of the sand in the baking sun can be much higher. If you were to walk barefoot on the hot sand, it would burn your feet. The air and sand in Death Valley have a lot of thermal energy.

What Is Thermal Energy?

Why do the air and sand of Death Valley feel so hot? It's because their particles are moving very rapidly. Anything that is moving has kinetic energy, and the faster it is moving, the more kinetic energy it has. The total kinetic energy of moving particles of matter is called **thermal energy**. It's not just hot things such as the air and sand of Death Valley that have thermal energy. All matter has thermal energy, even matter that feels cold. That's because the particles of all matter are in constant motion and have kinetic energy.

Thermal Energy, Temperature, and Mass

Thermal energy and temperature are closely related. Both reflect the kinetic energy of moving particles of matter. However, **temperature** is the *average* kinetic energy of particles of matter, whereas thermal energy is the *total* kinetic energy of particles of matter. Does this mean that matter with a lower temperature has less thermal energy than matter with a higher temperature? Not necessarily. Another factor also affects thermal energy. The other factor is mass.

Q: Look at the pot of soup and the tub of water in the **Figure** 1.1. Which do you think has greater thermal energy?

A: The soup is boiling hot and has a temperature of 100 °C, whereas the water in the tub is just comfortably warm, with a temperature of about 38 °C. Although the water in the tub has a much lower temperature, it has greater thermal energy.

FIGURE 1.1

The particles of soup have greater average kinetic energy than the particles of water in the tub, explaining why the soup has a higher temperature. However, the mass of the water in the tub is much greater than the mass of the soup in the pot. This means that there are many more particles of water than soup. All those moving particles give the water in the tub greater total kinetic energy, even though their average kinetic energy is less. Therefore, the water in the tub has greater thermal energy than the soup.

Q: Could a block of ice have more thermal energy than a pot of boiling water?

A: Yes, the block of ice could have more thermal energy if its mass was much greater than the mass of the boiling water.

Summary

- The total kinetic energy of moving particles of matter is called thermal energy.
- The thermal energy of matter depends on how fast its particles are moving on average, which is measured by temperature, and also on how many particles there are, which is measured by mass.

Review

1. Compare and contrast thermal energy and temperature.
2. Explain how an object with a higher temperature can have less thermal energy than an object with a lower temperature.

Resources

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PhET Simulation to visualize thermal energy as it relates to the particle model of matter.

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References

1. left: Simon Doggett; right: Flickr:EscapadaRural. High temperature compared to high thermal energy . CC BY 2.0

CONCEPT 2

Heat

Learning Objectives

- Define heat.
- Explain how thermal energy is transferred.

This chef is taking corn bread out of a hot oven. What happened to the batter when it was put in the oven? Did the hot oven add "heat energy" to the batter? Not exactly. Contrary to popular belief, heat is not a form of energy.

What Is Heat?

Heat is the transfer of thermal energy between substances. Thermal energy is the kinetic energy of moving particles of matter, measured by their temperature. Thermal energy always moves from matter with greater thermal energy to matter with less thermal energy, so it moves from warmer to cooler substances. You can see this in the **Figure** 2.1. Faster-moving particles of the warmer substance bump into and transfer some of their energy to slower-moving particles of the cooler substance. Thermal energy is transferred in this way until both substances have the same thermal energy and temperature.

Q: How is thermal energy transferred in an oven?

A: Thermal energy of the hot oven is transferred to the cooler food, raising its temperature.

Cooling Down by Heating Up

How do you cool down a glass of room-temperature cola? You probably add ice cubes to it, as in the **Figure** 2.2. You might think that the ice cools down the cola, but in fact, it works the other way around. The warm cola heats up the ice. Thermal energy from the warm cola is transferred to the much colder ice, causing it to melt. The cola loses thermal energy in the process, so its temperature falls.

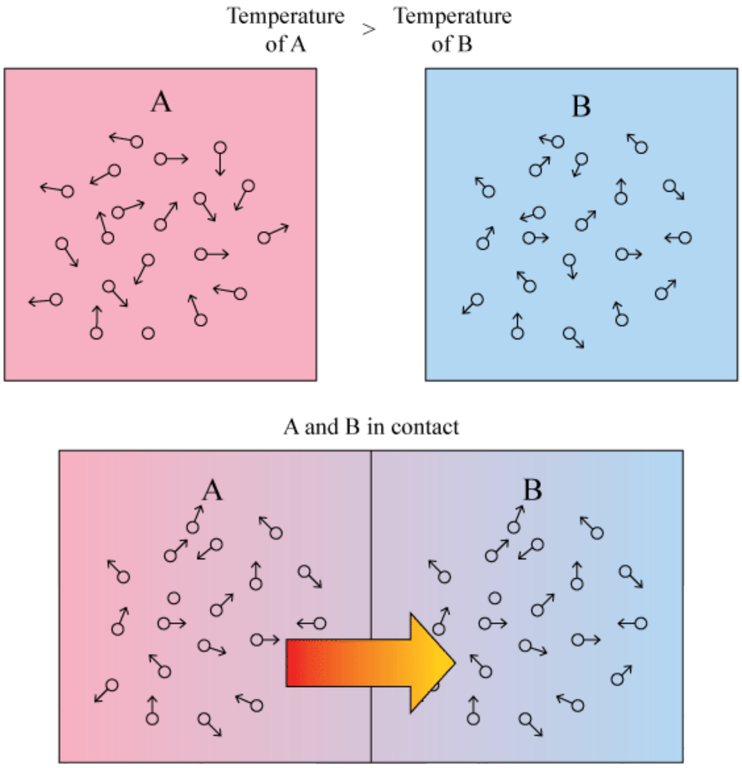


FIGURE 2.1

FIGURE 2.2

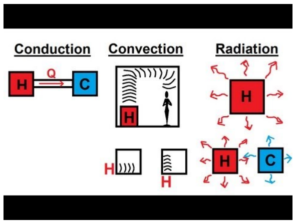
Summary

- Heat is the transfer of thermal energy between substances. Thermal energy is the kinetic energy of moving particles of matter, measured by their temperature.
- Thermal energy always moves from warmer to cooler substances until both substances have the same temperature.

Review

1. Define heat.
2. Describe how thermal energy is transferred.
3. Hot cocoa is poured into a cold mug. Apply the concept of heat to explain what happens next.

Resources



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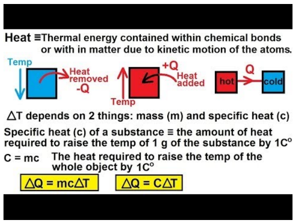
Heat ≡Thermal energy contained within chemical bonds or with in matter due to kinetic motion of the atoms.

ΔT depends on 2 things: mass (m) and specific heat (c)

Specific heat (c) of a substance ≡ the amount of heat required to raise the temp of 1 g of the substance by 1C°

C = mc The heat required to raise the temp of the whole object by 1C°

$\Delta Q = mc\Delta T$ $\Delta Q = C\Delta T$

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References

1. Zachary Wilson. Diagram illustrating transfer of thermal energy . CC BY-NC 3.0
2. Simon Cousins. Ice cubes in cola cause the cola to lose thermal energy . CC BY 2.0

CONCEPT 3

Heat Conduction

Learning Objectives

- Define conduction and explain how it occurs.
- Describe examples of conduction.

