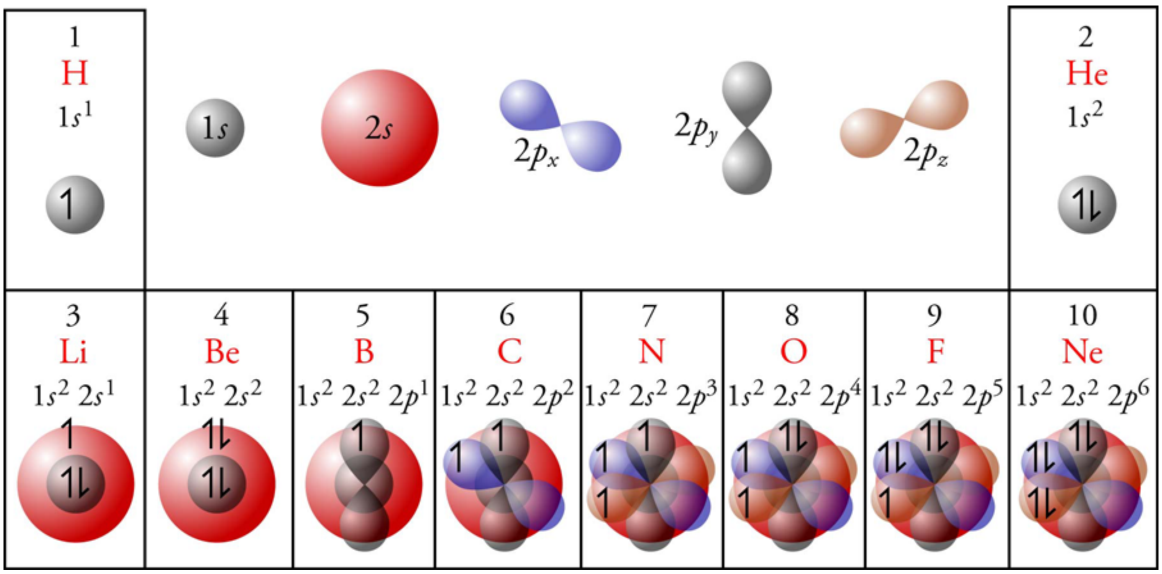
Chapter 4
Modern Atomic Theory



Section Goals and Introductions

Section 4.1 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 4.2 The Mysterious Electron

Goals

- *To explain why it is very difficult to describe the modern view of the electron.*
- *To give you some understanding of the nature of the electron by describing how it is like a guitar string.*
- *To explain what atomic orbitals are.*
- *To describe the atomic orbitals available to the electron of a hydrogen atom.*
- *To explain what energy levels and sublevels are.*

The electron is extremely tiny, and modern physics tells us that strange things happen in the realm of the very, very small. This makes it difficult for us to get a good understanding of the nature of the extremely tiny electron. For us, it’s easier to consider what the electron is *like* rather than what it *is*. This section begins by giving you a glimpse of the modern view of the electron by showing how it is like a guitar string and how atomic orbitals that are possible for an electron in a hydrogen atom are like the possible ways that a guitar string can vibrate.

The most important component of this section is the introduction of the idea of atomic orbitals. Be sure you understand what the electron clouds that we call orbitals represent, both in terms of the effect they have on the space around the nucleus (which relates to their negative charge) and in terms of the probability of finding the electron in any position outside the nucleus. It will be useful for you to know the different shapes and sizes of the possible orbitals for the one electron in a hydrogen atom and to know how these orbitals can be arranged into energy levels and sublevels.

Section 4.3 Multi-Electron Atoms

Goals

- *To show how the knowledge of the atomic orbitals of hydrogen can be applied to atoms of the other elements.*
- *To describe how electrons of atoms are arranged with respect to orbitals, sublevels, and energy levels.*

