# *Biology The Dynamic Science 4th edition Russell Solutions Manual*

SKU: 9781305389892-SOLUTIONS

# 2
# LIFE, CHEMISTRY, AND WATER

## Chapter Outline

WHY IT MATTERS

2.1 THE ORGANIZATION OF MATTER: ELEMENTS AND ATOMS

Living organisms are composed of about 25 key elements.

Elements are composed of atoms, which combine to form molecules.

2.2 ATOMIC STRUCTURE

The atomic nucleus contains protons and neutrons.

The nuclei of some atoms are unstable and tend to break down to form simpler atoms.

The electrons of an atom occupy orbitals around the nucleus.

Orbitals occur in discrete layers around an atomic nucleus.

The number of electrons in the outermost energy level of an atom determines its chemical activity.

*FOCUS ON APPLIED RESEARCH:* USING RADIOISOTOPES IN MEDICINE

2.3 CHEMICAL BONDS AND CHEMICAL REACTIONS

Ionic bonds are multidirectional and vary in strength.

Covalent bonds are formed by electrons in shared orbitals.

Unequal electron sharing results in polarity.

Polar molecules tend to associate with each other and exclude nonpolar molecules.

Hydrogen bonds also involve unequal electron sharing.

Van der Waals forces are weak attractions over very short distances.

Molecules have characteristic geometries that determine their functions in the cell.

Bonds form and break in chemical reactions.

2.4 HYDROGEN BONDS AND THE PROPERTIES OF WATER

A lattice of hydrogen bonds gives water several unusual, life-sustaining properties.

The differing densities of water and ice.

The boiling point and temperature-stabilizing effects of water.

Cohesion and surface tension.

The polarity of water molecules in the hydrogen-bond lattice contributes to polar and nonpolar environments in and around cells.

The small size and polarity of its molecules makes water a good solvent.

In the cell, chemical reactions involve solutes dissolved in aqueous solutions.

2.5 WATER IONIZATION AND ACIDS, BASES, AND BUFFERS

Substances act as acids or bases by altering the concentrations of $H^+$ and $OH^-$ ions in water.

Buffers help keep pH under control.

THINK OUTSIDE THE BOOK

UNANSWERED QUESTIONS

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

## Learning Objectives

2.1 Explain the composition of matter in terms of elements and atoms.
- 2.1.1 Describe the elemental composition of living organisms.
- 2.1.2 Describe atoms, molecules, elements, and compounds.

2.2 Describe the basic structure of atoms.
- 2.2.1 Summarize the constitution and properties of atoms and their isotopes.
- 2.2.2 Illustrate the arrangement of electrons around an atomic nucleus.
- 2.2.3 Explain how electrons determine the chemical properties of atoms.

2.3 Compare the four major types of chemical bonds.
- 2.3.1 Compare ionic, covalent, and hydrogen bonds.
- 2.3.2 Discuss polar and nonpolar bonds and molecular associations.
- 2.3.3 Describe van der Waals forces.
- 2.3.4 Explain the role of chemical bonds in chemical reactions and determining molecular shape.

2.4 Illustrate the structure and properties of water.
- 2.4.1 Discuss the role of the hydrogen bond lattice in determining the properties of water.
- 2.4.2 Discuss how molecular polarity contributes to the properties of water.

2.5 Describe the constitution and properties of acids, bases, and buffers.
- 2.5.1 Compare acids and bases.
- 2.5.2 Describe the pH scale.
- 2.5.3 Discuss the role of buffers in biological systems.

.

## Key Terms

element
matter
trace elements
atoms
molecules
formula
compounds
atomic nucleus
electrons
protons
atomic number
neutrons
isotopes
dalton
mass number
mass
weight
radioactivity
radioisotope
radiometric dating
tracers
orbital
energy levels
shells
valence electrons
chemical bonds
cation
anion
covalent bonds
electronegativity
nonpolar covalent bonds
polar covalent bonds
polar associations
nonpolar associations
hydrophilic
hydrophobic
hydrogen bonds
van der Waals forces
molecular geometry
reactants
products
chemical equations
water lattice
ice lattice
specific heat
calories
calorie
kilocalorie (kcal)
heat of vaporization
cohesion
surface tension
bilayer
hydration layer
solution
solvent
solute
concentration
atomic weight
Avogadro's number
molecular weight
mole (mol)
molarity
dissociate
reversible
acids
bases
acidity
pH scale
acid precipitation
buffers

## Lecture Outline

Why It Matters

A. All plants, animals, and other organisms are collections of atoms and molecules linked together by chemical bonds.
   1. Decades of research have confirmed that the same laws of chemistry and physics govern both living and nonliving things.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

2. Therefore, an understanding of the relationship between the structure of chemical substances and their behavior is the first step in learning biology.