Yummy! These cookies look delicious. But watch out! They just finished baking in a hot oven, so the cookie sheet is too hot to handle without an oven mitt. Touching the cookie sheet with bare hands could cause a painful burn. Do you know why? The answer is conduction.

What Is Conduction?

Conduction is the transfer of thermal energy between particles of matter that are touching. Thermal energy is the total kinetic energy of moving particles of matter, and the transfer of thermal energy is called heat. Conduction is one of three ways that thermal energy can be transferred (the other ways are convection and thermal radiation). Thermal energy is always transferred from matter with a higher temperature to matter with a lower temperature.

Pass It On

To understand how conduction works, you need to think about the tiny particles that make up matter. The particles of all matter are in constant random motion, but the particles of warmer matter have more energy and move more quickly than the particles of cooler matter. When particles of warmer matter collide with particles of cooler matter, they transfer some of their thermal energy to the cooler particles. From particle to particle, like dominoes falling, thermal energy moves through matter.

In the opening photo above, conduction occurs between particles of metal in the cookie sheet and anything cooler that comes into contact with it—hopefully, not someone's bare hands!

Examples of Conduction

The cookie sheet in the opening image transfers thermal energy to the cookies and helps them bake. There are many other common examples of conduction. The **Figure** 3.1 shows a few situations in which thermal energy is transferred in this way.

FIGURE 3.1
Hot Iron: A hot iron removes the wrinkles in a shirt. Hot Cocoa: Holding a cup of hot cocoa feels good when you have cold hands. Camp Stove: This camp stove can be used to cook food in a small pot. Snow: Ouch! Can you imagine how cold this snow must feel on bare feet?

Q: How is thermal energy transferred in each of the situations pictured in the **Figure** 3.1?

A: Thermal energy is transferred by conduction from the hot iron to the shirt, from the hot cup to the hand holding it, from the flame of the camp stove to the bottom of the pot as well as from the bottom of the pot to the food inside, and from the feet to the snow. The shirt, hand, pot, food, and snow become warmer because of the transferred energy. Because the feet lose thermal energy, they feel colder.

Summary

- Conduction is the transfer of thermal energy between particles of matter that are touching. Thermal energy is always transferred from particles of warmer matter to particles of cooler matter.
- When particles of warmer matter collide with particles of cooler matter, they transfer some of their thermal energy to the cooler particles.

Review

1. What is conduction?
2. How does conduction occur?
3. Describe an original example of conduction.

Resources

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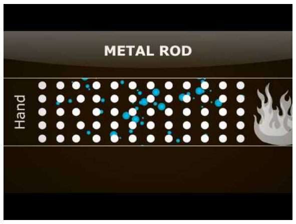

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Click image to the left or use the URL below.

URL: https://www.ck12.org/flx/render/embeddedobject/187455

References

1. Iron: Flickr:osseous; Cold hands: Jason Rogers; Camp stove: Simon Q (Flickr:simononly); Feet in snow: Flickr:woodleywonderworks. Other common examples of conduction . CC BY 2.0

Concept 4

Convection

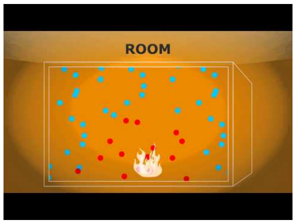
Learning Objectives

- Define convection, and explain how it occurs.
- Describe convection currents.
- Give examples of the transfer of thermal energy by convection.

Do you see the water bubbling in this pot? The water is boiling hot. How does all of the water in the pot get hot when it is heated only from the bottom by the gas flame? The answer is convection.

Defining Convection

Convection is the transfer of thermal energy by particles moving through a fluid (either a gas or a liquid). Thermal energy is the total kinetic energy of moving particles of matter, and the transfer of thermal energy is called heat. Convection is one of three ways that thermal energy can be transferred (the other ways are conduction and thermal radiation). Thermal energy is always transferred from matter with a higher temperature to matter with a lower temperature.



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How Does Convection Occur?

The **Figure** 4.1 shows how convection occurs, using hot water in a pot as an example. When particles in one area of a fluid (in this case, the water at the bottom of the pot) gain thermal energy, they move more quickly, have more collisions, and spread farther apart. This decreases the density of the particles, so they rise up through the fluid. As they rise, they transfer their thermal energy to other particles of the fluid and cool off in the process. With less energy, the particles move more slowly, have fewer collisions, and move closer together. This increases their density, so they sink back down through the fluid. When they reach the bottom of the fluid, the cycle repeats. The result is a loop of moving particles called a **convection current**.

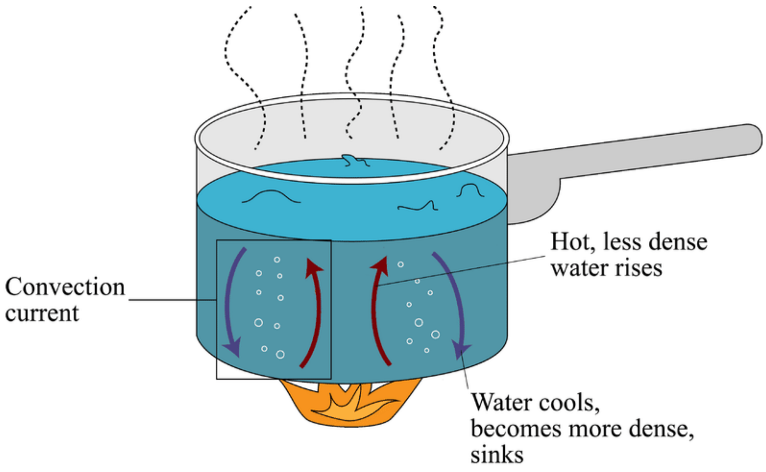


FIGURE 4.1

Examples of Convection

Convection currents transfer thermal energy through many fluids, not just hot water in a pot. For example, convection currents transfer thermal energy through molten rock below Earth's surface, through water in the oceans, and through air in the atmosphere. Convection currents in the atmosphere create winds. You can see one way this happens in the **Figure** 4.2. The land heats up and cools off faster than the water because it has lower specific heat. Therefore, the land gets warmer during the day and cooler at night than the water does. During the day, warm air rises above the land and cool air from the water moves in to take its place. During the night, the opposite happens. Warm air rises above the water and cool air from the land moves out to take its place.

Q: During the day, in which direction is thermal energy of the air transferred? In which direction is it transferred during the night?