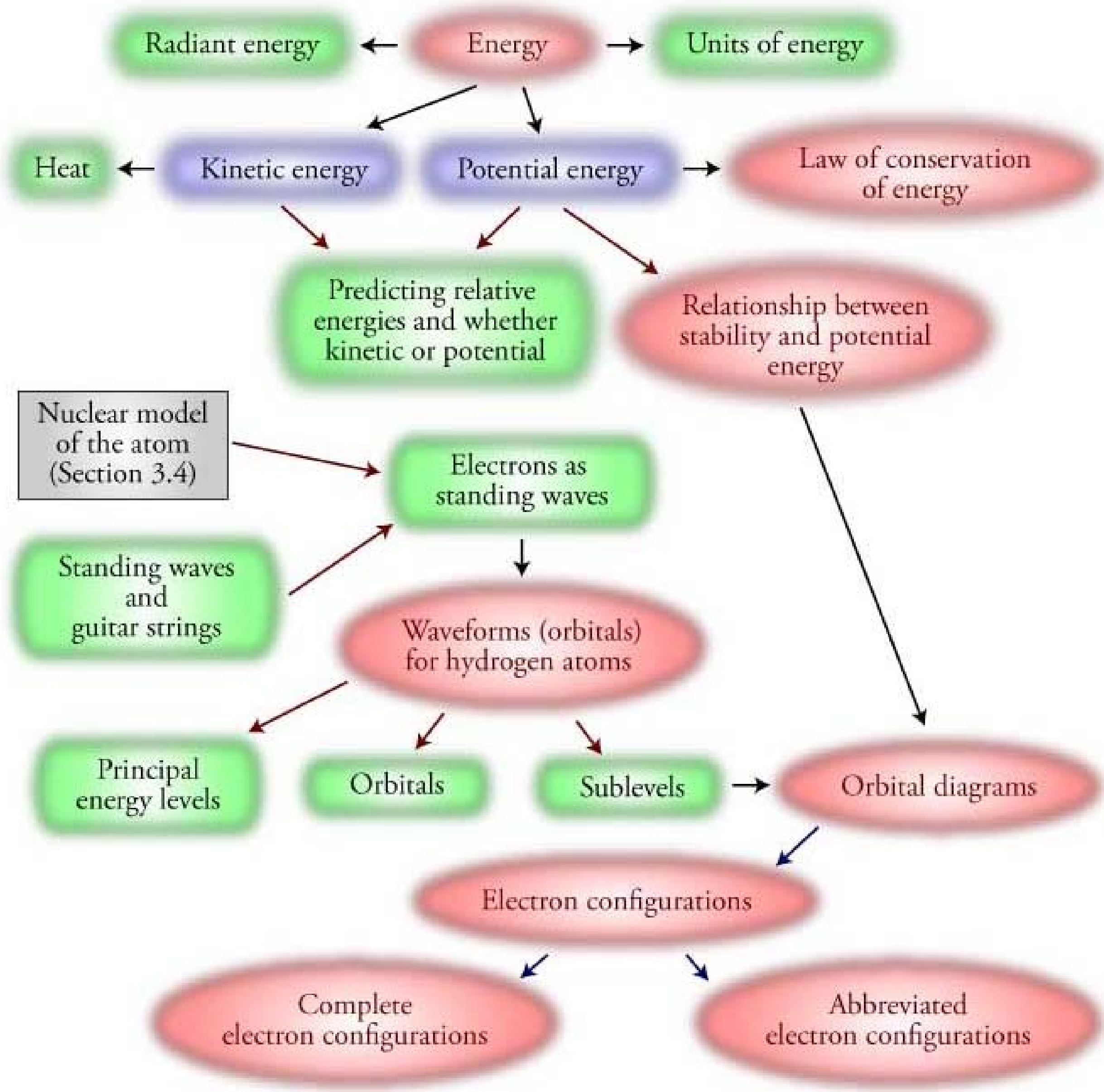
This section shows you how the information about the energy levels, sublevels, and orbitals for the hydrogen electron can be applied to the electrons in atoms of other elements. It's important that you learn how to describe the arrangement of electrons in these energy levels, sublevels, and orbitals with orbital diagrams and electron configurations. You will see in Chapter 5 that these orbital diagrams and electron configurations will help us explain the bonding patterns of the elements. See the three sections on our Web site that are related to this section:

Internet: Electron Configurations

Internet: Abbreviated Electron Configurations

Internet: Elements with Electron Configurations Other Than Predicted

Chapter 4 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 on our 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, 30, and 31.)
- ☐ Reread the Study Sheets in this chapter and decide whether you will use them or some variation on them to complete the tasks they describe.

