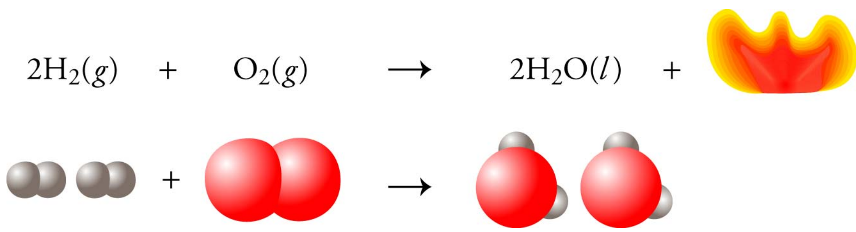
Chapter 8
Energy and Chemical Reactions



Section Goals and Introductions

Section 8.1 Energy

Goals

- *To introduce the terms energy, kinetic energy, and potential energy.*
- *To introduce the Law of Conservation of Energy.*
- *To describe the relationships between stability, capacity to do work, and potential energy.*
- *To explain why breaking chemical bonds requires energy and why the formation of chemical bonds releases energy.*
- *To show how energy can be classified as kinetic energy or potential energy.*
- *To describe the units used to describe energy: joules, calories, and dietary calories.*
- *To describe internal kinetic energy, temperature, and heat.*
- *To describe radiant energy.*

Chemical changes are accompanied by energy changes. This section begins to develop your understanding of this relationship by introducing some important terms that relate to energy. An understanding of what potential energy is and how it is related to stability is probably the most important (and perhaps the most difficult) part of this section. Understanding potential energy will help you to understand why energy is absorbed in the breaking of chemical bonds and why it is released in the making of chemical bonds. Be sure that you understand the distinctions between kinetic energy and potential energy and between internal kinetic energy and heat energy. The section ends with a description of radiant energy, including descriptions of what it is, how it is described, and what its different forms are.

Section 8.2 Chemical Changes and Energy

Goals

- *To describe the relationship between energy and chemical reactions.*
- *To explain why some chemical changes release energy as they proceed and why others need to absorb energy to take place.*

This section uses what you have learned in Section 8.1 to explain why some chemical reactions absorb heat energy from their surroundings and why others release heat energy to their surroundings.

Section 8.3 Ozone: Pollutant and Protector

Goals

- *To describe why ozone is a pollutant in the lower atmosphere and why it helps to protect us from potentially harmful radiant energy when it is in the stratosphere.*
- *To describe how ozone is created in the lower atmosphere and to explain why it is created in greater quantities in large industrial cities with lots of cars and lots of sun.*

