Chapter 2

Essential Chemistry for Biology

Biology and Society: More Precious than Gold

- A drought is
  - a period of abnormally dry weather that changes the environment and
  - one of the most devastating disasters.

Figure 2.0

- Droughts can cause
  - severe crop damage,
  - shortages of drinking water,
  - dust storms,
  - famine,
  - habitat loss, and
  - mass migration.
- Throughout human history, droughts have helped wipe out societies and even whole civilizations.
- Droughts are catastrophic because life cannot exist without water.

SOME BASIC CHEMISTRY

- Take any biological system apart, and you eventually end up at the chemical level.
- Chemical reactions are always occurring in the human body.

Matter: Elements and Compounds

- **Matter** is anything that occupies space and has mass.
- Matter is found on Earth in three physical states:
  - solid,
  - liquid, and
  - gas.
- Matter is composed of chemical elements.
  - An **element** is a substance that cannot be broken down into other substances by chemical reactions.
  - There are 92 naturally occurring elements on Earth.
- All of the elements are listed in the periodic table.

Figure 2.1a
Figure 2.1b
Figure 2.1c
Figure 2.1d

- Twenty-five elements are essential to people.
- Four elements make up about 96% of the weight of most cells:
  - oxygen,
  - carbon,
  - hydrogen, and
  - nitrogen.

Figure 2.2

- **Trace elements** are
  - required in only very small amounts and
  - essential for life.
- An iodine deficiency causes goiter.
- Fluorine
  - is added to dental products and drinking water and
  - helps to maintain healthy bones and teeth.

Figure 2.3
Figure 2.3a
Figure 2.3b

- Elements can combine to form compounds.
  - **Compounds** are substances that contain two or more elements in a fixed ratio.
  - Common compounds include
    - NaCl (table salt) and

- H_2O (water).

Atoms

- Each element consists of one kind of atom.
  - An **atom** is the smallest unit of matter that still retains the properties of an element.

The Structure of Atoms

- Atoms are composed of subatomic particles.
  - A **proton** is positively charged.
  - An **electron** is negatively charged.
  - A **neutron** is electrically neutral.
- Most atoms have protons and neutrons packed tightly into the nucleus.
  - The **nucleus** is the atom's central core.
  - Electrons orbit the nucleus.

Figure 2.4

- Elements differ in the number of subatomic particles in their atoms.
  - The number of protons, the **atomic number**, determines which element it is.
  - **Mass** is a measure of the amount of material in an object.
  - An atom's **mass number** is the sum of the number of protons and neutrons in its nucleus.

Isotopes

- **Isotopes** are alternate mass forms of an element.
- Isotopes
  - have the same number of protons and electrons but
  - differ in their number of neutrons.

Table 2.1

- The nucleus of a **radioactive isotope** decays spontaneously, giving off particles and energy.
- Radioactive isotopes have many uses in research and medicine.
  - They can be used to determine the fate of atoms in living organisms.
  - They are used in PET scans to diagnose heart disorders and some cancers.

Figure 2.5

- Uncontrolled exposure to radioactive isotopes can harm living organisms by damaging DNA.
  - The 1986 Chernobyl nuclear accident released large amounts of radioactive isotopes.
  - Naturally occurring radon gas may cause lung cancer.

Electron Arrangement and the Chemical Properties of Atoms

- Of the three subatomic particles, only electrons are directly involved in the chemical activity of an atom.
- Electrons orbit the nucleus of an atom in specific electron shells.
- The farther an electron is from the nucleus, the greater its energy.
- The number of electrons in the outermost shell determines the chemical properties of an atom.

Figure 2.6
Figure 2.6a
Figure 2.6b

Chemical Bonding and Molecules

- Chemical reactions enable atoms to give up or acquire electrons, completing their outer shells.
- Chemical reactions usually result in atoms
  - staying close together and
  - being held together by attractions called **chemical bonds**.

Ionic Bonds

- When an atom loses or gains electrons, it becomes electrically charged.
  - Charged atoms are called **ions**.
  - **Ionic bonds** are formed between oppositely charged ions.

Figure 2.7-1
Figure 2.7-2

Covalent Bonds

- A **covalent bond** forms when two atoms *share* one or more pairs of outer-shell electrons.
- Covalent bonds are the strongest of the various bonds.
- Covalent bonds hold atoms together in a **molecule**.
- The number of covalent bonds an atom can form is equal to the number of additional electrons needed to fill its outer shell.

Figure 2.8
Hydrogen Bonds

- Water is a compound in which the electrons in its covalent bonds are not shared equally.
  - This causes water to be a **polar molecule**, one with an uneven distribution of charge.

