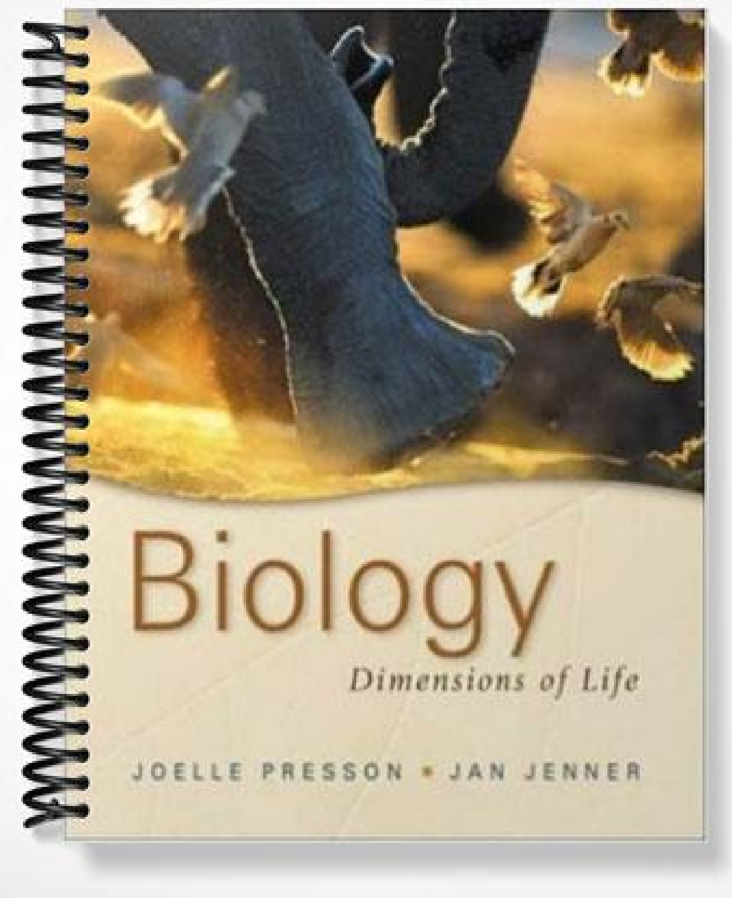
SOLUTIONS MANUAL



Chapter 2 Life Emerges from Chemistry: Atoms and Molecules

CHAPTER OVERVIEW

Of the 92 naturally occurring elements, only a few make up the bulk of living organisms. Beginning with the atomic structure of matter, the energy and number of electrons within an atom influences atomic bonding. The type of bonds which occur influence chemical reactions within organisms, with water playing an especially critical role overall.

In order to develop an understanding of the natural world, a basic understanding of matter, atomic structure and bonding is necessary.

LEARNING OBJECTIVES

A student should learn the following concepts:

1. Emergent properties arise at the atomic and molecular level in both structure and interactions.
2. Any substance that has mass and takes up space is called matter; the basic forms of matter are elements.
3. Atoms, the smallest units of elements which retain that element's properties, are formed from the subatomic particles, protons and neutrons in a nucleus, and electrons moving around the nucleus.
4. Influencing interactions within and between atoms, protons are positively charged, neutrons are neutral, and electrons are negatively charged.
5. Atoms may exist as ions, either anions or cations, and isotopes with varying numbers of neutrons.
6. The atomic number and atomic mass are important characteristics of atoms.
7. An electron is designated by an orbital which predicts the possible location of the electron.
8. How the orbitals are filled in an atom has an important effect on interactions between atoms and molecules, with less than full orbitals being critically important.
9. Electric force describes how the positively charged protons interact with the negatively charged electrons both within and between atoms.
10. Interacting atoms are held within a compound through the formation of chemical bonds.
11. Ionic bonds join ions; covalent bonds result in molecules which share electrons equally or unequally as found in polar molecules; and hydrogen bonds are important in many biological molecules and processes.
12. Chemical reactions involve a rearranging of atoms and energy in reactants resulting in products.
13. Water is a polar molecule with many characteristics important to living organisms such as its occurrence on earth as a gas, liquid and solid, resistance to temperature change, its cohesiveness and adhesiveness and its role as universal solvent.