2.1 The Organization of Matter: Elements and Atoms

A. There are 92 different elements occurring naturally on Earth, and more than 15 artificial elements have been synthesized in the laboratory.
   1. An element is a pure substance that cannot be broken down into simpler substances by ordinary chemical or physical techniques.
   2. Matter is anything that occupies space and has mass.

B. Living organisms are composed of about 25 key elements.
   1. Four elements make up 96% of the weight of living organisms: carbon, hydrogen, oxygen, and nitrogen.
   2. Seven elements compose most of the remaining 4%: calcium, phosphorus, potassium, sulfur, sodium, chlorine, and magnesium.
   3. Trace elements are those that compose <0.01% of an organism.
   4. The relative proportion of different elements in humans, plants, Earth's crust, and seawater are quite different from one another (Figure 2.1).
      a. The differences in the proportions of elements in living organisms compared to those in Earth's crust and seawater reflect the highly ordered chemical structure of living organisms.

C. Elements are composed of atoms, which combine to form molecules.
   1. Atoms are the smallest units that retain the chemical and physical properties of an element.
   2. Atoms are identified by a one- or two-letter symbol (Table 2.1).
   3. Atoms combine in fixed numbers and ratios to form molecules of living and nonliving molecules.
      a. Oxygen is a molecule formed from the chemical combination of two oxygen atoms.
      b. Carbon dioxide is a molecule of one carbon and two oxygen atoms chemically combined.
      c. The name of the molecule is written in chemical shorthand as a formula using the symbols $O_2$ and $CO_2$.
   4. Molecules whose component atoms are different, such as carbon dioxide, are called compounds.
      a. Chemical and physical properties of compounds are different from the atoms that make them up.
      b. Water ($H_2O$) is liquid, while hydrogen ($H_2$) and oxygen ($O_2$) are both gases.
      c. Water ($H_2O$) does not burn, while hydrogen ($H_2$) and oxygen ($O_2$) are quite explosive.

2.2 Atomic Structure

A. All atoms consist of the same basic structure, an atomic nucleus surrounded by one or more electrons (Figure 2.2).
   1. The electrons may occupy more than 99.99% of the space, and the nucleus makes up more than 99.99% of the total mass.

B. The atomic nucleus contains protons and neutrons.
   1. All atomic nuclei contain positively charged particles called protons.
      a. The number of protons in the nucleus of each kind of atom is referred to as the atomic number and specifically identifies the atom.
      b. The smallest atom is hydrogen and has a single proton in its nucleus (an atomic number of 1).
      c. The heaviest naturally occurring element is uranium and has 92 protons in its nucleus (an atomic number of 92).
      d. Carbon has six protons, nitrogen has seven, and oxygen has eight; therefore, they have atomic numbers of 6, 7, and 8 respectively (Table 2.1).
   2. The nucleus of all atoms (except one) contains uncharged particles called neutrons.
      a. The neutrons occur in variable numbers approximately equal to the number of protons.
      b. The exception is hydrogen; its nucleus commonly contains only one proton.
      c. Forms of hydrogen that contain neutrons are deuterium (one neutron with one proton in nucleus) and tritium (two neutrons with one proton in nucleus).
   3. Other atoms have common and less common forms with different numbers of nuclei.
      a. Carbon's most common form has six protons and six neutrons; the next most common (1%) contains six protons and seven neutrons.
   4. Distinct forms of the atoms of an element with the same number of protons but different numbers of neutrons are called isotopes (Figure 2.3).
      a. Various isotopes of an atom differ in mass and other physical characteristics, but all have essentially the same chemical properties.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

5. Atoms are assigned a mass number based on the total number of protons and neutrons in the atomic nucleus.
    a. Neutrons and protons have almost the same mass: $1.66 \times 10^{-24}$ grams (g).
    b. The standard unit of atomic mass is the dalton, named after John Dalton.
    c. The electrons are ignored because they are so small (1/1800 the mass of a proton).
    d. A hydrogen isotope with only one proton in its nucleus has a mass number of 1, and its mass is 1 dalton. Deuterium has a mass number of 2, and tritium 3.
    e. Carbon with six protons and six neutrons has a mass number of 12, expressed as $^{12}C$ or carbon-12. A Carbon with six protons and seven neutrons has a mass number of 13, expressed as $^{13}C$ or carbon-13.
6. Mass compared to weight.
    a. Mass is the amount of matter in an object.
    b. Weight measures the pull of gravity on an object.
    c. Weight can change with the pull of gravity; near weightless conditions occur in outer space.
    d. As long as an object is on the Earth's surface, measures of weight are equivalent.