  Sample Study Sheet 4.1: Writing Complete Electron Configurations and Orbital Diagrams for Uncharged Atoms

  Sample Study Sheet 4.2: Abbreviated Electron Configurations
- ☐ 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: Electron Configurations

Internet: Abbreviated Electron Configurations

Internet: Elements with Electron Configurations Other Than Predicted

Internet: Glossary Quiz

Exercises Key

Exercise 4.1 - 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, (1) a nitric acid molecule or (2) 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, (1) an NO_2 molecule moving at 439 m/s or (2) 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, (1) a nitrogen monoxide molecule, NO, emitted from your car's tail pipe at 450 m/s or (2) 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 moving 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, (1) liquid nitrogen or (2) 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.

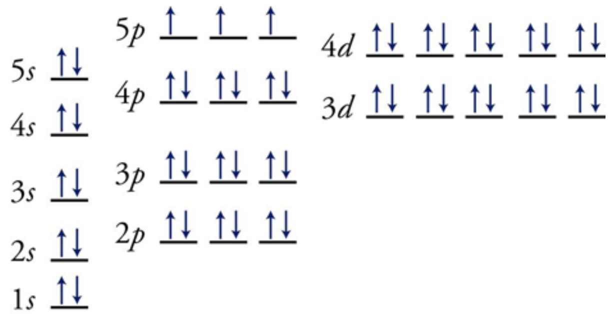
e. Halons, such as halon-1301 (CF_3Br) and halon-1211 (CF_2ClBr), which have been used as fire-extinguishing agents, are a potential threat to Earth's protective ozone layer, partly because they lead to the production of $BrONO_2$ in the upper atmosphere. Which has greater energy, (1) separate BrO and NO_2 molecules or (2) 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 $BrONO_2$, the faster moving molecule could bump into something and move it and therefore do work.

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

Exercise 4.2 - Electron Configurations and Orbital Diagrams: Write the complete electron configuration and draw an orbital diagram for antimony, Sb. *(Objs 12 & 13)*

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^3$



Exercise 4.3 - Abbreviated Electron Configurations: Write abbreviated electron configurations for (a) rubidium, Rb, (b) nickel, Ni, and (c) bismuth, Bi.
(Obj 14)

a. rubidium, Rb **[Kr] $5s^1$**
b. nickel, Ni **[Ar] $4s^2\ 3d^8$**
b. bismuth, Bi **[Xe] $6s^2\ 4f^{14}\ 5d^{10}\ 6p^3$**

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 can 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.

3. Describe the nuclear model of the atom.

   Protons and neutrons are in a tiny core of the atom called the nucleus, which has a diameter of about 1/100,000 the diameter of the atom. The position and motion of the electrons are uncertain, but they generate a negative charge that is felt in the space that surrounds the nucleus.

Key Ideas Answers

4. 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**.
6. 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.
8. 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.
10. A system's stability is a measure of its tendency to **change**.
12. Any time a system shifts from a more stable state to a less stable state, the potential energy of the system **increases**.
14. 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.
16. The U.S. National Institute of Standards and Technology defines the calorie as **4.184** joules.
18. The energy associated with internal motion of particles that compose an object can be called either internal kinetic energy or **thermal** energy.
20. Heat is the thermal energy that is transferred from a region of higher temperature to a region of lower temperature as a consequence of the **collisions** of particles.
22. Radiant energy can be viewed as a stream of tiny, **massless** packets of energy called photons.
24. 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.
26. The electron is extremely tiny, and modern physics tells us that **strange** things happen in the realm of the very, very small.
28. Modern physics tells us that it is **impossible** to know **exactly** where an electron is and what it is doing.
30. In order to accommodate the uncertainty of the electron's position and motion, scientists talk about where the electron **probably** is within the atom, instead of where it **definitely** is.
32. In the wave view, an electron has an effect on the space around it that can be described as a wave of **negative charge** varying in its intensity.
34. Just as the **intensity of movement** of a guitar string can vary, so can the **intensity of the negative charge** of the electron vary at different positions outside the nucleus.