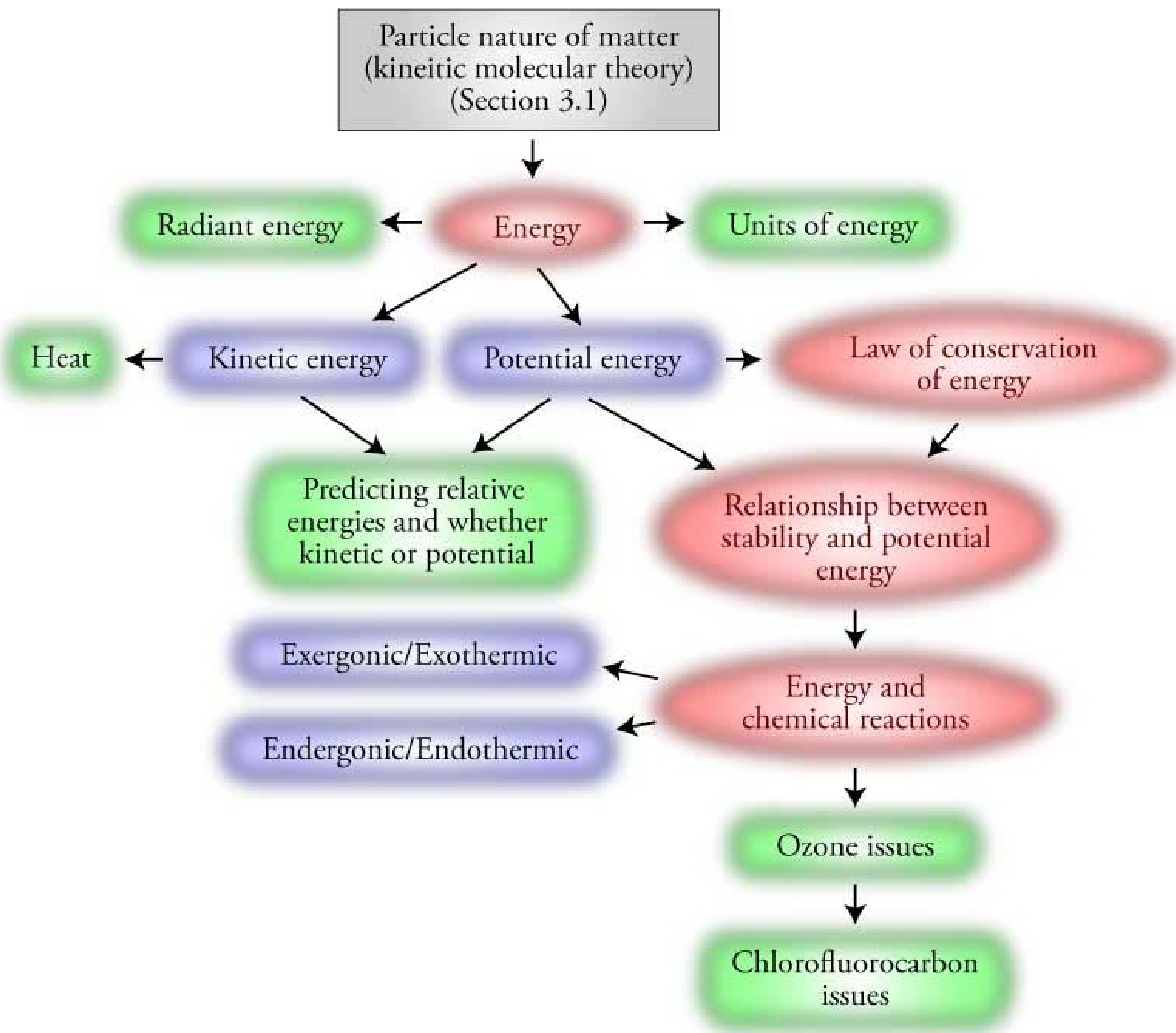
Because the issues relating to ozone are so important, this section is dedicated to explaining why ozone is either a pollutant or a protector, depending on where it is found. You will discover why the levels of the pollutant ozone are much higher in Los Angeles than in other places in the United States and why we are concerned by decreased levels of ozone in the stratosphere.

Section 8.4 Chloroflurocarbons: A Chemical Success Story Gone Wrong

Goal: To describe what chlorofluorocarbons (CFCs) are and explain how they are thought to destroy ozone in the stratosphere.

This section continues the ozone story by describing how chlorofluorocarbons (CFCs) (used as aerosol propellants, solvents, expansion gases in foams, heat-exchanging fluids in air conditioners, and temperature-reducing fluids in refrigerators) can destroy the ozone molecules in the stratosphere that help to protect us from high-energy ultraviolet radiation. More information on this topic can be found on our Web site in a section called *Ozone and CFCs*.

Chapter 8 Map



Chapter Checklist

- ☐ Read the Review Skills section. If there is any skill mentioned that you have not yet mastered, review the material on that topic before reading this chapter.
- ☐ Read the chapter quickly before the lecture that describes it.
- ☐ Attend class meetings, take notes, and participate in class discussions.
- ☐ Work the Chapter Exercises, perhaps using the Chapter Examples as guides.
- ☐ Study the Chapter Glossary and test yourself at the textbook's Web site.
  Internet: Glossary Quiz
- ☐ Study all of the Chapter Objectives. You might want to write a description of how you will meet each objective. (Although it is best to master all of the objectives, the following objectives are especially important because they pertain to skills that you will need while studying other chapters of this text: 5, 7, 8, and 22.)
- ☐ To get a review of the most important topics in the chapter, fill in the blanks in the Key Ideas section.
- ☐ Work all of the selected problems at the end of the chapter, and check your answers with the solutions provided in this chapter of the study guide.
- ☐ Ask for help if you need it.