C. The nuclei of some atoms are unstable and tend to break down to form simpler atoms.
1. The nuclei of some isotopes are unstable and can break down or decay.
    a. Radioactivity is particles of matter and energy given off by the breakdown of unstable isotopes.
    b. An unstable, radioactive isotope is called a radioisotope.
    c. The decay or breakdown occurs at a steady rate.
    d. The radioisotope can break down to other elements.
    e. In carbon-14, one of its neutrons splits into a proton and an electron. The electron is ejected from the nucleus, but the proton is retained, giving a new total of seven protons and seven neutrons, which is nitrogen.
2. Estimating age of organic material using unstable isotopes.
    a. These techniques have been vital in dating animal remains and tracing evolutionary lineages (Chapter 22).
    b. Isotopes are easily detected and are used in biological research as tracers. (Focus on Research: Applied Research). Common tracers included $^{14}C$, $^{32}P$, and $^{35}S$.

D. The electrons of an atom occupy orbitals around the nucleus.
1. The number of electrons surrounding the nucleus is equal to the number of protons in the nucleus (a neutral atom).
2. Electrons move very fast around a nucleus, approaching the speed of light.
    a. Electrons spend most of their time in specific regions around the nucleus called orbitals.
    b. Most orbitals contain two electrons for balance.
3. Electrons are maintained in their orbitals by a combination of attraction to positively charged protons and repulsion by negatively charged electrons.
4. Electrons can sometimes move from one orbital to another.

E. Orbitals occur in discrete layers around an atomic nucleus.
1. An atom contains regions of space called energy levels, or simply *shells*.
    a. The closest orbital has a spherical shape (1s), found in hydrogen and helium.
2. Atoms between atomic numbers 3 and 10 have two energy levels. Two electrons occupy the first orbital (1s). One to eight electrons occupy orbitals in the next energy level (Figure 2.5).
3. The third energy level, which may contain as many as 18 electrons in 9 orbitals, includes atoms from sodium (11 electrons) to argon (18 electrons).
    a. No matter the number of orbitals, the outermost energy level typically contains one to eight electrons, occupying a maximum of four orbitals.

F. The number of electrons in the outermost energy level of an atom determines its chemical activity.
1. Electrons in the outermost energy level are known as valence electrons.
    a. Atoms with the outermost energy level not completely filled with electrons tend to be chemically reactive.
    b. Hydrogen with one electron is highly reactive, while helium with two and a full outer shell is inert.
    c. Atoms with higher than two electrons commonly need eight electrons to fill the outer shell.
2. Atoms with outer energy levels that contain electrons near the stable number tend to gain or lose electrons.
    a. Sodium has one electron in its outer shell and tends to lose that electron to leave the inner level with a full eight.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

b. Chlorine with seven electrons in its outer shell tends to gain an electron to have a stable eight in the outer shell.

3. Atoms that have a stable configuration by more than one or two electrons tend to share electrons in joining orbitals with other atoms to reach a stable configuration.
   a. Oxygen and nitrogen tend to share electrons with other atoms.

*Focus on Applied Research:* Using Radioisotopes to Save Lives

A. Radioisotopes are used to diagnose and cure diseases.
   1. Radioisotopes are used to diagnose thyroid gland diseases.
   2. The thyroid gland absorbs iodine in large quantities.
   3. By injecting small amounts of radioactive iodine in a patient's blood, an image of the thyroid can be made from the radioactivity from the thyroid.

B. Treatment using radioactivity uses the fact that high doses of radioactivity kill cells.
   1. Dangerously overactive thyroid glands are treated using calculated doses of radioactive iodine to kill cells and bring the cells into a normal production level.

2.3 Chemical Bonds and Chemical Reactions

Four chemical linkages that are important for biological systems are ionic, covalent, and hydrogen bonds as well as van der Waals forces.