Figure 2.UN01
Figure 2.UN02

- The polarity of water results in weak electrical attractions between neighboring water molecules.
  - These weak attractions are called **hydrogen bonds**.

Figure 2.9
Chemical Reactions

- Cells constantly rearrange molecules by breaking existing chemical bonds and forming new ones.
  - Such changes in the chemical composition of matter are called **chemical reactions**.
  - A simple example is the reaction between oxygen gas and hydrogen gas that forms water.

Figure 2.UN03

- Chemical reactions include
  - **reactants**, the starting materials, and
  - **products**, the end materials.
- Chemical reactions
  - can rearrange matter
  - but cannot create or destroy matter.

WATER AND LIFE

- Life on Earth began in water and evolved there for 3 billion years.
  - Modern life remains tied to water.
  - Your cells are composed of 70–95% water.
- The abundance of water is a major reason Earth is habitable.

Figure 2.10
Water's Life-Supporting Properties

- The polarity of water molecules and the hydrogen bonding that results explain most of water's life-supporting properties.
  - Water molecules stick together.
  - Water has a strong resistance to change in temperature.
  - Frozen water floats.
  - Water is a common solvent for life.

The Cohesion of Water

- Water molecules stick together as a result of hydrogen bonding.
  - This tendency of molecules of the same kind to stick together is called **cohesion**.
  - Cohesion is vital for the transport of water from the roots to the leaves of plants.

Figure 2.11
Figure 2.11a
Figure 2.11b

- Surface tension is the measure of how difficult it is to stretch or break the surface of a liquid.
  - Hydrogen bonds give water an unusually high surface tension.

Figure 2.12
How Water Moderates Temperature

- Because of hydrogen bonding, water has a strong resistance to temperature change.
- Heat and temperature are related, but different.
  - **Heat** is the amount of energy associated with the movement of the atoms and molecules in a body of matter.
  - **Temperature** measures the intensity of

heat.

- Water can absorb and store large amounts of heat while only changing a few degrees in temperature.
- Water can moderate temperatures.
  - Earth's giant water supply causes temperatures to stay within limits that permit life.
  - **Evaporative cooling** occurs when a substance evaporates and the surface of the liquid remaining behind cools down.

Figure 2.13

The Biological Significance of Ice Floating

- When water molecules get cold enough, they move apart, forming ice.
- A chunk of ice has fewer water molecules than an equal volume of liquid water.
- Ice floats because it is less dense than liquid water.

Figure 2.14

- If ice did not float, ponds, lakes, and even the oceans would freeze solid.
- Life in water could not survive if bodies of water froze solid.

Water as the Solvent of Life

- A **solution** is a liquid consisting of a homogeneous mixture of two or more substances.
  - The dissolving agent is the **solvent**.
  - The dissolved substance is the **solute**.
- When water is the solvent, the result is an **aqueous solution**.

Figure 2.15

The Process of Science:
Can Exercise Boost Your Brain Power?

- **Observation**: Human brains shrink as we age.
- **Question**: Can aerobic exercise slow or reverse brain loss?
- **Hypothesis**: MRI scans will reveal differences between people who regularly exercised aerobically and those who did not.

Figure 2.UN04

- **Prediction**: Brains of active people shrink less than the brains of less active people.
- **Experiment**: Twenty-nine people in their 60s and 70s exercised for three one-hour sessions per week. A control group of 29 people engaged in non-aerobic stretching exercises for the same periods.
- **Results**: The aerobic group showed significant increases in brain volume compared to the non-aerobic group.

Figure 2.16

Acids, Bases, and pH

- A chemical compound that releases H^+ to a solution is an **acid**.
- A compound that accepts H^+ and removes them from solution is a **base**.
- To describe the acidity of a solution, chemists use the **pH scale**.

Figure 2.17
Figure 2.17a

- **Buffers** are substances that resist pH change.
- Buffers
  - accept H^+ ions when they are in excess and
  - donate H^+ ions when they are depleted.
- Increases in global CO_2 concentrations may lead to
  - the acidification of the oceans and
  - ecological disasters.

Figure 2.18

Evolution Connection:
The Search for Extraterrestrial Life

- If life similar to ours has evolved elsewhere in the universe, then it too would depend upon water.
- Researchers at NASA missions have found evidence that water was once abundant on Mars.
- Microbial life may exist below the Martian surface.

Figure 2.19
Figure 2.19a
Figure 2.19b
Figure 2.UN05
Figure 2.UN06
Figure 2.UN07
Figure 2.UN08

Figure 2.UN09a
Figure 2.UN09b
Figure 2.UN10
Figure 2.UN11
Figure 2.UN12