Web Resources

Internet: Glossary Quiz

Exercises Key

✍ **Exercise 8.1 - Energy:** For each of the following situations, you are asked which of two objects or substances has greater energy. Explain your answer with reference to the capacity of each to do work, and indicate whether the energy that distinguishes them is kinetic energy or potential energy.

a. Nitric acid molecules, HNO_3, in the upper atmosphere decompose to form HO molecules and NO_2 molecules by the breaking of a bond between the nitrogen atom and one of the oxygen atoms. Which has greater energy, a nitric acid molecule or the HO molecule and NO_2 molecule that come from its decomposition?

$$HNO_3(g) \rightarrow HO(g) + NO_2(g)$$

HO and NO_2 have higher potential energy than HNO_3. Separated atoms are less stable and have higher potential energy than atoms in a chemical bond, so energy is required to break a chemical bond. Thus energy is required to separate the nitrogen and oxygen atoms being held together by mutual attraction in a chemical bond. The energy supplied goes to an increased potential energy of the separated HO and NO_2 molecules compared to HNO_3. If the bond is reformed, the potential energy is converted into a form of energy that could be used to do work.

b. Nitrogen oxides, NO(g) and NO_2(g), are released into the atmosphere in the exhaust of our cars. Which has greater energy, an NO_2 molecule moving at 439 m/s or the same NO_2 molecule moving at 399 m/s? (These are the average velocities of NO_2 molecules at 80 °C and 20 °C, respectively.)

A nitrogen dioxide molecule with a velocity of 439 m/s has greater kinetic energy than the same molecule with a velocity of 399 m/s. Any object in motion can collide with another object and move it, so any object in motion has the capacity to do work. This capacity to do work resulting from the motion of an object is called kinetic energy, KE. The particle with the higher velocity will move another object (such as another molecule) farther, so it can do more work. It must therefore have more energy.

c. Which has greater energy, a nitrogen monoxide molecule, NO, emitted from your car's tail pipe at 450 m/s or a nitrogen dioxide molecule, NO_2, moving at the same velocity?

The more massive nitrogen dioxide molecule has greater kinetic energy than the less massive nitrogen monoxide molecule with the same velocity. The moving particle with the higher mass can move another object (such as another molecule) farther, so it can do more work. It must therefore have more energy.

d. Liquid nitrogen is used for a number of purposes, including the removal (by freezing) of warts. Assume that the temperature remains constant. Which has greater energy, liquid nitrogen or gaseous nitrogen?

Gaseous nitrogen has higher potential energy than liquid nitrogen. When nitrogen goes from liquid to gas, the attractions that link the N_2 molecules together are broken. The energy that the nitrogen liquid must absorb to break these attractions goes to an increased potential energy of the nitrogen gas. If the nitrogen returns to the liquid form, attractions are re-formed, and potential energy is converted into a form of energy that could be used to do work.

e. Halons, such as halon-1301 (CF_3Br) and halon-1211 (CF_2ClBr), which have been used as fire-extinguishing agents, are a potential threat to Earth's protective ozone layer, partly because they lead to the production of $BrONO_2$ in the upper atmosphere. Which has greater energy, separate BrO and NO_2 molecules or the $BrONO_2$ that they form?

Separate BrO and NO_2 molecules have a higher potential energy than the $BrONO_2$ molecule that they form. Atoms in a chemical bond are more stable and have lower potential energy than separated atoms, so energy is released when chemical bonds form. When BrO and NO_2 are converted into $BrONO_2$, a new bond is formed, and some of the potential energy of the BrO and NO_2 is released. The energy could be used to do some work. For example, if some of the potential energy is converted into increased kinetic energy of a molecule such as N_2, the faster moving molecule could bump into something and move it and therefore do work.

$$BrO(g) + NO_2(g) \rightarrow BrONO_2(g)$$

f. The so-called alpha particles released by large radioactive elements such as uranium are helium nuclei consisting of two protons and two neutrons. Which has greater energy, an uncharged helium atom or an alpha particle and two separate electrons?

An alpha particle and two separate electrons have higher potential energy than an uncharged helium atom. The attraction between the alpha particle and the electrons will pull them together, and as they move together, they could bump into something, move it, and do work.

Review Questions Key

For questions 1 and 2, illustrate your answers with simple drawings of the particles that form the structures of the substances mentioned. You do not need to be specific about the nature of the particles. Think of them as simple spheres, and draw them as circles. Provide a general description of the arrangement of the particles, the degree of interaction between them, and their freedom of movement.

1. A pressurized can of a commercial product used to blow the dust off computer components contains tetrafluoroethane, $C_2H_2F_4$. At room temperature, this substance is a liquid at pressures slightly above normal pressure and a gas at normal pressures. Although most of the tetrafluoroethane in the can is in the liquid form, $C_2H_2F_4$ evaporates rapidly, resulting in a significant amount of vapor above the liquid. When the valve on the top of the can is pushed, the tetrafluoroethane gas rushes out, blowing dust off the computer. When the valve closes, more of the liquid $C_2H_2F_4$ evaporates to replace the vapor released. If the can is heated, the liquid evaporates more quickly, and the increase in gas causes the pressure to build up to possibly dangerous levels.

   a. Describe the general structure of liquids, such as tetrafluoroethane.