A. Ionic bonds are multidirectional and vary in strength.
   1. Ionic bonds occur between atoms that lose or gain valance electrons, forming a positive or negative ion.
      a. For example, sodium can give up an electron to become a positive 1 charge (called a cation), and chlorine can take an electron to become a negative 1 (called an anion) (Figure 2.6).
      b. The difference in charge that causes the two ions to attract to each other is an ionic bond.
   2. Many atoms can lose or gain electrons in the outer shell. When hydrogen loses its one electron, all that remains is a proton. This is often called a proton. When other atoms lose or gain electrons, the symbol reflects it with a positive or negative number (e.g., $Mg^{2+}$, $Fe^{2+}$, or $Ca^{2+}$).
   3. Ionic bonds hold ions, atoms, and molecules together in living organisms and have three key features.
      a. They exert an attractive force over a greater distance than any other bond.
      b. Their attractive force extends in all directions.
      c. They vary in strength depending on the presence of other charged substances.
      d. These features lead to certain molecules being held tightly by ionic bonds, like metal ions in biological molecules, or weakly, like water molecules. Many enzymatic proteins bind and release molecules by forming and breaking relatively weak ionic bonds.

B. Covalent bonds are formed by electrons in shared orbitals.
   1. Covalent bonds form when electrons are shared to fill valance electrons—such as hydrogen ($H_2$) when two atoms come together, each with one electron in the outer shell, and share to make two electrons in the low-energy shell, filling that valance.
   2. The description of $H_2$ is represented as H:H or H-H.
   3. Unlike ionic bonds, covalent bonds form attractions in directions forming three-dimensional structures.
   4. Carbon with four electrons in its outer shell forms four covalent bonds. These bonds can be with separate molecules like hydrogen or form double or triple bonds with oxygen or nitrogen.
   5. Oxygen, hydrogen, nitrogen, and sulfur often form covalent bonds in biological molecules with oxygen forming two, hydrogen forming one, nitrogen forming three, and sulfur forming two.

C. Unequal electron sharing results in polarity.
   1. Electronegativity is the measure of an atom's attraction for an electron shared in a chemical bond.
   2. Atoms vary in electronegativity and, therefore, share electrons differently.
      a. Nonpolar covalent bonds share electrons equally.
      b. Polar covalent bonds share electrons unequally.
      c. There is great variation in the sharing of electrons, giving part of the molecule a partial charge and no clear line between polar and nonpolar.
   3. Examples of nonpolar bonds are hydrogen ($H_2$) and oxygen ($O_2$).
   4. An example of polar bonds is water (Figure 2.8). Oxygen is more electronegative and gives partial charges to the molecule.
      a. The bonds are at angles, giving a unique shape and charge distribution.
      b. The partial charge allows water to dissolve polar materials.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

5. Oxygen, nitrogen, and sulfur all share electrons unequally; therefore, when they are present, the molecules tend to be more polar. (e.g., –OH, NH, or SH groups).
6. Carbon and hydrogen share electrons unequally; however, the distribution of hydrogen around a carbon (for example, $CH_4$) tends to cancel out to make the molecule as a whole nonpolar.

D. Polar molecules tend to associate with each other and exclude nonpolar molecules.
1. Polar molecules associate more readily with each other and are called hydrophilic (water-preferring), while nonpolar molecules do not associate with polar molecules and are called hydrophobic (water-avoiding).
2. An example of this can be demonstrated with water and vegetable oil. Place each in a single container and mix. After the bottle is at rest, the two will separate.

E. Hydrogen bonds also involve unequal electron sharing.
1. Hydrogen atoms are often made partially positive by unequal sharing with atoms, and these weak positive charges can attract the weak negative charges on other molecules, forming weak bonds called hydrogen bonds (Figure 2.9a).
2. Hydrogen bonds are weak compared to ionic or covalent bonds but are important in maintaining the stability of the large three-dimensional structure of biological molecules.
3. These weak bonds tend to be easy to break and will start breaking at 45 ºC and be nonexistent at 100 ºC.
   a. Thermophilic (temperature-loving) organisms have special biological molecules that are stable at these temperatures.

F. Van der Waals forces are weak attractions over very short distances.
1. Van der Waals forces are created by electrons accumulating by change in one part of a molecule, causing a partial charge.
2. A striking example is of geckos walking up a vertical, smooth surface (Figure 2.10).
   a. The toes are covered with millions of hairs, called setae, that are about 100 micrometers; at the tip are thousands of toe pads that are about 200 nanometers (smaller than the wavelength of visible light).
   b. Study of this has led to the development of a super adhesive prototype tape capable of holding 3 kg of weight with a 1 $cm^2$ piece.

G. Molecules have characteristic geometries that determine their functions in the cell.
1. Every molecule has a characteristic size and three-dimensional shape.
2. Molecular shape is crucial in biology because it determines the function of a molecule.
3. A number of drugs have been developed that work by mimicking the shape of natural molecules so that they block or interfere with the interactions of, and therefore the functions of, those natural molecules.
   a. For example, acetylcholine ($C_7H_{16}NO_2$) that binds in a lock-and-key fashion to a specific receptor, brings about contraction of the circular papillary sphincter muscle to contract the pupil in the eye.