14. Nonpolar molecules which do not dissolve in water play an important role in living organisms.
15. The pH of solutions within or surrounding living cells affect their function.
16. Cryopreservation is a process being developed in which humans are frozen to be revived later.

CHAPTER OUTLINE

2.1 New properties emerge when substances interact.
At the level of atoms and molecules, emergent properties arise which are critical to living organisms.

2.2 Matter is made of atoms.
Matter describes anything which has mass and takes up space. Matter on earth is found within 92 naturally occurring elements and some elements formed in the laboratory.

Elements are types of atoms.
Atoms are the units of elements which retain the properties of elements. Atoms are composed of the subatomic particles protons, neutrons, and electrons. Positively charged protons and neutral neutrons form the nucleus of an atom while negatively charged electrons move around the nucleus. Atoms may exist as ions, either anions or cations, and isotopes. The atomic number and atomic mass are important characteristics of each element.

Electrons move around an atom's nucleus in distinct orbitals.
The energy of electrons influence the orbital and shell in which they are found within an atom. Whether an orbital is full or less than full greatly impacts how one atom interacts with other atoms.

Internal electrical forces hold atoms together.
The positive charge of protons and the negative charge of electrons represent the electrical forces which cause attraction or repulsion within and between atoms.

2.3 Bonds hold atoms together in more complex structures.
Chemical bonds can hold atoms of different elements together in compounds. Ionic bonds join two ions in an ionic compound, while covalent bonds result in molecules.

Some atoms form molecules more readily than others do.
The number of electrons found in the outermost shell of an atom influences how atoms interact.

New properties emerge when atoms combine to form molecules.
As atoms interact, properties emerge which affect how ions or molecules function within living systems; the examples of sugar and collagen are discussed.

Bonds form within and between molecules, making even more complex structures.
The biologically important hydrogen bond is a relatively weak bond which forms between chemical groups that carry a partial and opposite electrical charge. Water molecules have polar covalent bonds in which electrons are shared unequally, creating positive and negative areas in the molecule. Water is a polar molecule and hydrogen bonds occur between water molecules.

Chemical bonds can be broken with an input of energy.
An input of energy can break the bonds found within or between molecules; the amount of energy required depends on the type of bond and the atoms involved.
Atoms are rearranged in chemical reactions that can transform one substance to another.
Chemical reactions involve reactants, energy and products.
2.4 The chemicals of life interact in water.
Water has unique characteristics important to living organisms.
Water is an unusual molecule.
Water can be found as a solid, liquid and gas at temperatures commonly found on Earth, but water is most commonly found as a liquid. Water resists temperature change, keeping temperatures on earth more stable. Because of their polar nature, water molecules are cohesive and adhesive. Water acts as the universal solvent, that is, many substances dissolve in water which facilitates chemical reactions.
The polar structure of water produces unusual properties.
Because water molecules are polar, hydrogen bonds form but these bonds are weak and easily broken with an input of energy. Because water molecules are polar, other polar molecules and ions readily dissolve in water. And because water molecules are polar, nonpolar substances cannot dissolve in water.
Chemical interaction within living organisms involve molecules and atoms dissolved in water.
The watery environment of cells, both internally and externally, allows for chemical reactions to occur.
Life's chemical interactions cannot occur in an environment that is too acidic or too basic.
The pH, or H^+ concentration, greatly affects chemical reactions and must be regulated within living organisms. The pH scale ranges from 0 to 14; pH 7 is neutral, less than 7 acidic, more than 7 basic.
2.5 How do you know? The science of cryopreservation.
Humans are interested in prolonging their lives through the freezing of their bodies at death. The technology of cryopreservation as of yet is not successful but organisms such as frogs and deep sea ocean fish which survive freezing temperatures are being studied.
What do you think?
Information and questions regarding the amount of water one should drink are introduced to stimulate discussion.