      The particles in the liquid are close together with the particles occupying about 70% of the total volume. Because the particles in a liquid are moving faster than in a solid, they break the attractions to the particles around them and constantly move into new positions to form new attractions. This leads to a less organized arrangement of particles compared to that of the solid. See Figure 3.2.

   b. Describe the general structure of gases, such as gaseous tetrafluoroethane.

      The particles of a gas are much farther apart than in the solid or liquid. For a typical gas, the average distance between particles is about ten times the diameter of each particle. This leads to the gas particles themselves taking up only about 0.1% of the total volume. The other 99.9% of the total volume is empty space. According to our model, each particle in a gas moves freely in a straight-line path until it collides with another gas particle or with a liquid or solid. The particles are usually moving fast enough to break any attraction that might form between them, so after two particles collide, they bounce off each other and continue on their way alone. See Figure 3.4.

c. Describe the process by which particles move from the liquid form to the gaseous form.

Particles that are at the surface of the liquid and that are moving away from the surface fast enough to break the attractions that pull them back will escape to the gaseous form. See Figure 3.3.

d. Describe the changes that take place in the liquid when it is heated, and explain why these changes lead to a greater rate of evaporation of the liquid.

Increased temperature leads to an increase in the average velocity of the particles in the liquid. This makes it easier for the particles to break the attractions between them and move from one position to another, including away from the surface into the gaseous form.

2. Sodium metal can be made by running an electric current through molten sodium chloride.

a. Describe the general structure of solid sodium chloride.

According to our model, the particles of a solid can be pictured as closely packed spheres. The spheres for NaCl are alternating Na^+ cations and Cl^- anions. Strong attractions hold these particles in the same general position, but the particles are still constantly moving (Figure 3.1). Each particle is constantly changing its direction and speeding up and slowing down. Despite the constant changes in direction and velocity, at a constant temperature, the strong attractions between particles keep them the same average distance apart and in the same general orientation to each other.

b. Describe the changes that take place when the temperature of NaCl solid increases.

When a solid is heated, the average velocity of the particles increases. The more violent collisions between the faster moving particles usually cause each particle to push its neighbors farther away. Therefore, increased temperature usually leads to an expansion of solids (Figure 3.1).

c. Describe the changes that take place when sodium chloride melts.

As the heating of a solid continues, the movement of each particle eventually becomes powerful enough to enable it to push the other particles around it completely out of position. Because there is very little empty space between the particles, each one that moves out of position has to push its neighbors out of their positions too. Therefore, for one particle to move out of its general position, all of the particles must be able to move. The organized structure collapses, and the solid becomes a liquid.

Key Ideas Answers

3. The simplest definition of **energy** is that it is the capacity to do work. Work, in this context, may be defined as what is done to move an object against some sort of **resistance**.
5. If two objects are moving at the same velocity, the one with the greater **mass** will have a greater capacity to do work and thus a greater kinetic energy.
7. The Law of Conservation of Energy states that energy can be neither **created** nor **destroyed**, but it can be **transferred** from one system to another and **changed** from one form to another.
9. A system's stability is a measure of its tendency to **change**.
11. Any time a system shifts from a more stable state to a less stable state, the potential energy of the system **increases**.
13. Because less stable separate atoms have higher potential energy than the more stable atoms that participate in a bond, the change from separate atoms to atoms in a bond corresponds to a(n) **decrease** in potential energy.
15. The U.S. National Institute of Standards and Technology defines the calorie as **4.184** joules.
17. The energy associated with internal motion of particles that compose an object can be called either **internal kinetic** energy.
19. Heat is the energy that is transferred from a region of higher temperature to a region of lower temperature as a consequence of the **collisions** of particles.
21. Radiant energy can be viewed as a stream of tiny, **massless** packets of energy called photons.
23. One distinguishing characteristic of the waves of radiant energy is wavelength, λ, the distance between two **peaks** on the wave of electromagnetic radiation. A more specific definition of wavelength is the distance in space over which a wave completes one **cycle** of its repeated form.
25. If in a chemical reaction, more energy is released in the formation of new bonds than was necessary to break old bonds, energy is **released** overall, and the reaction is exergonic.
27. If less energy is released in the formation of the new bonds than is necessary to break the old bonds, energy must be **absorbed** from the surroundings for the reaction to proceed.
29. Two forms of the element oxygen are found in nature: the life-sustaining diatomic **oxygen, O_2,** and **ozone, O_3,** which is a pale blue gas with a strong odor.
31. The highest concentrations of O_3 in the air we breathe are found in large industrial cities with lots of **cars** and lots of **sun**.
33. Radiant energy of wavelengths **shorter** than 400 nm has enough energy to break N–O bonds in NO_2 molecules, but radiant energy with wavelengths **longer** than 400 nm does not supply enough energy to separate the atoms.
35. The stratosphere extends from about **10** km to about **50** km above sea level.