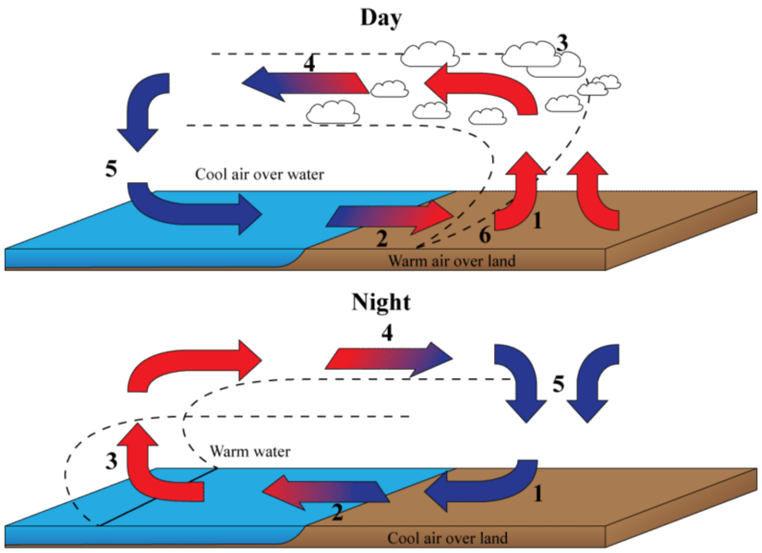


FIGURE 4.2

A: During the day, thermal energy is transferred from the air over the land to the air over the water. During the night, thermal energy is transferred in the opposite direction.

Summary

- Convection is the transfer of thermal energy by particles moving through a fluid. Thermal energy is always transferred from an area with a higher temperature to an area with a lower temperature.
- Moving particles transfer thermal energy through a fluid by forming convection currents.
- Convection currents move thermal energy through many fluids, including molten rock inside Earth, water in the oceans, and air in the atmosphere.

Review

1. What is convection?
2. Describe how convection occurs and why convection currents form.
3. Add arrows representing convection currents to the room in the **Figure** 4.3 to show how thermal energy moves from the radiator to the rest of the room. Label areas of the room that are warm and cool.

References

1. Zachary Wilson. Diagram illustrating how heat is transferred in a boiling pot . CC BY-NC 3.0
2. Zachary Wilson. Diagram illustrating convection currents in an ocean . CC BY-NC 3.0
3. Zachary Wilson. Exercise for drawing direction of convection currents created by a radiator . CC BY-NC 3.0

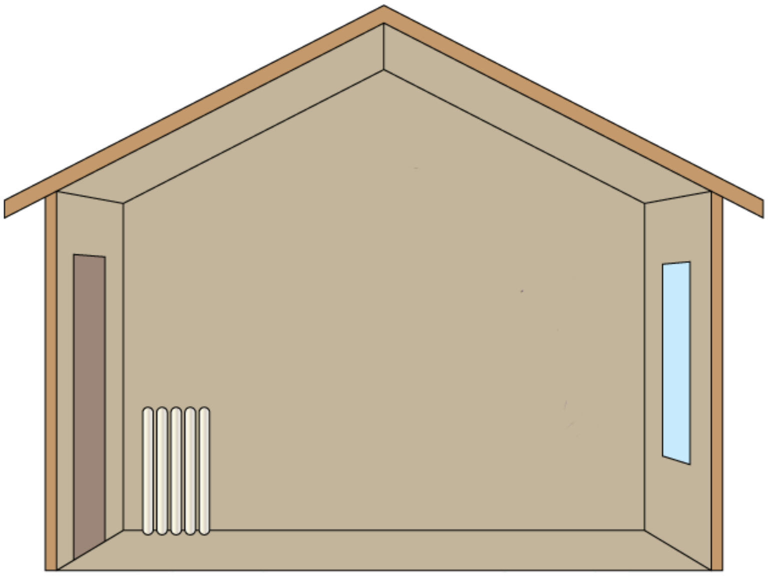


FIGURE 4.3

CONCEPT 5

Thermal Radiation

Learning Objectives

- Describe how thermal energy is transferred by thermal radiation.
- Give examples of thermal radiation.

Someone is warming their hands over a bonfire. They don't have to touch the fire to feel its warmth. How is warmth from the fire transferred to their hands? In this article, you'll find out.

Introducing Thermal Radiation

The bonfire from the opening image has a lot of thermal energy. Thermal energy is the total kinetic energy of moving particles of matter, and the transfer of thermal energy is called heat. Thermal energy from the bonfire is transferred to the hands by thermal radiation. **Thermal radiation** is the transfer of thermal energy by waves that can travel through air or even through empty space, as shown in the **Figure** 5.1. When the waves of thermal energy reach objects, they transfer the energy to the objects, causing them to warm up. This is how the fire warms the hands of someone sitting near the bonfire. This is also how the sun's energy reaches Earth and heats its surface. Without the energy radiated from the sun, Earth would be too cold to support life as we know it.

Thermal radiation is one of three ways that thermal energy can be transferred. The other two ways are conduction and convection, both of which need matter to transfer energy. Radiation is the only way of transferring thermal energy that doesn't require matter.

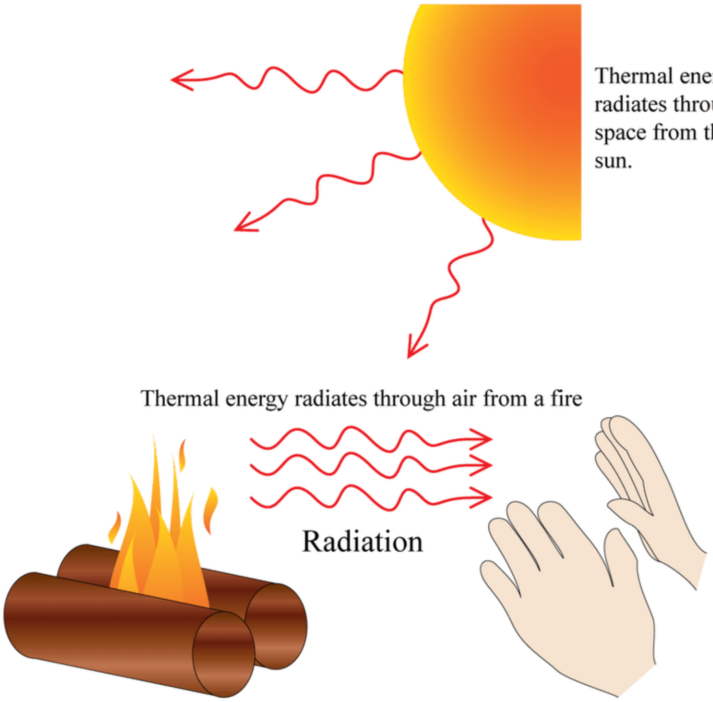


FIGURE 5.1

Sources of Thermal Radiation

You might be surprised to learn that everything radiates thermal energy, not just really hot things such as the sun or a fire. For example, when it's cold outside, a heated home radiates some of its thermal energy into the outdoor environment. A home that is poorly insulated radiates more energy than a home that is well insulated. Special cameras can be used to detect radiated heat. In the **Figure** 5.2, you can see an image created by one of these cameras. The areas that are yellow are the areas where the greatest amount of thermal energy is radiating from the home. Even people radiate thermal energy. In fact, when a room is full of people, it may feel noticeably warmer because of all the thermal energy the people radiate!

Q: Where is thermal radiation radiating from the home in the picture?

A: The greatest amount of thermal energy is radiating from the window on the upper left. A lot of thermal energy is also radiating from the edges of the windows and door.

Summary

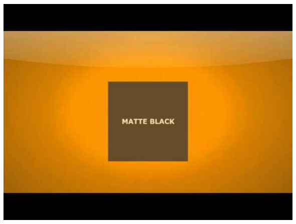
- Thermal radiation is the transfer of thermal energy by waves that can travel through air or even through empty space. This is how thermal energy from a fire is transferred to your hands and how thermal energy from the sun is transferred to Earth.
- Everything radiates thermal energy, even objects that aren't very warm.

