CHAPTER

3

The Macromolecules of the Cell

3-1.

(a)	2, 3, 6		(d)	1, 3, 9
(b)	4, 7, 9, 10		(e)	4, 7, 9, 10
(c)	4, 5, 9, 10		(f)	4, 5, 9, 10

3-2.

Bond	Amino Acids	Levels of Structure
Peptide (covalent)	All	Primary
Hydrogen	All	Secondary
Hydrophobic	Leucine	Tertiary, Quaternary
Ionic	Glutamate	Tertiary, Quaternary
Disulfide (covalent)	Cysteine	Tertiary, Quaternary

3-3. (a) Alanine; phenylalanine; glutamate; methionine (the less polar member of each pair).

(b) The free sulfhydryl group is polar and ionizable; the disulfide bond is much less polar.

3-4. (a) The amino acid glutamate is hydrophilic and ionizes at cellular pH, whereas valine is hydrophobic and nonionic. Substitution of the latter for the former is likely to change the chemical nature of that part of the molecule significantly.

(b) Aspartate is another acidic amino acid and is therefore a conservative change. Others that are unlikely to have major effects are the polar but uncharged amino acids serine, threonine, tyrosine, and cysteine.

(c) Yes, if the substitutions are always of like-for-like amino acids in terms of chemical properties. These are chemically conservative changes.

3-5. (a) To pull on both ends of an α-keratin polypeptide is to pull against the hydrogen bonds that account for its helical structure. These "give" readily, allowing the polypeptide to be stretched to its full, uncoiled length, at which point you would begin to pull against the covalent peptide bonds. For fibroin, you are pulling against the covalent peptide bonds immediately. (As an analogy, you might compare pulling on opposite ends of a coiled spring versus a straight length of uncoiled wire.)

(b) Fibroin consists mainly of the two smallest amino acids, so it has few bulky R groups and can accommodate the constraints of a pleated sheet. Keratin, on the other hand, has most of the amino acids present, and the distance between bulky R groups is maximized when these protrude from a twisted helical shape.

3-6. (a) Hair proteins are first treated with a sulfhydryl reducing agent to break disulfide bonds and thereby destroy much of the natural tertiary structure and shape of the hair. After being "set" in the desired shape, the hair is treated with an oxidizing agent to allow disulfide bonds to re-form, but now between different cysteine groups, as determined by the positioning imposed by the curlers. These unnatural disulfide bonds then stabilize the desired configuration.

(b) There are two reasons for the lack of permanence: (1) Disulfide bonds occasionally break and re-form spontaneously, allowing the hair proteins to return gradually to their original, thermodynamically more favorable shape. (2) Hair continues to grow, and the new α-keratin molecules will have the natural (correct) disulfide bonds.

(c) There is probably a genetic difference in the positioning of cysteine groups and hence in the formation of disulfide bonds.

3-7. (a) R; only RNA contains the base uracil. In DNA, uracil is replaced with the base thymine.

(b) D; thymidine is unique to DNA.

(c) D; typically RNA is single-stranded, whereas DNA usually exists as a double-stranded molecule.

(d) DR; both RNA and DNA are polymers consisting of repeating nucleotides.

(e) DR; both RNA and DNA contain a repeating sugar-phosphate backbone.

(f) N; that describes a protein!

3-8. (a) Nucleic acids are informational polymers which contain non-identical monomeric units known as nucleotides. DNA and RNA each contain four different kinds of nucleotides.

(b) An α-helix is an example of a protein secondary structure. An α-helix is spiral in shape but stabilized by hydrogen bonds, not covalent bonds, between the NH and CO group.

(c) A protein can be denatured by high temperature treatment or by extremes of pH, both of which disrupt tertiary structure.

(d) Nucleic acids are synthesized from monomers that contain a high-energy phosphodiester bond. Thus, they are already activated and do not require a carrier molecule.

(e) Maltose is a disaccharide composed of two glucose monomers covalently linked together. Sucrose contains one fructose and one glucose monosaccharide.