LECTURE ENRICHMENT

2.1 New properties emerge when substances interact.
1. The Miller-Urey reaction: In a quest for knowledge about early life on earth, many scientists have explored, hypothesized and experimented and continue to do so. In 1952, Harold Urey proposed a set of conditions that could have been present on the earth before life forms, conditions which might have led to the development of life. Stanley Miller, in 1953, published his experiment using Urey's conditions to see, if indeed, something would arise which could lead to life. The experiment was conducted in a closed system containing hydrogen, ammonia, and methane gases as well as water vapor. An electric

discharge was applied to simulate lightning. This was repeated for several weeks. Miller found than some amino acids were formed in this vessel along with certain organic molecules including formaldehyde (HCHO) and hydrogen cyanide (HCN). There was no oxygen in the early atmosphere; that had to wait for photosynthesis to evolve.
2. Bonding in starch vs. cellulose: Both amylopectin (a type of starch) and cellulose are long chains of monosaccharides (specifically glucose) found in plants but each has a very different function. How can this be? Amylopectin is made of alpha-glucose and it is a long, branched molecule. Amylopectin is an energy-storage molecule; easily digested by plants, animals, and bacteria. Cellulose, on the other hand, is made of beta-glucose and it is a long, linear chain – no branches. Cellulose is not digestible by most organisms; it is a structural molecule, giving plants strength to grow to greater heights. The difference between alpha- and beta-linkages? The position of one –OH group which influences how the subunits are assembled. How's that for emergent properties!

2.2 Matter is made of atoms.
1. Have the students work in small groups of two or three to compare and contrast the effect electrons and protons have on atomic interactions. (protons have an effect on the electrons and where they are orbiting the nucleus; electrons interact with other atoms depending on what orbital they occupy)
2. When Dmitri Mendeleev in 1869 discovered the pattern that elements could follow as expressed in the Periodic Table, not all elements were known. There were gaps. Mendeleev predicted the properties the elements would have should fill the gaps. Scientists then looked for and eventually found the elements which fit the gaps. Following Mendeleev's publication of the periodic table, the elements gallium (1875), scandium (1879), and germanium (1886) were discovered which filled three of the gaps and displayed the properties Mendeleev predicted.
3. Ask the students if they can come up with examples of the elements sulfur, phosphorus, helium, chlorine, sodium, aluminum, nickel, silicon, radium, uranium, or neon in everyday life. (e.g., coins such as nickels, metals in belt buckles or metal buttons on jeans have nickel; look at the label on a bottle of soda pop; is phosphorus found?; aluminum in pots and pans; silicon in glass; neon signs; helium for balloons; uranium in nuclear power plants; sodium and chloride in table salt or packaged food)
4. The element nitrogen is critical to many biological molecules. Proteins are full of nitrogen atoms. The air is also full of nitrogen atoms as the N_2 molecule. Air is 78% nitrogen so it is plentiful for everyone to use. Not so fast; plants are unable to use atmospheric nitrogen. This may seem odd as plants are set up to absorb the gas carbon dioxide from the air. However, plants depend on soil bacteria to convert gaseous nitrogen to a form plants can use or to decompose organic matter, returning nitrogen to the ecosystem for plants to use.
5. The students will in future chapters discover how important the hydrogen ion, H^+, is for chemical processes in living organisms. Hydrogen is the most prevalent element in the universe. Stars, including our sun, are made of hydrogen atoms fusing into helium atoms and releasing great amounts of energy from which all life benefits.
6. The nature of oxygen. Oxygen is an atom with two unpaired electrons in its outer shell. In air, oxygen typically occurs as O_2. Some O_2 molecules react with each other when exposed to ultraviolet light or electrical discharge within the atmosphere to form

O_3, or ozone. Ozone forms a critical layer in our atmosphere which protects living organisms from much of the ultraviolet radiation which strikes the atmosphere. Certain aerosols degrade ozone, hence the banning of some of these aerosol propellants and certain coolants. Because of the unpaired electrons, oxygen molecules can actually pick up an extra electron or two. This is one way an oxygen radical, also known as reactive oxygen species, can form. These anions are highly reactive. As part of normal metabolic processes, oxygen radicals are used in a number of ways by living organisms. But sometimes, oxygen radicals form which cause great damage to DNA, proteins and other organic molecules. Consuming foods which contain molecules that are anti-oxidants, such as blueberries, help protect us from the damage.