Review

1. What is thermal radiation?
2. If you sit close to a campfire, the fire warms you. Describe how thermal energy is transferred from the fire to you.

FIGURE 5.2

Resources



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References

1. Zachary Wilson. Diagram illustrating heat transfer by radiation . CC BY-NC 3.0
2. Janet McKnight. Thermal camera view of house . CC BY 2.0

CONCEPT 6

Thermal Conductors and Insulators

Learning Objectives

- Define and give examples of thermal conductors.
- Describe thermal insulators and ways they are used.

Do you like toast? Did you ever look inside a toaster while it's toasting bread? When you push down the lever to turn on the toaster, the metal heating element inside starts to glow orange or red almost instantly. You can see the glowing heating element inside this yellow toaster. The glowing metal shows that the heating element has become very hot. It gets hot so quickly because metals are good conductors of thermal energy.

Thermal Conductors

Conduction is the transfer of thermal energy between particles of matter that are touching. Thermal conduction occurs when particles of warmer matter bump into particles of cooler matter and transfer some of their thermal energy to the cooler particles. Conduction is usually faster in certain solids and liquids than in gases. Materials that are good conductors of thermal energy are called **thermal conductors**. Metals are especially good thermal conductors because they have freely moving electrons that can transfer thermal energy quickly and easily.

Besides the heating element inside a toaster, another example of a thermal conductor is a metal radiator, like the one in the **Figure** 6.1. When hot water flows through the coils of the radiator, the metal quickly heats up by conduction and then radiates thermal energy into the surrounding air.

Q: Thermal conductors have many uses, but sometimes it's important to prevent the transfer of thermal energy. Can you think of an example?

FIGURE 6.1

A: One example is staying warm on a cold day. You will stay warmer if you can prevent the transfer of your own thermal energy to the outside air.

Thermal Insulators

One way to retain your own thermal energy on a cold day is to wear clothes that trap air. That's because air, like other gases, is a poor conductor of thermal energy. The particles of gases are relatively far apart, so they don't bump into each other or into other things as often as the more closely spaced particles of liquids or solids. Therefore, particles of gases have fewer opportunities to transfer thermal energy. Materials that are poor thermal conductors are called **thermal insulators**. Down-filled snowsuits, like those in the **Figure** 6.2, are good thermal insulators because their feather filling traps a lot of air.

FIGURE 6.2

Another example of a thermal insulator is pictured in the **Figure** 6.3. The picture shows fluffy pink insulation inside the attic of a home. Like the down filling in a snowsuit, the insulation traps a lot of air. The insulation helps to prevent the transfer of thermal energy into the house on hot days and out of the house on cold days. Other materials that are thermal insulators include plastic and wood. That's why pot handles and cooking utensils are often made of these materials. Notice that the outside of the toaster pictured in the opening image is made of plastic. The plastic casing helps prevent the transfer of thermal energy from the heating element inside to the outer surface of the toaster where it could cause burns.

Q: Thermal insulators have many practical uses besides the uses mentioned above. Can you think of others?

Home insulation looks a little like cotton candy. Like cotton candy, it is light and fluffy and full of tiny holes that trap air.

FIGURE 6.3

A: Thermal insulators are often used to keep food or drinks hot or cold. For example, Styrofoam® coolers and thermos containers are used for these purposes.

Summary

- Materials that are good conductors of thermal energy are called thermal conductors. Metals are very good thermal conductors.
- Materials that are poor conductors of thermal energy are called thermal insulators. Gases such as air and materials such as plastic and wood are thermal insulators.

Review

1. What is a thermal conductor? Give an example.
2. Why do metals often feel cool to the touch?
3. Define thermal insulator. Describe one way thermal insulators are used.

Resources

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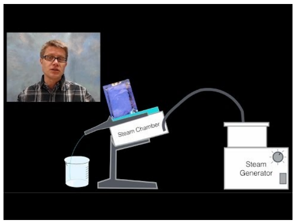

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References

1. Dominic Alves. Metal radiators quickly heatup . CC BY 2.0
2. Skiers: Image copyright Anna Chelnokova, 2014; Feathers: Image copyright Gertan, 2014. Insulators help snowsuits keep heat in . Used under license from Shutterstock.com
3. Image copyright V. J. Matthew, 2014. Home insulation helps reduce unwanted heat loss . Used under license from Shutterstock.com

CONCEPT 7 Temperature

Learning Objectives

- Define temperature.
- Explain how temperature is measured and how a thermometer works.
- Describe three temperature scales, and show how to convert temperatures from one scale to another.

This girl has a fever, and it makes her feel miserable. She feels achy and really tired. She also feels hot because her temperature is higher than normal. She has a thermometer in her mouth to measure her temperature.

What Is Temperature?

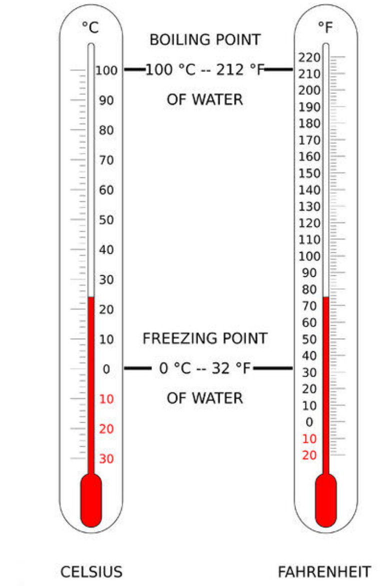
No doubt you already have a good idea of what temperature is. You might say that it's how warm or cool something feels. In physics, **temperature** is defined as the average kinetic energy of the particles of matter. When particles of matter move more quickly, they have more kinetic energy, so their temperature is higher. With a higher temperature, matter feels warmer. When particles move more slowly, they have less kinetic energy on average, so their temperature is lower. With a lower temperature, matter feels cooler.

How Thermometers Measure Temperature

Many thermometers measure temperature with a liquid that expands when it gets warmer and contracts when it gets cooler. Look at the common household thermometer pictured in the **Figure** 7.1. The red liquid rises or falls in the glass tube as the temperature changes. Temperature is read off the scale at the height of the liquid in the tube.

Q: Why does the liquid in the thermometer expand and contract when temperature changes?

A: When the temperature is higher, particles of the liquid have greater kinetic energy, so they move about more and spread apart. This causes the liquid to expand. The opposite happens when the temperature is lower and particles of liquid have less kinetic energy. The particles move less and crowd closer together, causing the liquid to contract.



The red liquid in the thermometer is alcohol. Alcohol expands uniformly over a wide range of temperatures. This makes it ideal for use in thermometers.

FIGURE 7.1

Temperature Scales

The thermometer pictured in the **Figure** 7.1 measures temperature on two different scales: Celsius (C) and Fahrenheit (F). Although some scientists use the Celsius scale, the SI scale for measuring temperature is the **Kelvin scale**. If you live in the U.S., you are probably most familiar with the Fahrenheit scale. The **Table** 7.1 compares all three temperature scales. Each scale uses as reference points the freezing and boiling points of water. Notice that temperatures on the Kelvin scale are not given in degrees (°).