(f) A β-pleated sheet is an extended sheet-like conformation with the R groups of successive amino acids jutting out on alternating sides of the sheet.

(g) Although a polypeptide's primary sequence will determine its final folded (tertiary) structure, because there are nearly limitless ways in which even a small protein can fold, it is still not possible to predict this tertiary structure from the primary sequence.

(h) MircoRNAs are small endogenous RNAs that down-regulate the expression of specific genes by binding to their mRNAs and either promoting mRNA degradation or inhibiting translation. Abnormal regulation by miRNAs is associated with certain human diseases. Other small RNAs known as small interfering RNAs (siRNAs) are derived from exogenous sources (e.g., infection by an RNA virus).

3-9. (a) Compared to a linear molecule, a branched-chain polymer has more termini for addition or hydrolysis of glucose units per unit volume of polymer, thereby facilitating both the deposition and mobilization of glucose by providing more sites for enzymatic activity.

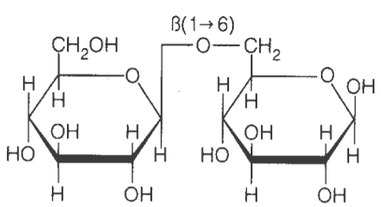
(b) Amylopectin consists of $\alpha(1\rightarrow4)$ bonds, as well as $\alpha(1\rightarrow6)$ bonds at each branch point. Amylase only breaks down $\alpha(1\rightarrow4)$ and therefore other enzymes are required to break the $\alpha(\rightarrow6)$ bonds.

(c) Grass contains the structural polysaccharide cellulose. Like starch and glycogen, cellulose is a polymer of glucose; however, the repeating monomer is β-Dglucose, and the linkage is therefore $\beta(1\rightarrow4)$. Mammals do not possess an enzyme that can hydrolyze this $\beta(1\rightarrow4)$ bond and therefore cannot utilize cellulose as food. Animals such as cows, also cannot cleave β glycosidic bonds; they rely on microorganisms (bacteria and protozoa) in their digestive systems to do this for them.

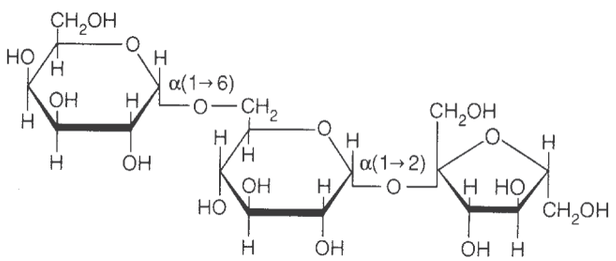
(d) Cellulose molecules are rigid, linear rods that aggregate laterally into microfibrils. Cell walls have been aptly compared to reinforced concrete, in which steel rods are embedded in the cement before it hardens to add strength. In cell walls, the cellulose microfibrils are the "rods" and the non-cellulosic matrix is the "cement."

3-10. See Figure S3.1 for the structures of (a) gentiobiose, (b) raffinose, and (c) a portion of a dextran chain.

(a) Gentiobiose:



(b) Raffinose:



(c) Portion of a dextran:

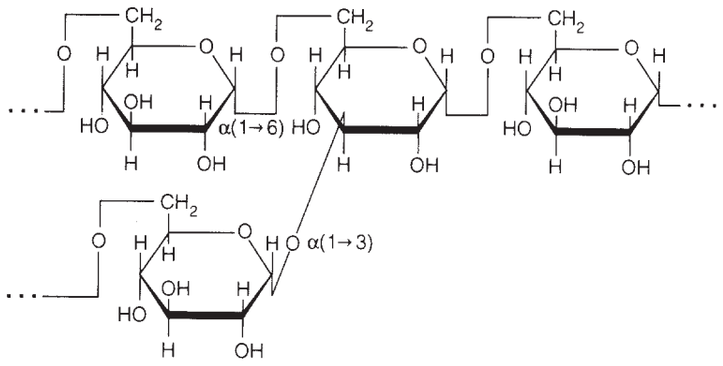


Figure S3-1 Carbohydrate Structures. The structures of the carbohydrates (a) gentiobiose, (b) raffinose, and (c) a portion of a dextran. See Problem 3-10.