36. As in the case of the guitar string, only certain waveforms are **possible** for the electron in an atom.
38. The information calculated for the hydrogen electron is used to describe the **other elements** as well.
40. The allowed waveforms for the electron are also called orbitals. Another definition of orbital is as the volume that contains a given **high percentage** of the electron charge. An orbital can also be defined as the **volume** within which an electron has a high probability of being found.
42. In the particle view, the electron **cloud** can be compared to a multiple-exposure photograph of the electron.
44. Because the **strength** of the attraction between positive and negative charges decreases with increasing distance between the charges, an electron is more strongly attracted to the nucleus and therefore is more stable when it has the smaller 1*s* waveform than when it has the larger 2*s* waveform. Increased stability is associated with **decreased** potential energy, so a 1*s* electron has lower potential energy than a 2*s* electron.
46. After the electron is excited from the 1*s* orbital to the 2*s* orbital, it **spontaneously returns** to its lower-energy 1*s* form.
48. Orbitals that have the same potential energy, the same size, and the same shape are in the same **sublevel**.
50. Note that the first principal energy level has one sublevel, the second has two, the third has three, and the fourth has four. If ***n*** is the number associated with the principal energy level, each principal energy level has *n* sublevels.
52. None of the known elements in its ground state has any electrons in a principal energy level higher than the **seventh**.
54. We can visualize the two electrons in a helium atom as **spinning** in opposite directions.
56. An atomic orbital may contain **2** electrons at most, and the electrons must have different **spins**.
58. The highest-energy electrons for all of the elements in groups 1 (1A) and 2 (2A) in the periodic table are in ***s* orbitals**.
60. The last electrons to be added to an orbital diagram for the atoms of the transition metal elements go into ***d*** orbitals.

Problems Key

Section 4.1 Energy

62. 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. (1) An ozone molecule, O_3, with a velocity of 393 m/s or (2) 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. (1) An ozone molecule, O_3, moving at 300 m/s or (2) 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. (1) A proton and an electron close together or (2) 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. (1) An HOCl molecule or (2) 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. (1) Two separate chlorine atoms in the stratosphere or (2) 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. (1) Water in the liquid form or (2) 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.

65. 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.

67. 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.*

70. 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.

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

72. 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.

74. 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.

75. 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 4.11). 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.

77. 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 4.2 The Mysterious Electron

79. Explain why, in theory, a guitar string can vibrate with an infinite number of possible waveforms but not all waveforms are possible. *(Obj 20)*

The possible waveforms are limited by the fact that the string is tied down and cannot move at the ends, but there are an infinite number of possible waveforms that allow the string to remain stationary at the ends.

81. Describe the 1*s* orbital in a hydrogen atom in terms of negative charge and in terms of the electron as a particle. *(Obj 22)*

The negative-charge distribution of an electron in a 1s orbital of a hydrogen atom looks like the image in Figure 4.15 of the text. The cloud is pictured as surrounding the nucleus and represents the variation in the intensity of the negative charge at different positions outside the nucleus. The negative charge is most intense at the nucleus and diminishes with increasing distance from the nucleus. The variation in charge intensity for this waveform is the same in all directions, so the waveform is a sphere. Theoretically, the charge intensity decreases toward zero as the distance from the nucleus approaches infinity. The 1s orbital can be described as a sphere that contains a high percentage (for example 90% or 99%) of the charge of the 1s electron.

According to the particle interpretation of the wave character of the electron, a 1s orbital is a surface within which we have a high probability of finding the electron. In the particle view, the electron cloud can be compared to a multiple-exposure photograph of the electron (once again, we must resort to an analogy to describe electron behavior). If we were able to take a series of sharply focused photos of an electron over a period of time without advancing the film, our final picture would look like the image in Figure 4.17 of the text. We would find a high density of dots near the nucleus (because most of the times when the shutter snaps, the electron would be near the nucleus) and a decrease in density with increasing distance from the nucleus (because some of the times the shutter snaps, the electron would be farther away from the nucleus). This arrangement of dots would bear out the wave equation's prediction of the probability of finding the electron at any given distance from the nucleus.

83. Describe a 2*s* orbital for a hydrogen atom. *(Obj 24)*

The 2s orbital for an electron in a hydrogen atom is spherical like the 1s orbital, but it is a larger sphere. For an electron in the 2s orbital, the charge is most intense at the nucleus, it diminishes in intensity to a minimum with increasing distance from the nucleus, it increases again to a maximum, and finally it diminishes again. The section of the 2s orbital where the charge intensity goes to zero is called a node. Figure 4.19 of the text, shows cutaway, quarter section views of the 1s and 2s orbitals.