TABLE 7.1: Temperature Scales

Scale	**Freezing Point of Water**	**Boiling Point of Water**
Kelvin	273 K	373 K
Celsius	0 °C	100 °C
Fahrenheit	32 °F	212 °F

Because all three temperature scales are frequently used, it's useful to know how to convert temperatures from one scale to another. It's easy to convert temperatures between the Kelvin and Celsius scales. Each 1-degree change on the Kelvin scale is equal to a 1-degree change on the Celsius scale. Therefore, to convert a temperature from Celsius to Kelvin, just add 273 to the Celsius temperature. For example, 10 °C equals 283 Kelvin.

Q: How would you convert a temperature from Kelvin to Celsius?

A: You would subtract 273 from the Kelvin temperature. For example, a temperature of 300 Kevin equals 27 °C.

Converting between Celsius and Fahrenheit is more complicated. The following conversion factors can be used:

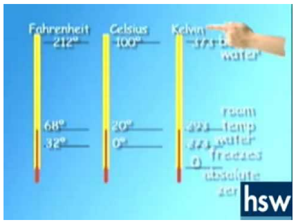
$$\textit{Celsius} \rightarrow \textit{Fahrenheit}: (^\circ\text{C} \times 1.8) + 32 = {}^\circ\text{F}$$
$$\textit{Fahrenheit} \rightarrow \textit{Celsius}: (^\circ\text{F} - 32) \div 1.8 = {}^\circ\text{C}$$

For example, to convert 10 °C to Fahrenheit, use the first conversion factor:

$$(10\ ^\circ\text{C} \times 1.8) + 32 = 50\ ^\circ\text{F}$$

3. Assume that the temperature outside is 293 Kelvin but you're familiar only with the Fahrenheit scale. Do you need to wear a hat and gloves when you go outside? To find out, convert the Kelvin temperature to Fahrenheit. (Hint: Convert the Kelvin temperature to Celsius first.)

Resources



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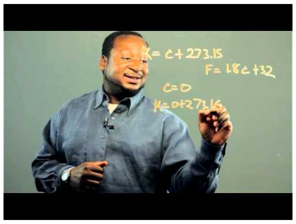

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References

1. User:Gringer/Wikimedia Commons. Illustration of a thermometer . Public Domain

CONCEPT 8 Heat Capacity and Specific Heat

Learning Objectives

- Define heat capacity.
- Define specific heat.
- Perform calculations involving specific heat.

Which pool will warm up faster?

If a swimming pool and wading pool, both full of water at the same temperature were subjected to the same input of heat energy, the wading pool would certainly rise in temperature more quickly than the swimming pool. The heat capacity of an object depends both on its mass and its chemical composition. Because of its much larger mass, the swimming pool of water has a larger heat capacity than the bucket of water.

Heat Capacity and Specific Heat

Different substances respond to heat in different ways. If a metal chair sits in the bright sun on a hot day, it may become quite hot to the touch. An equal mass of water in the same sun will not become nearly as hot. We would say that water has a high **heat capacity** (the amount of heat required to raise the temperature of an object by 1°C.) Water is very resistant to changes in temperature, while metals in general are not. The **specific heat** of a substance is the amount of energy required to raise the temperature of 1 gram of the substance by 1°C. **Table** 8.1 lists the specific heats of some common substances. The symbol for specific heat is c_p, with the p subscript referring to the fact that specific heats are measured at constant pressure. The units for specific heat can either be joules per gram per degree (J/g°C) or calories per gram per degree (cal/g°C). This text will use J/g°C for specific heat.

TABLE 8.1: Specific Heats of Some Common Substances

Substance	**Specific Heat (J/g°C)**
Water (l)	4.18
Water (s)	2.06
Water (g)	1.87
Ammonia (g)	2.09
Ethanol (l)	2.44

TABLE 8.1: (continued)

Aluminum (s)	0.897
Carbon, graphite (s)	0.709
Copper (s)	0.385
Gold (s)	0.129
Iron (s)	0.449
Lead (s)	0.129
Mercury (l)	0.140
Silver (s)	0.233

Notice that water has a very high specific heat compared to most other substances. Water is commonly used as a coolant for machinery because it is able to absorb large quantities of heat (see **Table** 8.1). Coastal climates are much more moderate than inland climates because of the presence of the ocean. Water in lakes or oceans absorbs heat from the air on hot days and releases it back into the air on cool days.

FIGURE 8.1

This power plant in West Virginia, like many others, is located next to a large lake so that the water from the lake can be used as a coolant. Cool water from the lake is pumped into the plant, while warmer water is pumped out of the plant and back into the lake.

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Summary

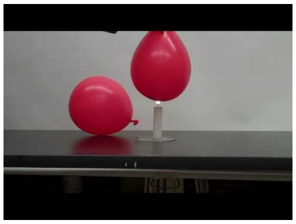
- Heat capacity and specific heat are defined.

Review

1. What is heat capacity?
2. What is specific heat?
3. You have a 10 gram piece of aluminum and a 10 gram piece of gold sitting in the sun. Which metal will warm by ten degrees first?
4. You have a 20 gram piece of aluminum and a 40 gram piece of aluminum sitting in the sun. Which piece will arm by ten degrees first?

Explore More

Use the resource below to answer the questions that follow.



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1. What was in the first balloon?
2. What was in the send balloon?
3. Why did the first balloon not burst?
4. Why did the second balloon burst?

Vocabulary

- **heat capacity:** The amount of heat required to raise the temperature of an object by 1°C.
- **specific heat:** The amount of energy required to raise the temperature of 1 gram of the substance by 1°C.

References

1. Swimming pool: User:Mhsb/Wikimedia Commons; Wading pool: User:Aarchiba/Wikipedia. Swimming pool: http://commons.wikimedia.org/wiki/File:Freshwater_swimming_pool.jpg; Wading pool: http://commons.wikimedia.org/wiki/File:Wading-pool.jpg .
2. User:Raeky/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Mount_Storm_Power_Plant,_-Areial.jpg .

CONCEPT 9

Heating Systems

Learning Objectives

- State the function of a home heating system.
- Explain how hot-water and warm-air heating systems work.

A roaring blaze in a fireplace is a good way to keep toes toasty on a cold winter day. But you probably wouldn't use a fireplace to heat an entire house. Do you know how your home is heated?

Heating the Home

Modern home heating systems keep us comfortable in cold weather. We may even depend on them for our survival. But we often take them for granted. Two common types of home heating systems are hot-water and warm-air heating systems. Both types are described below.

Thermal energy is the total energy of moving particles of matter. The transfer of thermal energy is called heat. Therefore, a heating system is a system for the transfer of thermal energy. Regardless of the type of heating system in a home, the basic function is the same: to produce thermal energy and transfer it to air throughout the house.

Hot-Water Heating System

A hot-water heating system produces thermal energy to heat water and then pumps the hot water throughout the building in a system of pipes and radiators. You can see a simple diagram of this type of heating system in the **Figure** 9.1.

- Water is heated in a boiler that burns a fuel such as natural gas or heating oil. The boiler converts the chemical energy stored in the fuel to thermal energy.