37. **UV-B** radiation has wavelengths from about 290 to 320 nm. Some of it is removed by the gases in the stratosphere, but some of it reaches the surface of the earth. Radiation in this portion of the spectrum has energy great enough that excessive exposure can cause **sunburn**, **premature aging**, and **skin cancer**.

39. Oxygen molecules, O_2, and ozone molecules, O_3, work together to absorb high-energy UV radiation. Oxygen molecules absorb UV radiation with wavelengths less than **242 nm**, and ozone molecules absorb radiant energy with wavelengths from **240 nm to 320 nm**.

41. One of the reasons why CFCs were so successful is that they are extremely **stable** compounds; very few substances react with them.

Problems Key

Section 8.1 Energy

43. For each of the following situations, you are asked which of two objects or substances has greater energy. Explain your answer with reference to the capacity of each to do work, and indicate whether the energy that distinguishes them is kinetic energy or potential energy. *(Objs 2, 3, & 5)*

    a. An ozone molecule, O_3, with a velocity of 393 m/s or the same molecule moving with a velocity of 410 m/s. (These are the average velocities of ozone molecules at 25 °C and 50 °C.)

    An ozone molecule, O_3, with a velocity of 410 m/s has greater kinetic energy than the same molecule with a velocity of 393 m/s. Any object in motion can collide with another object and move it, so any object in motion has the capacity to do work. This capacity to do work resulting from the motion of an object is called kinetic energy, KE. The particle with the higher velocity will move another object (such as another molecule) farther, so it can do more work. It must therefore have more energy.

    b. An ozone molecule, O_3, moving at 300 m/s or an oxygen molecule, O_2, moving at the same velocity.

    An ozone molecule, O_3, has greater kinetic energy than an O_2 molecule with the same velocity. The moving particle with the higher mass can move another object (such as another molecule) farther, so it can do more work. It must therefore have more energy.

    c. A proton and an electron close together or a proton and an electron farther apart.

    The attraction between the separated electron and a proton will pull them together, and as they move together, they could bump into something, move it, and do work. Therefore, a proton and an electron farther apart have higher potential energy than a proton and an electron close together.

d. An HOCl molecule or an OH molecule and a chlorine atom formed by breaking the chlorine-oxygen bond in the HOCl molecule. (The conversion of HOCl into Cl and OH takes place in the stratosphere.)

Separated atoms are less stable than atoms in a chemical bond, so the potential energy of OH and Cl is higher than HOCl. Energy is required to separate the oxygen atom and the chlorine atom being held together by mutual attraction in a chemical bond. The energy supplied goes to an increased potential energy of the separate OH and Cl compared to HOCl. If the bond is re-formed, the potential energy is converted into a form of energy that could be used to do work.

e. Two separate chlorine atoms in the stratosphere or the chlorine, Cl_2, molecule that can form when they collide.

Separated atoms are less stable than atoms in a chemical bond, so the potential energy of two separate Cl atoms is greater than one Cl_2 molecule. When two Cl atoms are converted into a Cl_2 molecule, a new bond is formed, and some of the potential energy of the Cl atoms is released. The energy could be used to do some work.

$$2Cl(g) \rightarrow Cl_2(g)$$

f. Water in the liquid form or water in the gaseous form. (Assume that the two systems are at the same temperature.)

Gaseous water has higher potential energy than liquid water. When water evaporates, the attractions that link the water molecules together are broken. The energy that the water must absorb to break these attractions goes to an increased potential energy of the water vapor. If the water returns to the liquid form, attractions are reformed, and the potential energy is converted into a form of energy that could be used to do work.