2.3 Bonds hold atoms together in more complex structures.

1. Have the students work in small groups of two or three and discuss what effects on bonding between atoms would occur if individual atoms were to suddenly lose the structure of electron orbitals.
2. Have the students work in small groups of two or three to compare and contrast ionic bonds and polar covalent bonds.
3. A sodium atom has 11 electrons; only one electron is in the third orbital. This lone electron is a wild and active electron, ready to be given away. Once this electron is given away, the sodium atom, Na^+, is stable, having a full outer shell. A chlorine atom has 17 electrons. One more electron will create a full outer shell; a chloride ion, Cl^-, is thus more stable.
4. The importance of shape: The DNA molecule is a long, fibrous molecule containing the instructions to run a living organism. When the instructions need to be copied, areas of the DNA molecule are exposed by stretching out the fiber. However, when an area of DNA is not in use or a cell is getting ready to divide, the long molecule is wrapped around proteins called histones in part using hydrogen bonding.
5. Ask the students to categorize ionic bond, covalent bond and hydrogen bond either as 'between particles' or 'within molecules.' Why can't we use molecule instead of particle in the first category? Ions are not molecules!
6. The sweetness of sugars depends on the structure of the carbohydrate. Glucose, a single-unit sugar or monosaccharide, is the all-important energy molecule used in cellular respiration. There are alpha and beta forms which differ only in the placement of one hydroxyl group. Maltose, a disaccharide which forms as a result of starch digestion, is made of two glucose subunits in a 1 alpha – 4 linkage – that is, carbon 1 of the first alpha glucose is bonded to carbon 4 of the second alpha glucose. Maltose is sweet, about one third as sweet as sucrose. Cellobiose is also a disaccharide, made of two beta glucoses with a 1 beta – 4 linkage. Cellobiose is a breakdown product of cellulose – a plant molecule not digestible by many organisms other than bacteria, fungi, and a few single-celled organisms found in termites. Cellobiose is not sweet at all.

2.4 The chemicals of life interact in water.

1. Have the students work in groups of two or three and consider the following: Which characteristic of water is more important; its ability to dissolve many chemicals or its ability to resist temperature change? Justify your answer. (no correct answer, justifications and discussion is what is important)

2. Water stabilizes environments on earth from great temperature swings. Tropical rain forests have temperature ranges about 25 to 32 degrees C while many deserts have temperatures ranges around 15 to 35 degrees C. Many other factors influence air temperatures including latitude and elevation.

3. Ask the students to imagine beads of water on a freshly waxed car or on the surface of a shiny leaf. What two properties of water are demonstrated here? (cohesion of bead, repelling of polar water and nonpolar wax of both the car and leaf)

4. Testing pH. Take into class some pH paper and the color charts. Bring in items for students to test or ask them to test any drinks they've brought into class with them. Some suggestion of items to test: coffee, soda pop, juice, fruit, yogurt, water. Human's appear to be well adapted to acidic foods but not basic substances. A human's stomach pH is 2.

5. Carbon dioxide dissolved in water forms a weak acid called carbonic acid (if you tested soda pop in #4, it should have tested as an acidic pH). Ask the students: where in the human body will you find CO_2 dissolved in fluid? (in the blood, carbon dioxide is a metabolic waste released from cells to the bloodstream and from the bloodstream to the air in the lungs) Blood must contain a substance called a buffer which has the capacity to either take up or release H^+ in order to maintain a pH, for blood it is typically 7.4, nearly neutral. If pH is not maintained at 7.4 in the blood, other molecules would be affected, causing malfunctions.

2.5 How do you know? The science of cryopreservation.

1. Have the students work in small groups of three or four and discuss the following: predict what frostbite is at the cellular level and what action specifically causes the damage. (actual freezing of cells at extremities, ice formation in cells causes tearing by the expansion of solid water versus liquid water and the formation of sharp edges by the ice crystals)

2. Frozen frogs; how do they do it? The common wood frog, *Rana sylvaticus*, is the only frog found in the Arctic Circle, however it does occur in many places in North America and as far south as Georgia. During their active season, the wood frog stores up large amounts of glycogen in its liver. As its body begins to freeze when temperatures drop, the liver converts the glycogen to glucose which is dispersed throughout the frog's body. As ice crystals form under the skin and in between the skeletal muscles, the cells, full of glucose, are prevented from freezing as glucose lowers the freezing point of the cytoplasm. About two thirds of the frog's body freezes, but not the cytoplasm, protecting the cell membrane and organelles. While frozen, breathing, heartbeat and blood flow cease. Studies show that thawing occurs from the inside out with the heart resuming function first, followed by the brain with the limbs being last. There are a number of insects which can freeze during winter as well.