Chapter 3

The Molecules of Life

Biology and Society: Got Lactose?

- Lactose is the main sugar found in milk.
- Lactose intolerance is the inability to properly digest lactose.
  - Instead of lactose being broken down and absorbed in the small intestine,
  - lactose is broken down by bacteria in the large intestine, producing gas and discomfort.

Biology and Society: Got Lactose?

- Lactose intolerance can be addressed by
  - avoiding foods with lactose or
  - consuming lactase pills along with food.

Figure 3.0

ORGANIC COMPOUNDS

- A cell is mostly water.
- The rest of the cell consists mainly of carbon-based molecules.
- Carbon forms large, complex, and diverse molecules necessary for life's functions.
- **Organic compounds** are carbon-based molecules.

Carbon Chemistry

- Carbon is a versatile atom.
  - It has four electrons in an outer shell that holds eight electrons.
  - Carbon can share its electrons with other atoms to form up to four covalent bonds.

Carbon Chemistry

- Carbon can use its bonds to
  - attach to other carbons and
  - form an endless diversity of carbon skeletons varying in size and branching pattern.

Figure 3.1
Figure 3.1a
Figure 3.1b
Figure 3.1c
Figure 3.1d

- The simplest organic compounds are **hydrocarbons,** which contain only carbon and hydrogen atoms.
- The simplest hydrocarbon is methane, a single carbon atom bonded to four hydrogen atoms.

Figure 3.2

- Larger hydrocarbons form fuels for engines.
- Hydrocarbons of fat molecules are important fuels for our bodies.

Figure 3.3

- Each type of organic molecule has a unique three-dimensional shape.
- The shapes of organic molecules relate to their functions.
- The unique properties of an organic compound depend on
  - its carbon skeleton and
  - the atoms attached to the skeleton.
- The groups of atoms that usually participate in chemical reactions are called **functional groups**. Two common examples are
  - hydroxyl groups (-OH) and
  - carboxyl groups (-COOH).
- Many biological molecules have two or more functional groups.

Giant Molecules from Smaller Building Blocks

- On a molecular scale, many of life's molecules are gigantic, earning the name **macromolecules**.
- Three categories of macromolecules are
  - carbohydrates,
  - proteins, and
  - nucleic acids.
- Most macromolecules are polymers.
- **Polymers** are **made** by stringing together many smaller molecules called **monomers**.
- A **dehydration reaction**
  - links two monomers together and

- removes a molecule of water.

Figure 3.4
Figure 3.4a
Figure 3.4b

LARGE BIOLOGICAL MOLECULES

- There are four categories of large biological molecules:
  - carbohydrates,
  - lipids,
  - proteins, and
  - nucleic acids.

Carbohydrates

- **Carbohydrates** include sugars and polymers of sugar. They include
  - small sugar molecules in energy drinks and
  - long starch molecules in spaghetti and French fries.

Carbohydrates

- In animals, carbohydrates are
  - a primary source of dietary energy and
  - raw material for manufacturing other kinds of organic compounds.
- In plants, carbohydrates serve as a building material for much of the plant body.

Monosaccharides

- **Monosaccharides** are
  - simple sugars that cannot be broken down by hydrolysis into smaller sugars and
  - the monomers of carbohydrates.
- Common examples are
  - glucose in sports drinks and
  - fructose found in fruit.

Monosaccharides

- Both glucose and fructose are found in honey.
- Glucose and fructose are **isomers**, molecules that have the same molecular formula but different structures.

Figure 3.5
Figure 3.5a

- Monosaccharides are the main fuels for cellular work.
- In water, many monosaccharides form rings.

Figure 3.6
Figure 3.6a
Figure 3.6b

Disaccharides

- A **disaccharide** is
  - a double sugar,
  - constructed from two monosaccharides, and
  - formed by a dehydration reaction.

Figure 3.7
Figure 3.7a

- Disaccharides include
  - lactose in milk,
  - maltose in beer, malted milk shakes, and malted milk ball candy, and
  - sucrose in table sugar.
- Sucrose is
  - the main carbohydrate in plant sap and
  - rarely used as a sweetener in processed foods in the United States.
- High-fructose corn syrup is made by a commercial process that converts
  - natural glucose in corn syrup to
  - much sweeter fructose.