46. Energy is the capacity to do work. With reference to this definition, describe how you would demonstrate that each of the following has potential energy. (There is no one correct answer in these cases. There are many ways to demonstrate that a system has potential energy.)

a. A brick on the top of a tall building

If you nudge the brick off the top of the building, its potential energy will be converted into kinetic energy as it falls. If it hits the roof of a parked car, it will move the metal of the roof down, making a dent. When an object, such as the metal roof, is moved, work is done.

b. A stretched rubber band

You can shoot the rubber band across the room at a paper airplane. When you release the rubber band, its potential energy is converted into kinetic energy, which is used to do the work of moving the airplane.

c. Alcohol molecules added to gasoline

It is possible to run a car on pure alcohol. When the alcohol is burned, its potential energy is converted into energy that does the work of moving the car.

48. For each of the following changes, describe whether (1) kinetic energy is being converted into potential energy, (2) potential energy is being converted into kinetic energy, or (3) kinetic energy is transferred from one object to another. (More than one of these changes may be occurring.)

   a. An archer pulls back a bow with the arrow in place.

      Some of the **kinetic energy** of the moving hand is **transferred** to the string to set it moving and to the tips of the bow as it bends. Some of this **kinetic energy is converted into potential energy** of the stretched string and bow.

   b. The archer releases the arrow, and it speeds toward the target.

      Some of the **potential energy** of the stretched string and bow are **converted into kinetic energy** of the moving arrow.

51. Methyl bromide is an agricultural soil fumigant that can make its way into the stratosphere, where bromine atoms are stripped away by radiant energy from the sun. The bromine atoms react with ozone molecules (thus diminishing the earth's protective ozone layer) to produce BrO, which in turn reacts with nitrogen dioxide, NO_2, to form $BrONO_2$. For each of these reactions, indicate whether energy is absorbed or released. Explain why. Describe how energy is conserved in each reaction. *(Objs 7 & 8)*

   a. $CH_3Br(g) \rightarrow CH_3(g) + Br(g)$

      Because a chemical bond is broken in this reaction, energy would need to be absorbed to supply the energy necessary to move to the higher potential energy products. In the stratosphere, this energy comes from the radiant energy of a photon.

   b. $BrO(g) + NO_2(g) \rightarrow BrONO_2(g)$

      Because a chemical bond is made in this reaction, energy would be released as the system moves to the lower potential energy product. This potential energy could be converted into kinetic energy.

$$BrO(g) + NO_2(g) \rightarrow BrONO_2(g)$$

53. A silver bullet speeding toward a vampire's heart has both external kinetic energy and internal kinetic energy. Explain the difference between the two. *(Obj 11)*

   A speeding bullet has a certain kinetic energy that is related to its overall mass and its velocity. This is its external kinetic energy. The bullet is also composed of silver atoms that, like all particles, are moving in a random way. The particles within the bullet are constantly moving, colliding with their neighbors, changing their direction of motion, and changing their velocities. The kinetic energy associated with this internal motion is the internal kinetic energy. The internal motion is independent of the overall motion of the bullet.

55. When a room-temperature thermometer is placed in a beaker of boiling water, heat is transferred from the hot water to the glass of the thermometer and then to the liquid mercury inside the thermometer. With reference to the motion of the particles in the water, glass, and mercury, describe the changes that are taking place during this heat transfer. What changes in total energy and average internal kinetic energy occur for each substance? Why do you think the mercury moves up the thermometer? ***(Obj #14)***

A typical thermometer used in the chemical laboratory consists of a long cylindrical glass container with a bulb at the bottom that contains a reservoir of mercury and a thin tube running up the inside of the thermometer that the mercury can rise into as it expands.

When the thermometer is first placed in the hot water, the particles in the water have a greater average kinetic energy than the particles of the glass and mercury in the thermometer. When the more energetic water molecules collide with the particles in the glass, the particles of water slow down, and the particles in the glass speed up. The average kinetic energy of the water molecules decreases and the average kinetic energy of the particles of the glass increases. Energy has been transferred from the water to the glass. The glass particles then collide with the less energetic mercury atoms, speeding them up and slowing down themselves. The average kinetic energy of the mercury increases, as energy is transferred from the glass to the mercury. Thus, some of the kinetic energy of the water is transferred to the glass, which then transfers some of this energy to the mercury. This will continue until the particles of water, glass, and mercury all have the same average kinetic energy.

Try to picture the atoms of mercury in the liquid mercury. Now that they are moving faster, they collide with the particles around them with greater force. This pushes the particles farther apart and causes the liquid mercury to expand. Because the mercury has a larger volume, it moves farther up the thin column in the center of the thermometer.