- The heated water is pumped from the boiler through pipes and radiators throughout the house. There is usually a radiator in each room. The radiators get warm when the hot water flows through them.
- The warm radiators radiate thermal energy to the air around them. The warm air then circulates throughout the rooms in convection currents.
- The hot water cools as it flows through the system and transfers its thermal energy. When it finally returns to the boiler, it is heated again and the cycle repeats.

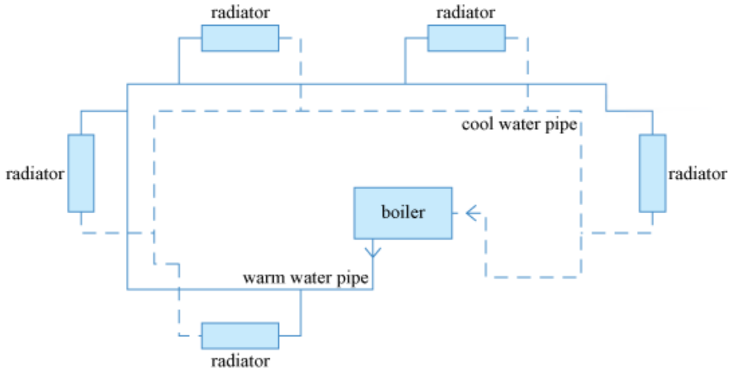


FIGURE 9.1

Q: Look closely at the hot-water heating system in the **Figure** 9.1. The radiator is a coiled pipe through which hot water flows. What happens to the water as it flows through the radiator? Why is each radiator connected to two pipes? Why can't water flow directly from one radiator to another through a single pipe?

A: The radiator is where most of the energy transfer occurs. Water passes through such a great length of pipe in the radiator that it transfers a lot of thermal energy to the radiator. As the water transfers thermal energy, it gets cooler. The cool water flows into a return pipe rather than going directly to another radiator because the cool water no longer has enough thermal energy to heat a room.

Warm-Air Heating System

A warm-air heating system uses thermal energy to heat air and then forces the warm air through a system of ducts and registers. You can see a this type of heating system in the **Figure** 9.2.

- The air is heated in a furnace that burns fuel such as natural gas, propane, or heating oil.
- After the air gets warm, a fan blows it through the ducts and out through the registers that are located in each room.
- Warm air blowing out of a register moves across the room, pushing cold air out of the way.
- The cold air enters a return register across the room and returns to the furnace with the help of another fan.
- In the furnace, the cold air is heated, and the cycle repeats.

Q: How does a home heating system "know" when to run and when to stop running?

A: A home heating system is turned on or off by a thermostat.

How a Thermostat Works

A **thermostat**, like the one seen in the **Figure** 9.3, is an important part of any home heating system. It is like the "brain" of the entire system. It constantly monitors the temperature in the home and "tells" the boiler or furnace

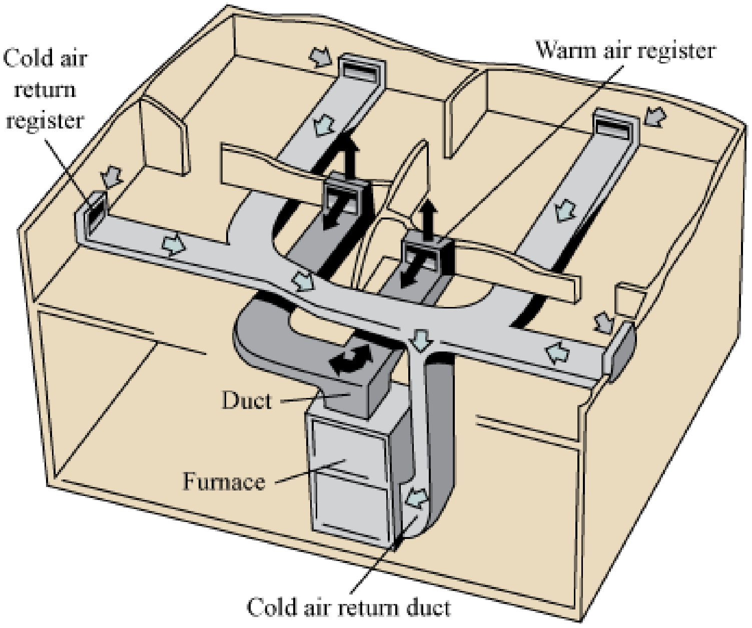


FIGURE 9.2
Warm-air heating system.

when to turn on or off. The thermostat is set at a selected temperature, say 71 °F. When the temperature in the home starts to fall below this point, the thermostat triggers the boiler or furnace to start running. When the temperature starts to rise above this point, the thermostat triggers the boiler or furnace to stop running. In this way, the thermostat maintains the home's temperature at the set point.

FIGURE 9.3

Summary

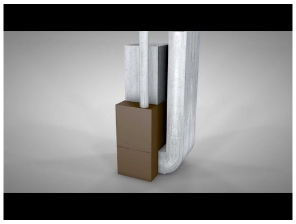
- Types of home heating systems include hot-water, warm-air, and solar heating systems. All of them have the same basic function: producing thermal energy and transferring it to air throughout the house.
- A hot-water heating system burns fuel in a boiler to produce thermal energy. The thermal energy is used to heat water, which is pumped through a system of pipes and radiators.

- A warm-air heating system burns fuel in a furnace to produce thermal energy. The thermal energy is used to heat air, which is forced through a system of ducts and registers.
- A thermostat controls a home heating system. It monitors the home's temperature and triggers the boiler or furnace to turn on or off to keep the temperature at a set point.

Review

1. What is the basic function of any home heating system?
2. Create a table comparing and contrasting hot-water and forced-air heating systems.
3. Try to identify the type of heating system (if any) where you live.

Resources



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References

1. Zachary Wilson. Schematic of a warm water heating system . CC BY-NC 3.0
2. Zachary Wilson. Warm air heating system . CC BY-NC 3.0
3. Image copyright Danylo Samiylenko, 2014. Thermostats help regulate temperature . Used under license from Shutterstock.com

CONCEPT 10 Cooling Systems

Learning Objectives

- State the purpose of a cooling system.
- Explain how a refrigerator works.
- Describe the role of the refrigerant in a cooling system

A refrigerator door makes a great message center. Its smooth metal surface is perfect for sticky notes and magnets. In most homes, a refrigerator is one of the hardest working appliances, but not just because it holds messages. Unlike most other home appliances, a refrigerator generally runs nonstop every day of the year. Can you think of another home appliance that gets such constant use?

Purpose of a Cooling System

A refrigerator is an example of a cooling system. Another example is an air conditioner. The purpose of any cooling system is to transfer thermal energy in order to keep things cool. A refrigerator, for example, transfers thermal energy from the cool air inside the refrigerator to the warm air in the kitchen. If you've ever noticed how warm the back of a running refrigerator gets, then you know that it releases a lot of thermal energy into the room.

Q: Thermal energy always moves from a warmer area to a cooler area. How can thermal energy move from the cooler air inside a refrigerator to the warmer air in a room?

