Chapter 3

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

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

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

Disaccharides
- A disaccharide is
  - a double sugar,
  - constructed from two monosaccharides, and
  - formed by a dehydration reaction.
- 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.
- 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.
- 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.
- Glycogen is
  - used by animals cells to store energy and
  - converted to glucose when it is needed.
- 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.
- 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.

Fats

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

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.
- 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.

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.

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.

Proteins as Polymers

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

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.
- 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.

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."

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

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.

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.