56. With reference to both their particle nature and their wave nature, describe the similarities and differences between visible light and ultraviolet radiation. ***(Objs 15-18)***

In the particle view, radiant energy is a stream of tiny, massless packets of energy called photons. Different forms of radiant energy differ with respect to the energy of each of their photons. The energies of the photons of visible light are lower than for ultraviolet radiation.

In the wave view, as radiant energy moves away from the source, it has an effect on the space around it that can be described as a wave consisting of an oscillating electric field perpendicular to an oscillating magnetic field (Figure 8.11). Different forms of radiant energy differ with respect to the wavelengths and frequencies of these oscillating waves. The waves associated with visible light have longer wavelengths than the waves associated with ultraviolet radiation.

58. Consider the following forms of radiant energy: microwaves, infrared radiation, ultraviolet radiation, X rays, visible light, radio waves, and gamma rays. *(Obj 18)*

a. List them in order of increasing energy.

radio waves < microwaves < infrared radiation < visible light < ultraviolet radiation < X rays < gamma rays

b. List them in order of increasing wavelength.

gamma rays < X rays < ultraviolet radiation < visible light < infrared radiation < microwaves < radio waves

Section 8.2 Chemical Changes and Energy

60. Consider the following endergonic reaction. In general terms, explain why energy is absorbed in the process of this reaction. *(Obj 20)*

$N_2(g) + O_2(g) \rightarrow 2NO(g)$

The bonds in the products must be less stable and therefore higher potential energy than the bonds in the reactants. Energy is absorbed in the reaction to supply the energy necessary to increase the potential energy of the products compared to reactants.

more stable bonds + energy → less stable bonds

lower PE + energy → higher PE

62. Hydrazine, N_2H_4, is used as rocket fuel. Consider a system in which a sample of hydrazine is burned in a closed container, followed by heat transfer from the container to the surroundings. *(Objs 14 & 20)*

$N_2H_4(g) + O_2(g) \rightarrow N_2(g) + 2H_2O(g)$

a. In general terms, explain why energy is released in the reaction.

The bonds in the products must be more stable and therefore lower potential energy than the bonds in the reactants. The potential energy difference between reactants and products is released.

b. Describe the average internal kinetic energy of the product particles, compared to the reactant particles, before heat energy is transferred to the surroundings. If the average internal kinetic energy for the product(s) is greater than that for the reactants, from where did this energy come? If the average internal kinetic energy for the product(s) is lower than that for the reactants, where did this energy go?

Some of the potential energy of the reactants is converted into kinetic energy of the products, making the average kinetic energy of the products higher than the average kinetic energy of the reactants.

c. Describe the changes in particle motion that occur as heat is transferred from the products to the surroundings.

The particles of the higher-temperature products collide with the particles of the lower-temperature container with greater average force than the particles of the container. Therefore, collisions between the particles of the products and the container speed up the particles of the container, increasing its internal kinetic energy or thermal energy, while slowing the particles of the products, decreasing their thermal energy. In this way, thermal energy is transferred from the products to the container. Likewise, the container, which is now at a higher temperature, transfers thermal energy to the lower-temperature surroundings. Heat has been transferred from the products to the container to the surroundings.

65. Classify each of the following changes as exothermic or endothermic.

a. Leaves decaying in a compost heap **exothermic**

b. Dry ice (solid carbon dioxide) changing to carbon dioxide gas **endothermic**

c. Dew forming on a lawn at night **exothermic**

67. Explain why all chemical reactions either absorb or evolve energy. *(Obj 22)*

See Figure 8.15.

Section 8.3 Ozone: Pollutant and Protector

68. What characteristic of ozone makes it useful for some purposes and a problem in other situations? For what is it used in industry? What health problems does it cause? *(Obj 23)*

Ozone is a very powerful oxidizing agent. This can be useful. For example, ozone mixed with oxygen can be used to sanitize hot tubs, and it is used in industry to bleach waxes, oils, and textiles. Conversely, when the levels in the air get too high, the highly reactive nature of ozone becomes a problem. For example, O_3 is a very strong respiratory irritant that can lead to shortness of breath, chest pain when inhaling, wheezing, and coughing. It also damages rubber and plastics, leading to premature deterioration of products made with these materials. Furthermore, ozone causes significant damage to plants.