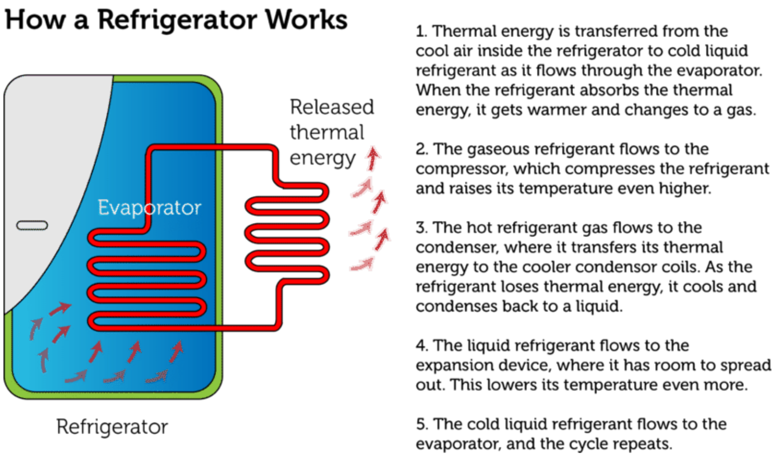
A: The answer is work.

How a Refrigerator Works

A refrigerator must do work to reverse the normal direction of thermal energy flow. Work involves the use of force to move something, and doing work takes energy. In a refrigerator, the energy is usually provided by electricity. You can read in detail in the **Figure** 10.1 how a refrigerator does its work.

The Refrigerant

The key to how a refrigerator or other cooling system works is the refrigerant. A **refrigerant** is a substance such as FreonTM that has a low boiling point and changes between liquid and gaseous states as it passes through the refrigerator. As a liquid, the refrigerant absorbs thermal energy from the cool air inside the refrigerator and changes to a gas. As a gas, it transfers thermal energy to the warm air outside the refrigerator and changes back to a liquid. Work is done by a refrigerator to move the refrigerant through the different components of the refrigerator.



1. Thermal energy is transferred from the cool air inside the refrigerator to cold liquid refrigerant as it flows through the evaporator. When the refrigerant absorbs the thermal energy, it gets warmer and changes to a gas.

2. The gaseous refrigerant flows to the compressor, which compresses the refrigerant and raises its temperature even higher.

3. The hot refrigerant gas flows to the condenser, where it transfers its thermal energy to the cooler condensor coils. As the refrigerant loses thermal energy, it cools and condenses back to a liquid.

4. The liquid refrigerant flows to the expansion device, where it has room to spread out. This lowers its temperature even more.

5. The cold liquid refrigerant flows to the evaporator, and the cycle repeats.

FIGURE 10.1

Summary

- The purpose of a cooling system such as a refrigerator or air conditioner is to transfer thermal energy in order to keep things cool.
- A refrigerator transfers thermal energy from the cool air inside the refrigerator to the warm air in the kitchen. Thermal energy normally moves from a warmer area to a cooler area, so a refrigerator must do work to reverse the normal direction of heat flow.
- The key to how a refrigerator or other cooling system works is the refrigerant. A refrigerant is a substance with a low boiling point that changes between liquid and gaseous states as it passes through the refrigerator.

Review

1. What is the purpose of a cooling system? What are examples of cooling systems?
2. Outline how a refrigerator works.
3. What is a refrigerant? Why is it the key to how a cooling system works?

Resources

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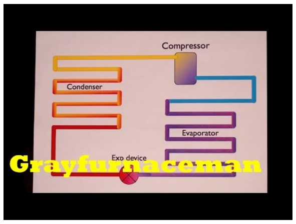

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References

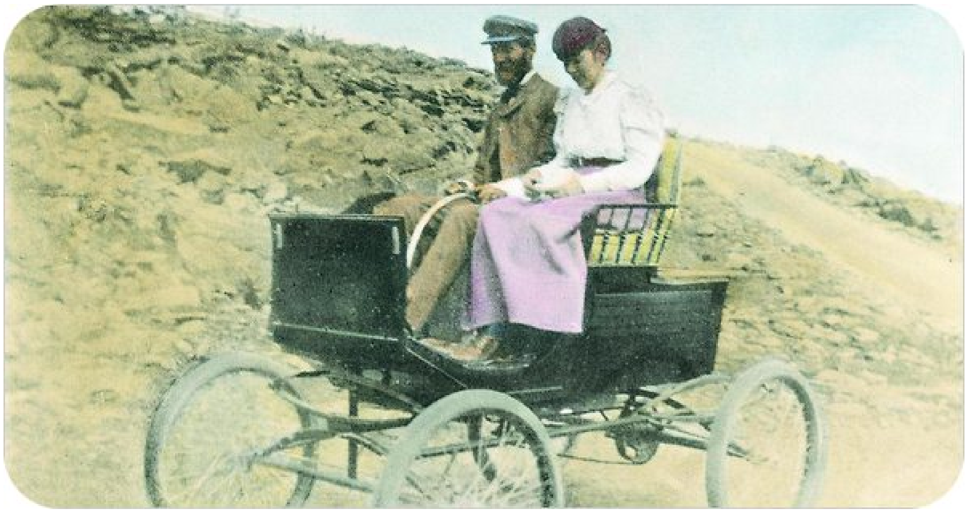
1. Christopher Auyeung. Diagram illustrating how a refrigerator works . CC BY-NC 3.0

CONCEPT 11

External Combustion Engines

Learning Objectives

- Identify the purpose of a combustion engine.
- Define external combustion engine.
- Outline how an external combustion engine works.



This picture was taken in 1899 (the color was added later). The picture shows the inventor of an early automobile, along with his wife, driving one of his inventions. The man and woman were on their way to the top of Mount Washington, the highest mountain in the eastern U.S. The purpose of the trip up the mountain was to get publicity for the steam-powered automobile. The inventor and his wife were the first people to ever reach the top of the mountain by car. Steam engines are not used very much anymore, because more efficient and powerful engines have been developed. But inventors and engineers learned a lot from these early combustion engines.

Q: How else were steam engines used?

A: Starting in the 1700s and up until the early 1900s, steam engines were commonly used to run factory machines, train locomotives, and ships. Their power led to a revolution in industry and transportation.

What Is a Combustion Engine?

A **combustion engine** is a complex machine that burns fuel to produce thermal energy and then uses the thermal energy to do work. There are two types of combustion engines: external and internal. A steam engine is an external combustion engine.

How External Combustion Engines Work

An **external combustion engine** burns fuel externally, or outside the engine. The burning fuel releases thermal energy, which is used to heat water and change it to steam. The pressure of the steam moves a piston back and forth

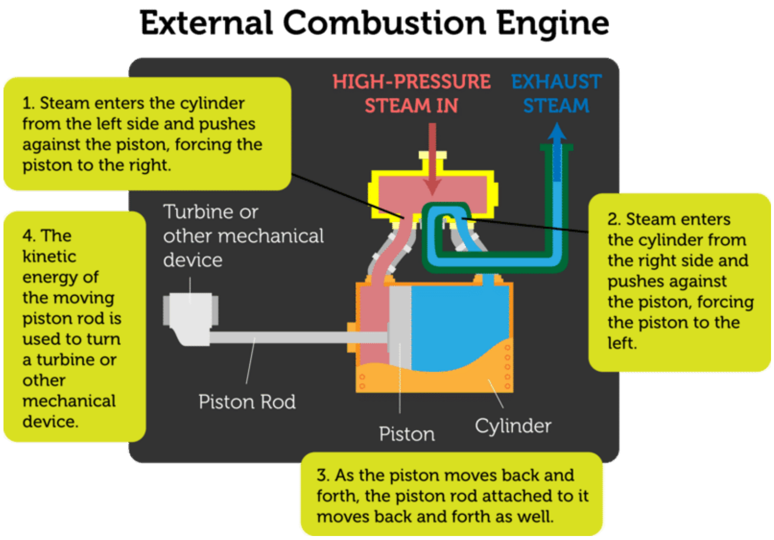


FIGURE 11.1

inside a cylinder. The kinetic energy of the moving piston can be used to turn a vehicle's wheels, a turbine, or other mechanical device. The **Figure** 11.1 explains in greater detail how this type of engine works.

