Macromolecules - Carbohydrates, lipids, proteins, nucleic acids

- When two monomers are joined together, the reaction usually involves the elimination of a hydrogen atom from one monomer and a hydroxy group from the other; this is called dehydration synthesis (Tortora et al., Figure 2.9) and results in formation of a molecule of water.
- In the reverse reaction, hydrolysis, atoms from a molecule of water are incorporated as the covalent bond joining the monomers is broken.

The carbohydrates (general formula (CH$_2$O)$_n$) are a diverse group of organic compounds that includes the sugars and starches.

- Carbohydrates perform a number of functions in living cells, but are especially important as components of structural elements (e.g., cell walls) and as energy storage compounds.
- The simplest carbohydrates are the monosaccharides or "simple sugars", such as glucose, fructose and ribose; simple sugars are classified according to the number and arrangement of carbon atoms.
- Disaccharides are formed when two monosaccharides bond in a dehydration synthesis reaction; for example, sucrose is formed from a molecule of glucose and a molecule of fructose (Tortora et al., Figure 2.9). Note that the molecular formulae for glucose and fructose are identical - C$_6$H$_{12}$O$_6$ - but that their properties differ due to the different arrangement of the atoms. Similarly, dehydration synthesis of the monosaccharides glucose and galactose forms the disaccharide lactose.
- Polysaccharides are formed from dehydration synthesis of numerous monosaccharides into long polymers; the monosaccharides may be identical (as in starch and cellulose, which are polymers of glucose) or diverse (as in some of the polysaccharides found in bacterial cell walls). Some polysaccharides, include starch and glycogen (another glucose polymer), have side chains branching off the main structure.

The lipids are a diverse group of macromolecules that share the property of possessing relatively few polar functional groups; this prevents formation of hydrogen bonds with water molecules and accounts for the characteristic insolubility of lipids in water.

- Fats are simple lipids synthesized from a molecule of glycerol and three fatty acids (Tortora et al., Figure 2.10); glycerol molecules (Tortora et al., Figure 2.10a) have three carbon atoms to which are attached three hydroxy (-OH) groups.
- Fatty acids (Tortora et al., Figure 2.12b) are long hydrocarbon chains ending in a carboxylic acid (-COOH) group.
- Fats are formed by dehydration synthesis reactions between the hydroxy groups on glycerol and the carboxylic acid groups on three fatty acids (Tortora et al., Figure 2.10c); the chemical bond formed is called an ester linkage.
- The properties of fats vary according to the structure of the component fatty acids; for example, unsaturated fats are fats in which there are one or more double bonds between carbon atoms in the hydrocarbon chains (see Tortora et al., Figure 2.11a).
- Phospholipids, which are a major component of cell membranes, are similar to fats except that one of the fatty acids is replaced by a phosphate group bonded to one of several organic groups (Tortora et al., Figure 2.1aa); this structure gives phospholipids polar as well as nonpolar regions, causing them to assemble into characteristic phospholipid bilayers (Tortora et al., Figure 2.11b).
The "head group", consisting of the phosphate and associated organic "R" group, is *hydrophilic* (literally, "water loving") and will form hydrogen bonds with water molecules. The "tails", consisting of the hydrocarbon chains, are *hydrophobic* (literally, "water fearing") and will tend to associate with one another, away from water.

Phospholipid bilayers are an essential component of cell membranes.

**Steroids** are lipids with a characteristic ring structure (Tortora et al., Figure 2.12). They are found in cell membranes of eucaryotes (and a few procaryotes) and are also used as hormones.

Cell membrane properties are influenced by the degree of saturation of the hydrocarbon chains of phospholipids as well as the presence of sterols.

**Proteins**, polymers of *amino acids*, account for 50% or more of a cell's dry weight. Virtually all enzymes are proteins, as are many of a cell's structural elements.

- All amino acids share the same structural formula (Tortora et al., Figure 2.13a) consisting of an "α-carbon" surrounded by an amino group, a carboxylic acid group and a characteristic R group.
  - The R group can be a simple as a proton (in the amino acid *glycine*) or as complex as the heterocyclic ring of *tryptophan* (see Tortora et al., Table 2.4).
  - All amino acids found naturally in proteins are L-isomers (Tortora et al., Figure 2.14), although D-isomers of amino acids are found in other natural polymers.
  - All proteins are formed from the twenty acids shown in Tortora et al., Table 2.4.
- **Polypeptides**, or proteins, are synthesized by successive dehydration reactions involving the amino and carboxylic acid groups of amino acids, forming *peptide bonds* (Tortora et al., Figure 2.15).
- The properties of proteins are determined by the sequence of amino acids from which they are synthesized.
  - *Primary structure* (Tortora et al., Figure 2.16a) refers to the unique order (sequence) in which the amino acids are linked together.
    - The primary structure is the major factor in determining "higher" levels of structure.
    - Alterations in amino acid sequence can have profound effects on protein function; for example, sickle-cell anemia results from a single amino acid substitution in the primary sequence of the protein *hemoglobin*.
  - *Secondary structure* (Tortora et al., Figure 2.16b) results from the localized, repeated folding of a polypeptide chain due to hydrogen bonding between groups (N-H-O=C) surrounding peptide bonds; two types of secondary structures are *helixes* and *pleated sheets*.
  - *Tertiary structure* (Tortora et al., Figure 2.16c) refers to the overall three-dimensional structure of a polypeptide chain.
    - Tertiary structure involves interactions - hydrogen bonds, ionic bonds and interactions between hydrophobic groups - among the R groups of the amino acid sequence.
    - In addition to these noncovalent interactions, sulfhydryl groups on two amino acid residues can form a covalent *disulfide link* by removal of hydrogen atoms (-SH-HS-reacts to form -S-S-).
  - Some proteins have a *quaternary structure* (Tortora et al., Figure 2.16d), which consists of an aggregation of two or more individual polypeptide chains ("subunits") that operate as a single functional unit.
    - The subunits may be identical or different.
    - The interactions contributing to quaternary structure are the same as those contributing to tertiary structure.
  - If the tertiary/quaternary structure of a protein "unravels" due to exposure to a hostile environment, the protein becomes *denatured*.
- Many natural proteins are *conjugated*, meaning that they possess additional chemical groups (e.g., carbohydrates (*glycoproteins*), lipids (*lipoproteins*), metal ions (*metalloproteins*), or phosphate groups (*phosphoproteins*)) that are covalently attached to the polypeptide chain.
Nucleic acids are regular polymers of nucleotides
- The major nucleic acids of cells are RNA, ribonucleic acid, and DNA, deoxyribonucleic acid
- Nucleotides (an example is ATP, adenosine triphosphate; Tortora et al., Figure 2.19) consist of:
  - a nitrogenous base, which may be either
    - a purine - adenine or guanine, or
    - a pyrimidine - cytosine, uracil or thymine
  - a five-carbon sugar
    - ribose in nucleotides of RNA
    - deoxyribose in nucleotides of DNA
  - one or more phosphate groups
- Nucleic acids are synthesized by formation of phosphodiester bonds between the sugar of one nucleotide and the phosphate group of the next
- Hydrogen bonds may form between the nitrogenous bases of nucleic acid chains; this base pairing, which is specific (A=T or A=U, and C≡G) provides for the characteristic DNA "double helix" (Tortora et al., Figure 2.17)
- In addition to their role as monomers of nucleic acids, nucleotides perform other important functions; for example, ATP is the principle molecule of "energy currency" in cells.