H. Bonds form and break in chemical reactions.
1. Chemical reactions occur when atoms or molecules interact to form new chemical bonds or break old ones.
   a. Chemical reactions are accelerated by enzymes (Chapter 6).
2. Atoms or molecules entering a reaction are called reactants, while atoms or molecules leaving a reaction are called products.
3. For example, the overall reaction of photosynthesis: 6 carbon dioxide + 6 water (reactants) + light → a sugar + 6 oxygen (products).
   a. The number in front of each molecule is the number of molecules of that type in the reaction.
   b. The chemical equation is written $6CO_2 + 6H_2O$ + light → $C_6H_{12}O_6 + 6O_2$.
4. You are now ready to examine the properties of water.

## 2.4 Hydrogen Bonds and the Properties of Water

A. Water is crucial for life; between 50 and 95% of an organism is made of water.

B. A lattice of hydrogen bonds gives water several unusual, life-sustaining properties.
1. The differing densities of water and ice.
   a. Hydrogen bonds form readily between liquid water molecules, forming a constantly changing water lattice (Figure 2.11).
   b. In ice, the water lattice is a rigid crystalline structure, with bonds further apart than in liquid water.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

c. Bonds in ice being at greater distances than in liquid water makes ice 10% less dense when solid. (Almost all other substances are denser in solid form than liquid form.)
d. Water's greatest density is at 4 ºC while it is still a liquid.
e. Because ice is less dense, it will float on water as it freezes, creating an insulating layer that keeps water below the ice from freezing solid and making life possible for aquatic plants and animals.

2. The boiling point and temperature-stabilizing effects of water.
a. More heat is required to break the hydrogen-bond lattice of liquid water and make water boil.
b. Molecules that do form the hydrogen-bond lattice have lower boiling point.
c. Water has a relatively higher specific heat—the amount of heat required to increase the temperature.
d. Higher specific heat of water has a stabilizing effect on living organisms and their environment.
e. The specific heat of water is measured in calories—a unit that refers to the amount of heat required to raise the temperature of 1 g of water by 1 °C.
f. Water has high heat of vaporization—the amount of heat required to break loose water molecules to go from liquid water to gas.
g. High heat of vaporization allows humans and other organisms to cool off when hot and prevents increase of body temperature.

3. Cohesion and surface tension
a. The high resistance of water molecules to separate and be able to maintain the hydrogen-bond lattice is known as cohesion.
b. Water also bonds with other polar molecules—adhesion.
c. Microscopic tubes that extend from the roots to the highest leaves allow water to rise with the help of cohesion and adhesion.
d. Water molecules on the surface of large bodies of water bond with each other to create a strong force called the surface tension (Figure 2.12a).
e. Surface tension allows small insects to land or walk on water (Figure 2.12b).

C. The polarity of water molecules in the hydrogen-bond lattice contributes to polar and nonpolar environments in and around cells.
1. Polar substances can disturb the water lattice by creating temporary hydrogen bonds with the water molecules and, therefore, can move in the lattice. Nonpolar molecules cannot disturb the lattice; thus a drop of oil will remain on the surface of water and form spheres when shaken.
2. Distinct polar and nonpolar environments created by water are critical to the organization of cells.
a. Biological cell membranes have polar and nonpolar components, allowing the formation of a double layer, or bilayer (Figure 2.13).
3. The membrane prevents mixing of materials inside and outside the cell, which is necessary for life.

D. The small size and polarity of its molecules makes water a good solvent.
1. The hydration layer (water penetrating the surface of substances) allows water to reduce the attraction between molecules or ions and promotes their separation and entry into a solution, where they are suspended individually, surrounded by water molecules.
a. Water is called the solvent in such a solution.
b. The substance dissolved is called the solute.
2. Example: When table salt is added to water, the hydration layer quickly penetrates the ions of salt and separates $Na^+$ and $Cl^-$ (Figure 2.14). If the water evaporates, the $Na^+$ and $Cl^-$ reform to salt.