85. Which is larger, a 2*p* orbital or a 3*p* orbital? Would the one electron in a hydrogen atom be more strongly attracted to the nucleus in a 2*p* orbital or in a 3*p* orbital? Would the electron be more stable in a 2*p* orbital or in a 3*p* orbital? Would the electron have higher potential energy when it is in a 2*p* orbital or a 3*p* orbital?

The 3p orbital is larger than the 2p orbital. Because the average distance between the positively charged nucleus and the negative charge of an electron in a 2p orbital would be less than for an electron in a 3p orbital, the attraction between a 2p electron and the nucleus would be stronger. This makes an electron in a 2p orbital more stable and gives it lower potential energy than an electron in a 3p orbital.

87. Describe the three 2*p* orbitals for a hydrogen atom. *(Obj 26)*

The three 2p orbitals are identical in shape and size, but each is 90° from the other two. Because they can be viewed as being on the x, y and z axes of a three-dimensional coordinate system, they are often called the $2p_x$, $2p_y$, *and* $2p_z$ *orbitals. One electron with a 2p waveform has its negative charge distributed in two lobes on opposite sides of the nucleus. Figures 4.20 and 4.21 of the text show two ways to visualize these orbitals, and Figure 4.22 of the text shows the three 2p orbitals together.*

90. How many orbitals are there in the 3*p* sublevel for the hydrogen atom? **3**

92. How many orbitals are there in the third principal energy level for the hydrogen atom?

    There are **nine** *orbitals in the third principal energy level: one in the 3s sublevel, three in the 3p sublevel, and five in the 3d sublevel.*

94. Which of the following sublevels do not exist?

    a. 5*p* **exists**
    b. 2*s* **exists**
    c. 3*f* **not exist**
    d. 6*d* **exists**

Section 4.3 Multi-Electron Atoms

97. What is the maximum number of electrons that can be placed in a 3*p* orbital?...in a 3*d* orbital?

    two *The maximum number of electrons in any orbital is 2.*

99. What is the maximum number of electrons that can be placed in a 3*p* sublevel?...in a 3*d* sublevel?

    The maximum number of electrons in any p sublevel is **six**. *The maximum number of electrons in any d sublevel is* **ten**.

101. What is the maximum number of electrons that can be placed in the third principal energy level?

    The third principal energy level can hold up to 18 *electrons: two in the 3s, six in the 3p, and ten in the 3d.*

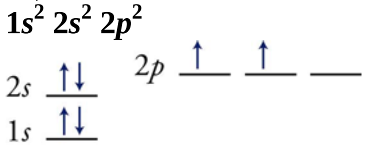
103. For each of the following pairs, identify the sublevel that is filled first.

    a. 2*s* or 3*s* **2*s***
    b. 3*p* or 3s **3*s***
    c. 3*d* or 4*s* **4*s***
    d. 4*f* or 6*s* **6*s***