Figure 3.8

- The United States is one of the world's leading markets for sweeteners.
- The average American consumes
  - about 45 kg of sugar (about 100 lb) per year,
  - mainly as sucrose and high-fructose corn syrup.

Polysaccharides

- **Polysaccharides** are

- complex carbohydrates
- made of long chains of sugar units—polymers of monosaccharides.

Figure 3.9

- **Starch**
  - is a familiar example of a polysaccharide,
  - is used by plant cells to store energy, and
  - consists of long strings of glucose monomers.
- Potatoes and grains are major sources of starch in our diet.

Figure 3.9a

- **Glycogen** is
  - used by animals cells to store energy and
  - converted to glucose when it is needed.

Figure 3.9b

- **Cellulose**
  - is the most abundant organic compound on Earth,
  - forms cable-like fibrils in the walls that enclose plant cells, and
  - cannot be broken apart by most animals.

Figure 3.9c
Figure 3.9d

- Monosaccharides and disaccharides dissolve readily in water.
- Cellulose does not dissolve in water.
- Almost all carbohydrates are **hydrophilic**, or "water-loving," adhering water to their surface.

Lipids

- **Lipids** are
  - neither macromolecules nor polymers and
  - **hydrophobic**, unable to mix with water.

Figure 3.10

Fats

- A typical **fat**, or **triglyceride,** consists of
  - a glycerol molecule,
  - joined with three fatty acid molecules,
  - via a dehydration reaction.

Figure 3.11
Figure 3.11a
Figure 3.11b

- Fats perform essential functions in the human body including
  - energy storage,
  - cushioning, and
  - insulation.
- If the carbon skeleton of a fatty acid
  - has fewer than the maximum number of hydrogens, it is **unsaturated**;
  - if it has the maximum number of hydrogens, it is **saturated**.
- A saturated fat has
  - no double bonds and
  - all three of its fatty acids saturated.
- Most animal fats
  - have a high proportion of saturated fatty acids,
  - can easily stack, tending to be solid at room temperature, and
  - contribute to **atherosclerosis**, in which lipid-containing plaques build up along the inside walls of blood vessels.
- Most plant and fish oils tend to be
  - high in unsaturated fatty acids and
  - liquid at room temperature.
- **Hydrogenation**
  - adds hydrogen,

- converts unsaturated fats to saturated fats,
- makes liquid fats solid at room temperature, and
- creates **trans fat**, a type of unsaturated fat that is particularly bad for your health.

Figure 3.12
Figure 3.12a
Figure 3.12b

Steroids

- **Steroids** are very different from fats in structure and function.
  - The carbon skeleton is bent to form four fused rings.
  - Steroids vary in the functional groups attached to this set of rings, and these chemical variations affect their function.

Steroids

- Cholesterol is
  - a key component of cell membranes and
  - the "base steroid" from which your body produces other steroids, such as estrogen and testosterone.

Figure 3.13
Figure 3.13a

- Synthetic anabolic steroids
  - are variants of testosterone,
  - mimic some of its effects,
  - can cause serious physical and mental problems,
  - may be prescribed to treat diseases such as cancer and AIDS, and
  - are abused by athletes to enhance performance.
- Most athletic organizations now ban the use of anabolic steroids because of their
  - health hazards and
  - unfairness, by providing an artificial advantage.

Figure 3.14
Figure 3.14a

Proteins

- **Proteins**
  - are polymers constructed from amino acid monomers,
  - account for more than 50% of the dry weight of most cells,
  - perform most of the tasks required for life, and
  - form enzymes, chemicals that change the rate of a chemical reaction without being changed in the process.

Figure 3.15
Figure 3.15a
Figure 3.15b
Figure 3.15c
Figure 3.15d
Figure 3.15e

The Monomers of Proteins: Amino Acids

- All proteins are macromolecules constructed from a common set of 20 kinds of amino acids.
- Each **amino acid** consists of a central carbon atom bonded to four covalent partners.
- Three of those attachment groups are common to all amino acids:
  - a carboxyl group (-COOH),
  - an amino group (-NH_2), and
  - a hydrogen atom.