E. In the cell, chemical reactions depend on solutes dissolved in aqueous solutions.
1. The reactions are dependent on concentration—the number of molecules or ions of substance in a unit volume of space.
2. The mass number of atoms can be added to calculate the weight of any molecule.
a. Carbon has six protons and six neutrons, each $1.66 \times 10^{-24}$ g: $12 * 1.66 \times 10^{-24} = 1.992 \times 10^{-23}$.
b. Dividing the total weight of an element by the weight of a single atom gives the total number of atoms in that sample: $12 \text{ g} / 1.992 \times 10^{-23} = 6.022 \times 10^{23}$ number of atoms.
c. In fact, if you divide the atomic weight of oxygen (16) by the weight of on oxygen atom you get the same number.
d. This number is called Avogadro's number.
3. This relationship holds true for molecules as well.
4. When concentrations are described, the amount containing $6.022 \times 10^{23}$ atoms or molecules is known as a mole (mol). The number of moles of a substance dissolved in one liter of solution is known as the molarity (M). This is useful in chemistry and biology, because if we have two solutions of the same molarity we know we have the same number of molecules of each.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

2.5 Water Ionization and Acids, Bases, and Buffers

A. Substances act as acids or bases by altering the concentrations of $H^+$ and $OH^-$ ions in water. Water can dissociate into hydrogen ions ($H^+$ or protons) and hydroxide ions ($OH^-$).
   1. In pure water, the hydrogen and hydroxide ions are equal; however, when you add some substances, this ratio is altered.
      a. Hydrochloric acid dissociates to add a proton to water: HCl $\leftrightarrow$ $H^+$ $H^+$ $Cl^-$.
      b. Other substances are bases that take a proton from water: NaOH $\leftrightarrow$ $Na^+$ + $OH^-$. The $OH^-$ + $H^+$ → $H^2O$.
   2. Some substances directly accept a proton, like ammonia $NH_3$.
   3. The concentration of $H^+$ compared to $OH^-$ determines the acidity of the solution, measured on a logarithmic scale from 0 to 14.
      a. Equation: pH = -log10 [$H^+$]. Concentrations are in moles per liter.
      b. A pH of 7 is neutral because of the negative log; low pH indicates acids, and high pH indicates base conditions (Figure 2.15).
   4. pH is important to cells because very small changes in pH (0.1 or 0.01) can cause drastic changes in biological reactions.
   5. Acidity is also important in the environment. Acid rain falls with a pH of 3, near the pH of vinegar, and can harm wildlife, such as fishes and birds (Figure 2.15).

B. Buffers help keep pH under control.
   1. Living organisms maintain pH by using buffers (substances that resist change in pH). Buffers can release or add $H^+$ to solution.
      a. Strong acids and bases dissociate completely like HCl or NaOH.
   2. Most buffers are weak acids or bases that only partially dissociate in water. Bicarbonate ions are the most common buffer in blood: $H_2CO_3$ $\leftrightarrow$ $HCO_3$ + $H^+$ (Figure 2.16).
   3. Hyperventilation, breathing too fast, can drastically alter pH of blood by removing $CO_2$. $CO_2$ is the primary source of carbonic acid in the bloodstream. The alteration can cause dizziness, visual impairment, fainting, seizures, or even death.
   4. This chapter focused on basic structure of atoms and molecules; the next looks more closely at carbon molecules.

*Think Outside the Book*

A. Carbonic acid – Bicarbonate is only one of the mechanisms by which the human body maintains blood pH at a relatively constant level..
B. Discuss with the students what happens when the body pH changes.

*Unanswered Questions*

A. How can the effectiveness of uranium bioremediation by bacteria in soils and sediments be optimized?
   1. Uranium contamination of soils is a big concern in areas where uranium is extracted or processed.
   2. One approach is to use naturally occurring bacteria whose metabolism transforms uranium from a soluble to an insoluble form to prevent its spread into groundwater systems.
   3. Li Li is examining the factors that determine the effectiveness of bioremediation treatment at a uranium mining and processing site near Rifle, Colorado.
   4. Spatial distribution of important minerals (e.g., iron) strongly influences the effectiveness of bioremediation.
   5. The complexity of the subsurface systems requires an interdisciplinary approach, involving input from microbiologists, geochemists, hydrogeologists, and geophysicists.

## Teaching Challenges

Students have many common misconceptions about chemistry. Many of these are related to bonds and bond formation. For example, many students believe that atoms "need" to have all of the orbitals filled. Some other widely held misconceptions are that only covalent and ionic bonds are "real" bonds and that covalent bonds occur with equal sharing of the electron. In the literature, these misconceptions have been attributed to the use of ball-and-stick models that give a visual representation of the stick as a chemical bond. It is important to emphasize that there are more than two types of bonds; hydrogen bonds are very important to biological systems. The idea that atoms "need" to have their orbitals filled

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

is an important one to address. The idea that there is "need" in biology will also come up in later chapters, especially those pertaining to evolution and natural selection.