105. Write the complete electron configuration and orbital diagram for each of the following. (Objs 29 & 30)

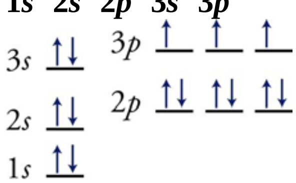
    a. carbon, C

    $1s^2\ 2s^2\ 2p^2$



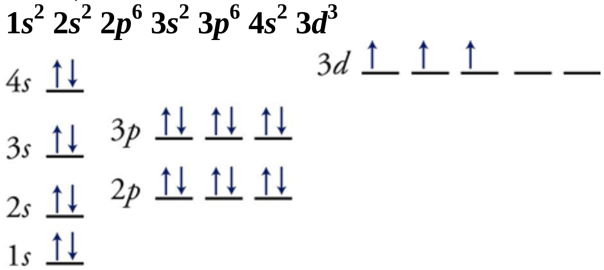
    b. phosphorus, P

    $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^3$



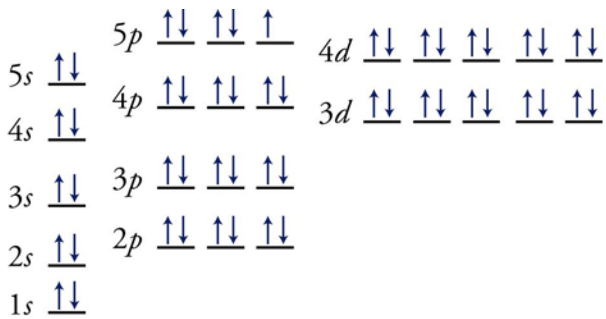
    c. vanadium, V

    $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^3$



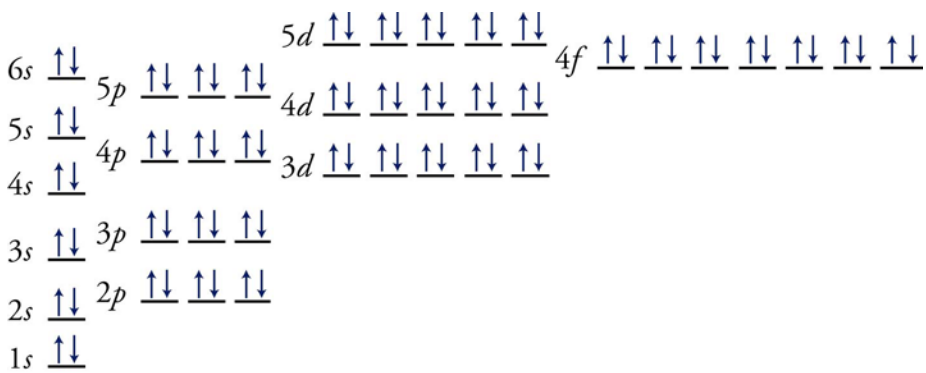
d. iodine, I

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^5$



e. mercury, Hg

$1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6\ 6s^2\ 4f^{14}\ 5d^{10}$



107. Which element is associated with each of the ground state electron configurations listed below?

a. $1s^2\ 2s^2$ **Be**

b. $1s^2\ 2s^2\ 2p^6\ 3s^1$ **Na**

c. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^5$ **Br**

d. $1s^2\ 2s^2\ 2p^6\ 3s^2\ 3p^6\ 4s^2\ 3d^{10}\ 4p^6\ 5s^2\ 4d^{10}\ 5p^6\ 6s^2\ 4f^{14}\ 5d^{10}\ 6p^2$ **Pb**

109. Would the following electron configurations represent ground states or excited states?

a. $1s^2\ 2s^1\ 2p^5$ **excited**

b. $1s^2\ 2s^2\ 2p^4$ **ground**

c. $1s^2\ 2s^2\ 2p^4\ 3s^1$ **excited**

d. $1s^2\ 2s^2\ 2p^5$ **ground**

111. Write the abbreviated electron configurations for each of the following. *(Obj 31)*

a. fluorine, F **[He] $2s^2\ 2p^5$**

b. silicon, Si **[Ne] $3s^2\ 3p^2$**

c. cobalt, Co **[Ar] $4s^2$ 3d^7**

d. indium, In **[Kr] $5s^2$ 4d^{10} $5p^1$**

e. polonium, Po **[Xe] $6s^2\ 4f^{14}$ 5d^{10} $6p^4$**

Additional Problems

113. Which sublevel contains:
    a. the highest-energy electron for francium, Fr? **7*s***
    b. the 25th electron added to an orbital diagram for elements larger than chromium, Cr? **3d**
    c. the 93rd electron added to an orbital diagram for elements larger than uranium, U? **5f**
    d. the 82nd electron added to an orbital diagram for elements larger than lead, Pb? **6p**

115. What is the first element on the periodic table to have
    a. an electron in the 3*p* sublevel **Al**
    b. a filled 4*s* sublevel. **Ca**
    c. a half-filled 3*d* sublevel. **Mn**

117. Which pair of the following ground-state, abbreviated electron configurations corresponds to elements in the same group on the periodic table? What elements are they? What is the name of the group to which they belong?
    a. [Ne] $3s^2$
    b. [Ar] $4s^2\ 3d^{10}$
    c. [Kr] $5s^2$
    d. [Xe] $6s^2\ 4f^{14}\ 5d^{10}\ 6p^1$

    The pair "a" and "c" represent the alkaline earth metals magnesium and strontium.

119. What is the maximum number of electrons in each of the following?
    a. the 8*j* sublevel **30**
    b. a 6*h* orbital **2**
    c. the n = 8 principle energy level **128**

122. Write the expected abbreviated electron configuration for the as-yet-undiscovered element with the atomic number of 121. Use Uuo for the symbol of the noble gas below xenon, Xe. (*Hint*: See Figure 4.29.)

    [Uuo] $8s^2\ 5g^1$ or [Uuo] $5g^1\ 8s^2$