70. Explain why UV radiation less than 400 nm in wavelength is able to break N–O bonds in NO_2 molecules, and explain why radiant energy greater than 400 nm in wavelength cannot break these bonds. *(Obj 26)*

Shorter wavelengths of radiant energy are associated with higher energy photons. Radiant energy of wavelengths less than 400 nm has enough energy to break N–O bonds in NO_2 molecules, but radiant energy with wavelengths longer than 400 nm does not supply enough energy to separate the atoms.

72. Explain why UV-B radiation can be damaging to us and our environment if it reaches Earth in greater quantities than it does now. *(Obj 29)*

The shorter wavelength UV-B radiation (from about 290 nm to 320 nm) has higher energy than UV-A radiation. Radiation in this portion of the spectrum has high enough energy so that excessive exposure can cause sunburn, premature skin aging, and skin cancer.

74. Explain how oxygen molecules, O_2, and ozone molecules, O_3, work together to protect us from high-energy ultraviolet radiation. *(Obj 31)*

O_2 molecules absorb UV radiation with wavelengths less than 242 nm, and O_3 molecules absorb radiant energy with wavelengths from 240 nm to 320 nm. See Figure 8.18.

Section 8.4 Chlorofluorocarbons: A Chemical Success Story Gone Wrong

76. Explain why CFCs eventually make their way into the stratosphere even though most chemicals released into the atmosphere do not. *(Obj 33)*

Gases are removed from the lower atmosphere in two general ways. They either dissolve in the clouds and are rained out, or they react chemically to be converted into other substances. Neither of these mechanisms are important for CFCs. Chlorofluorocarbons are insoluble in water, and they are so stable that they can exist in the lower atmosphere for years. During this time, the CFC molecules wander around in the atmosphere, moving wherever the air currents take them. They can eventually make their way up into the stratosphere.

Additional Problems

79. Energy is the capacity to do work. With reference to this definition, describe how you would demonstrate that each of the following objects or substances has potential energy. (There is no one correct answer in these cases. There are many ways to demonstrate that a system has potential energy.)

a. Natural gas used to fuel a city bus

When the natural gas burns, some of its potential energy is used to do the work of moving the bus.

b. A compressed spring

If you put an object, such as a small ball of paper, on one end of the compressed spring and then release the spring, the potential energy stored in the compressed spring will be converted into kinetic energy of the moving spring as it stretches out. The kinetic energy of the moving spring will do the work of moving the object.

c. A pinecone at the top of a tall tree

When a squirrel chews off the pinecone, allowing it to fall to the ground, the potential energy that it has because it is higher than the ground will be converted into kinetic energy as it falls. The falling pinecone can collide with another pinecone and do the work of knocking the second pinecone off its branch.

81. For each of the following changes, describe whether (1) kinetic energy is being converted into potential energy, (2) potential energy is being converted into kinetic energy, and/or (3) kinetic energy is transferred from one object to another. (More than one of these changes may be occurring.)
    a. Using an elaborate system of ropes and pulleys, a piano mover hoists a piano up from the sidewalk to the outside of a large third floor window of a city apartment building.
        The **kinetic energy** of the mover's hands is **transferred** to the kinetic energy of the moving ropes, which is transferred to the kinetic energy of the moving piano. Some of this **kinetic energy is converted into potential energy** as the piano rises.
    b. His hands slip and the piano drops 6 feet before he is able to stop the rope from unwinding.
        Some of the **potential energy** of the piano is **converted into kinetic energy** as it falls.
83. The following changes combine to help move a car down the street. For each change, describe whether (1) kinetic energy is being converted into potential energy, (2) potential energy is being converted into kinetic energy, and/or (3) kinetic energy is transferred from one object to another. (More than one of these changes may be occurring.)
    a. The combustion of gasoline in the cylinder releases heat energy, increasing the temperature of the gaseous products of the reaction.
        Some of the **potential energy** of the gasoline molecules is **converted into the kinetic energy** of moving product particles. This is reflected in an increase in the temperature of the gaseous products.
    b. The hot gaseous products push the piston down in the cylinder.
        Some of the **kinetic energy** of the moving gaseous product particles is **transferred into the kinetic energy** of the moving piston.
    c. The moving piston turns the crankshaft, which ultimately turns the wheels.
        Some of the **kinetic energy** of the moving piston is **transferred into the kinetic energy** of the moving crankshaft and ultimately into the kinetic energy of the moving wheels.
85. Classify each of the following changes as exothermic or endothermic.
    a. The burning fuel in a camp stove **exothermic**
    b. The melting of ice in a camp stove to provide water on a snow-camping trip **endothermic**