## Suggestions for Presenting the Material

- Bring a small amount of salt to class and a beaker of water. Dissolve the solid in front of the class. Then emphasize that, by the lecture, they will understand why the salt molecules dissolved in water and how the nature of atoms changes depending on the state.
- Discuss radioisotopes and tracking them either for medicinal purposes or for conservation (e.g., elucidating the foraging strategies of endangered species).
- Emphasize the importance of surface tension by putting water on a small glass plate (slowly) to show the curved nature of the droplet. Discuss how the availability of hydrogen accounts for the surface tension that gives the droplet its shape.
- Demonstrate surface tension and how it changes with the addition of other liquids by adding soap or pepper to the water in a petri dish.
- To reinforce the importance of van der Waals forces in biology, show a small clip of a gecko climbing on glass. (Pictures can be found on Google images and through some zoo cams).
- Bring pH paper to class and dip it into various substances: dish soap, lemon juice, a bit of saliva, anything that is readily available. This is many times better than just looking at Figure 2.15.

## Visual Learning Tips

- During lecture, show the periodic table of elements (or Figure 2.5) and discuss with students that the number of bonds an atom will form is based on its placement in the table.
- To illustrate the orbitals, show two animations: the electron arrangements in atoms and then the shell model of electron distribution. As you proceed through the lecture, students will have these visuals to draw on in order to understand the concepts being presented.
- To further help students understand the pH scale, show the animation on the pH scale in class.

## Educational Websites

These websites can be used for additional materials in lecture or discussion sections. In addition, you may choose to refer students to some of these websites for their own edification.

http://www.world-nuclear.org/info/Non-Power-Nuclear-Applications/Radioisotopes/Radioisotopes-in-Medicine/
http://www.sciencedaily.com/news/matter_energy/nature_of_water/
http://www.pmel.noaa.gov/co2/story/What+is+Ocean+Acidification%3F
http://study.com/academy/lesson/how-radioactive-isotopes-track-biological-molecules.html
http://news.bbc.co.uk/2/hi/science/nature/781611.stm
http://scifun.chem.wisc.edu/CHEMWEEK/BioBuff/BioBuffers.html

## Classroom Discussion

### *Why It Matters*

Have students discuss different types of chemical reaction and why understanding these reactions gives us a better insight into the processes that govern living and nonliving things.

### *Focus on Applied Research*

Ask students why isotopes exist; ask them to explain how they are formed and why they are unstable.
Ask students to explain why radioactive iodine isotope is useful for visualizing the thyroid.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

### *Unanswered Questions*

Discuss climate change and ocean acidification with students. Ask students to come up with ideas about what species are likely to be most impacted by ocean acidification and how it might impact their life. Have the students come up with potential solutions to the problem or ways to mitigate increasing ocean acidification.

### *Additional Discussion Ideas*

- Bring in a bag of chips and read the calorie content on the bag. Ask students to write a one-minute paper explaining what the term *calorie* really means.
- Show a picture of a jacana "walking" on water, and ask students to explain to a partner how this is possible.
- Discuss the pH of rain and what really causes acid rain.
- Discuss the path and the mechanism of water climbing up to the top of the tree.
- Use examples to discuss the types of chemical bonds.

## Classroom and Laboratory Enrichment

- Have students create a concept map relating chemical bonds to atoms. Key words included should be: chemical bonds, covalent, ionic, hydrogen, polar, and nonpolar. Have students build their concept map throughout lecture so the relatedness of topics from atoms to bonds can be seen.
- Have students form their own water lattice. Have multiple groups of three students make water molecules. Designate which students represent hydrogen and which represent oxygen. Have these students join hands, then drop hands and join hands with adjacent "oxygen." This is a very easy way to show that there can only be two bonds at a time (people only have two hands), but students can also see the fluidity, no pun intended, of water molecules as each hydrogen is moving around in front of class.
- Give students a list of atoms and ask them to rank the atoms from the highest to the lowest electronegativity. Next, give them a list of molecules made from the atoms, and ask whether they expect those molecules to form polar or nonpolar covalent bonds.
- Give the students a bowl of water, and have them put some oil in the water. Have them stir it around and watch as smaller drops of oil meet to form larger drops of oil (eventually one). Have the students write down why they think this phenomenon occurs. Next, have them drop in some dish soap and watch what happens. Have the students describe their observations and offer potential explanations.
- Give students a list of different atoms and have them see how many molecules they can form. Afterward, ask the students to look these atoms up in the CRC to see if they have actually been found in nature. For interesting molecules the students predict, say something about them and where they are found in nature.