Figure 3.16
Figure 3.16a
Figure 3.16b

Proteins as Polymers

- Cells link amino acids together
  - by dehydration reactions,
  - forming **peptide bonds,** and
  - creating long chains of amino acids called **polypeptides**.

Figure 3.17-1
Figure 3.17-2

- Your body has tens of thousands of different kinds of protein.
- Proteins differ in their arrangement of amino acids.
- The specific sequence of amino acids in a protein is its **primary structure**.

Figure 3.18

- A slight change in the primary structure of a protein affects its ability to function.
- The substitution of one amino acid for another in hemoglobin

causes sickle-cell disease, an inherited blood disorder.
Figure 3.19

Protein Shape

- A functional protein consists of
  - one or more polypeptide chains,
  - precisely twisted, folded, and coiled into a molecule of unique shape.

Protein Shape

- Proteins consisting of one polypeptide have three levels of structure.
- Proteins consisting of more than one polypeptide chain have a fourth level, quaternary structure.

Figure 3.20-1
Figure 3.20-2
Figure 3.20-3
Figure 3.20-4

- A protein's three-dimensional shape
  - typically recognizes and binds to another molecule and
  - enables the protein to carry out its specific function in a cell.

Figure 3.21

What Determines Protein Shape?

- A protein's shape is sensitive to the surrounding environment.
- An unfavorable change in temperature and/or pH can cause **denaturation** of a protein, in which it unravels and loses its shape.
- High fevers (above 104°F) in humans can cause some proteins to denature.
- Misfolded proteins are associated with
  - Alzheimer's disease,
  - mad cow disease, and
  - Parkinson's disease.

Nucleic Acids

- Nucleic acids are macromolecules that
  - store information,
  - provide the directions for building proteins, and
  - include **DNA** and **RNA**.
- DNA resides in cells in long fibers called chromosomes.
- A **gene** is a specific stretch of DNA that programs the amino acid sequence of a polypeptide.
- The chemical code of DNA must be translated from "nucleic acid language" to "protein language."

Figure 3.22

- Nucleic acids are polymers made from monomers called **nucleotides**.
- Each nucleotide has three parts:
  - a five-carbon sugar,
  - a phosphate group, and
  - a nitrogen-containing base.

Figure 3.23
Figure 3.23a

- Each DNA nucleotide has one of four possible nitrogenous bases:
  - adenine (A),
  - guanine (G),
  - thymine (T), or
  - cytosine (C).

Figure 3.24
Figure 3.24a
Figure 3.24b

- Dehydration reactions
  - link nucleotide monomers into long chains called polynucleotides,
  - form covalent bonds between the sugar of one nucleotide and the phosphate of the next, and
  - form a **sugar-phosphate backbone.**
- Nitrogenous bases hang off the sugar-phosphate backbone.

Figure 3.25

- RNA, ribonucleic acid, is different from DNA.
  - RNA uses the sugar ribose and the base uracil (U) instead of thymine (T).

- RNA is usually single-stranded, but DNA usually exists as a double helix.

Figure 3.26

The Process of Science:
Does Lactose Intolerance Have a Genetic Basis?

- **Observation**: Most lactose-intolerant people have a normal version of the lactase gene.
- **Question**: What is the genetic basis for lactose intolerance?
- **Hypothesis**: Lactose-intolerant people have a mutation but not within the lactase gene.
- **Prediction**: A mutation would be found near the lactase gene.
- **Experiment**: Genes of 196 lactose-intolerant people were examined.
- **Results**: Researchers found a 100% correlation between lactose intolerance and a nucleotide at a site approximately 14,000 nucleotides away from the lactase gene.

Figure 3.27

Evolution Connection:
The Evolution of Lactose Intolerance in Humans

- Most people are lactose-intolerant as adults.
- Lactose intolerance is found in
  - 80% of African Americans and Native Americans,
  - 90% of Asian Americans, but
  - only 10% of Americans of northern European descent.
- Lactose tolerance appears to have evolved in northern European cultures that relied upon dairy products.
- Ethnic groups in East Africa that rely upon dairy products are also lactose tolerant but due to different mutations.

Figure 3.28

Figure 3.UN01

Figure 3.UN02

Figure 3.UN02a

Figure 3.UN02b

Figure 3.UN02c

Figure 3.UN02d

Figure 3.UN03

Figure 3.UN04