Q: What type of energy does the piston have when it moves back and forth inside the cylinder?

A: Like anything else that is moving, the moving piston has kinetic energy.

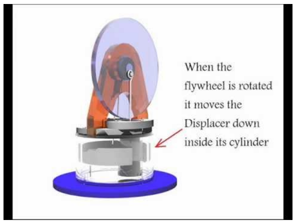
Summary

- A combustion engine is a complex machine that burns fuel to produce thermal energy and then uses the thermal energy to do work.
- An external combustion engine burns fuel externally, or outside the engine.
- An external combustion engine burns fuel to heat water and produce steam. The steam is under pressure and is used to push a piston back and forth inside a cylinder. As the piston moves back and forth, it moves a piston rod, which can do work.

Review

1. Define combustion engine.
2. What is an external combustion engine?
3. Explain how an external combustion engine works.

Resources



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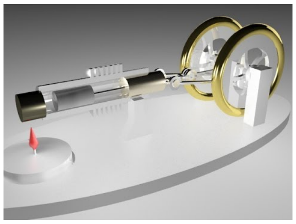

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References

1. Christopher Auyeung. Diagram illustrating how an external combustion engine works . CC BY-NC 3.0

CONCEPT 12

Internal Combustion Engines

Learning Objectives

- Define combustion engine and internal combustion engine.
- Explain how an internal combustion engine works.
- Describe how kinetic energy from an internal combustion engine is used to turn the wheels of a car.

This race car isn't really burning up the road. The flames were added digitally to suggest that the car is zooming down the road at a high rate of speed. A race car can move so fast because it has a powerful combustion engine.

Introducing Combustion Engines

A **combustion engine** is a complex machine that burns fuel to produce thermal energy and then uses the energy to do work. In a car, the engine does the work of providing kinetic energy that turns the wheels. The combustion engine in a car is a type of engine called an internal combustion engine. (Another type of combustion engine is an external combustion engine.)

How Internal Combustion Engines Work

An **internal combustion engine** burns fuel internally, or inside the engine. This type of engine is found not only in cars but in most other motor vehicles as well. The engine works in a series of steps, which keep repeating. You can follow the steps in the **Figure** 12.1.

1. A mixture of fuel and air is pulled-into a cylinder through a valve, which then closes.
2. A piston inside the cylinder moves upward, compressing the fuel-air mixture in the closed cylinder. The mixture is now under a lot of pressure and very warm.
3. A spark from a spark plug ignites the fuel-air mixture, causing it to burn explosively within the confined space of the closed cylinder.
4. The pressure of the hot gases from combustion pushes the piston downward.
5. The piston moves up again, pushing exhaust gases out of the cylinder through another valve.
6. The piston moves downward again, and the cycle repeats.

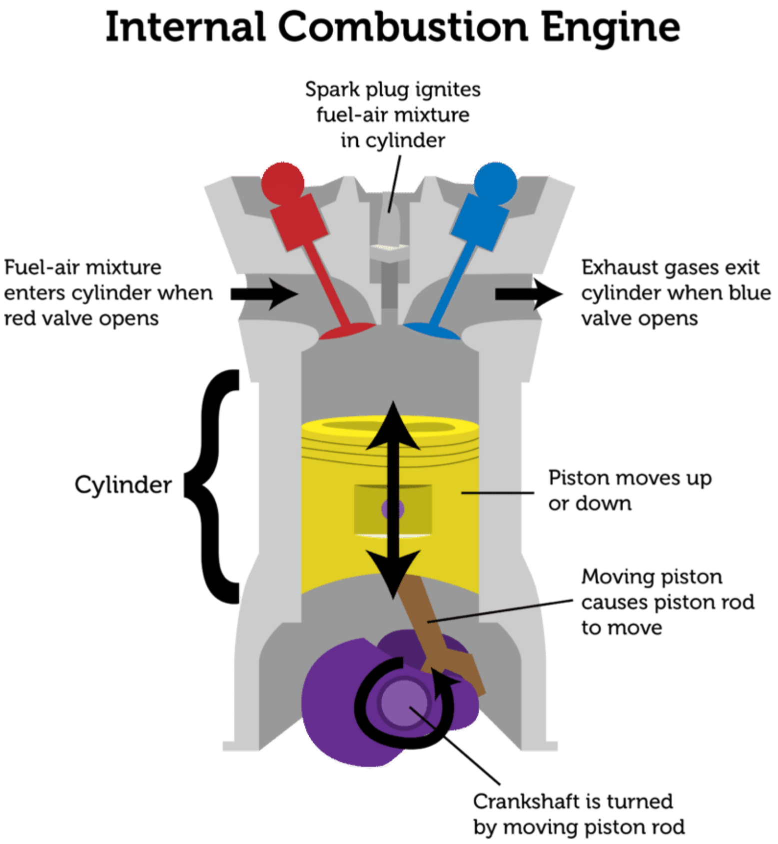

FIGURE 12.1

Q: The internal combustion engine converts thermal energy to another form of energy. Which form of energy is it?

A: The engine converts thermal energy to kinetic energy, or the energy of a moving object—in this case, the moving piston.

How Energy from the Engine Turns the Wheels

In a car, the piston in the engine is connected by the piston rod to the crankshaft. The crankshaft rotates when the piston moves up and down. The crankshaft, in turn, is connected to the driveshaft. When the crankshaft rotates, so does the driveshaft. The rotating driveshaft turns the wheels of the car.

How Many Cylinders?

Most cars have at least four cylinders connected to the crankshaft. Their pistons move up and down in sequence, one after the other. A powerful car may have eight pistons, and some race cars may have even more. The more cylinders a car engine has, the more powerful its engine can be.

Summary

- A combustion engine is a complex machine that burns fuel to produce thermal energy and then uses the energy to do work. An internal combustion engine burns fuel internally, or inside the engine.
- In an internal combustion engine, a mixture of fuel and air is burned in a closed cylinder, forcing a piston to move up and down.
- In a car, the moving piston rotates a crankshaft, which turns a driveshaft. The turning driveshaft causes the wheels of the car to turn.

Review

1. What is a combustion engine? What is an internal combustion engine?
2. Explain how an internal combustion engine works.
3. Describe how kinetic energy from a car engine is used to turn the wheels of the car.

Resources

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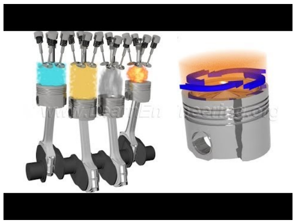

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References

1. Christopher Auyeung. Diagram illustrating the operation of an internal combustion engine . CC BY-NC 3.0