## Term Paper Topics, Library Activities, and Special Projects

- Ozone is a very important part of our atmosphere. Have students do a small research project on ozone and its breakdown by chlorofluorocarbons (CFCs). Ask them to include a discussion on what types of commercial products have changed in the past 20 years based on what we know about how ozone reacts with other molecules.
- Have students do a web-based research project on ocean acidification.
- Radioisotopes have long been used to study the foraging strategies of different species. Have students research different organisms where this approach has been applied. Have them discuss develop a project that would apply this technology to conservation and management of endangered species.
- Send students home with pH paper and ask them to keep a log of the pH of the food items they eat.

## Suggested Readings


- Brenner C.J. *Alaska Peninsula stable isotope and radioisotope chemistry: A study in temporal and adaptive diversity*. HUMAN BIOLOGY, *82*(5/6), 613-627, 2010.


© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

- Kroeker, K.J., R.L. Kordas, R. Crim, I.E. Hendriks, L. Ramajo, G.S. Singh, C.M. Duarte, and J.Gattuso. *Impacts of ocean acidification on marine organisms: quantifying sensitivities and interaction with warming*. GLOBAL CHANGE BIOLOGY 19(6): 1884-1896, 2013.
- Ruth, T. *Accelerating production of medical isotopes*. NATURE, *457*(7229), 536-537, 2009.


## Possible Ideas for *Think Outside the Book*

1. Discuss another example of a buffering system. Recall that a buffer is something that can both donate and accept protons.
2. How does this buffering system help maintain pH? Hopefully students will discuss the log scale of pH, and explain the equilibrium reactions that many buffers are capable of in biologic conditions. You can bring them back to this exercise when you discuss hemoglobin and the transport of carbon dioxide in the body, during the circulatory and respiratory systems chapters.

## Possible Responses to *Discuss Concepts*

1. Detergents are amphipathic, with both hydrophobic and hydrophilic regions. Because of this, they are able to interact with both water and oil at the molecular level. This allows for the oil to "mix" with the water and release the surface it is on.
2. If ice were denser than liquid water, it would sink rather than float. This would be seriously detrimental to the animal life in ponds and rivers. Most of the animal life in a small aquatic ecosystem will overwinter in the bottom of a lake or pond. The ice on top provides an insulating layer, which prevents the water from freezing at the bottom and protects the animals.
3. Metal conducts heat much better than does water. The water would travel through the metal first, before warming the water within.
4. You could add a buffer, such as bicarbonate, to the solution. This would cause the solution to absorb the excess $H^+$ and keep the pH constant. A bicarbonate solution is one of the many ways human blood is kept at a constant pH.

## Possible Response to *Design an Experiment*

If you have a 0.5 M NaCl solution, you would need to add enough NaOH to have 0.5 NaOH. If you had 100mL of a 0.5 M solution of HCl, you would need 0.5 mole/L x 0.1 L x 40 g/mL = 2 g NaOH.

## Possible Response to *Apply Evolutionary Thinking*

1. There are many properties of water that enabled the evolution of life:
   - Cohesiveness (hydrogen bonding and high vapor point)
   - Polarity (enables a phospholipid bilayer to form)
   - Floats when frozen (related to the hydrogen bonding)
   - Resists temperature changes, which is a stabilizing variable

## Answers to Video Quiz

1. b

2. c

3. 1000

## Answers to *Interpret the Data*

1. About 50 minutes

2. (a) Using a pH of 5.9, $H^+$ concentration is 0.0000012589 ($1.2589 \times 10^{-6}$) *M* and $OH^-$ concentration is 0.00000000789433 ($7.9433 \times 10^{-9}$) *M*. (b) Using a pH of 2.5, $H^+$ concentration is 0.00316228 ($3.16228 \times 10^{-3}$) *M* and $OH^-$ concentration is 0.0000000000031623 ($3.1623 \times 10^{-12}$) *M*.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual

3. Using a pH of 2.5 for peak reflux and pH of 4.0 for clinical reflux, the $H^+$ concentration is 0.003 *M* greater, and $OH^-$ concentration is 0.0000000000968377 ($9.68377 \times 10^{-11}$) *M* less than a pH of 4.0.

© 2017 Cengage Learning. All Rights Reserved. May not be scanned, copied or duplicated, or posted to a publicly accessible website, in whole or in part.

Biology The Dynamic Science 4th edition Russell Solutions Manual