3-11. (a) A distinguishing feature is the presence of phosphodiester bonds in the DNA but not in the protein. Either (i) digest (hydrolyze) the two molecules chemically and assay for inorganic phosphate (P_i) or (ii) determine whether the molecule can be digested (hydrolyzed) by the enzyme phosphodiesterase.

(b) A distinguishing feature is the presence of thymidine deoxyribonucleotide in DNA but not in RNA. Hydrolyze the two samples and assay for either (i) the purine thymidine or (ii) the pentose deoxyribose.

(c) A distinguishing feature is the presence of rigid microfibrils of β-D-glucose in cellulose but not in starch. Either (i) examine the polymer with an electron microscope to look for cellulose microfibrils (see Figure 3-25 on p. 90 of the textbook) or (ii) assay for the enzyme amylase, which can digest $\alpha(1 \rightarrow 4)$ glycosidic bonds but not $\beta(1 \rightarrow 4)$ glycosidic bonds and which will therefore digest starch but not cellulose.

(d) A distinguishing feature is the presence of $\alpha(1 \rightarrow 6)$ bonds in amylopectin but not in amylose. Assay for either (i) the presence of $\alpha(1 \rightarrow 6)$ bonds directly or (ii) sensitivity of the polymer to digestion by an enzyme that can hydrolyze $\alpha(1 \rightarrow 4)$ but not $\alpha(1 \rightarrow 6)$ bonds (or vice versa).

(e) A distinguishing feature is the presence of four subunits in hemoglobin but not in myoglobin. Either (i) determine the molecular weight of the native (intact) protein (by ultracentrifugation, most likely) and compare it with the known molecular weights of hemoglobin and myoglobin or (ii) subject the native protein to denaturing conditions to determine whether it will dissociate into multiple subunits or not.

(f) A distinguishing feature is the presence of glycerol but the absence of phosphorus in the case of the triacylglycerol. Hydrolyze the two samples and assay for the presence of (i) ions and (ii) inorganic phosphate specifically.

(g) A distinguishing feature is the presence on the glycolipid of a carbohydrate side chain instead of a phosphate group. Hydrolyze the two samples and assay for the presence of (i) carbohydrate and (ii) inorganic phosphate.

(h) A distinguishing feature is that chitin is a polymer consisting of a single repeating group (GlcNAc), whereas a bacterial cell wall polysaccharide consists of two repeating units (GlcNAc and MurNAc). Hydrolyze the two samples and assay for either (i) the presence of two rather than one digestion product (by chromatography, most likely) or (ii) the presence of MurNAc (by chemical assay, most likely).

3-12. Numerous different answers are possible because of the wide variety of individual proteins in cells. A few of these answers are given below:

(a) *Insulin*, produced by pancreatic islet cells and secreted into blood, regulates the balance of glucose in the blood; *glucagon-like peptide-1(GLP-1)*, produced in the pancreas and intestinal cells, stimulates production of insulin.

(b) *Collagen,* a fibrous protein giving strength to tissues, found in cells of connective tissue such as tendons; *keratin,* a fibrous protein giving stiffness to hair, found in hair-producing epidermal cells in mammals.

(c) *Actin,* a component of microfilaments, found in muscle cells and in the cytoskeleton of many cell types; *tubulin*, a component of microtubules, found in dividing eukaryotic cells where it helps pull chromosomes apart; *flagellin*, a component of bacterial flagella, found in motile bacteria.

(d) *Transcription factors* bind to DNA sequences to turn genes on and are found in nearly all cells; *lac repressor* binds to DNA to turn off genes encoding enzymes needed for lactose utilization and is found in bacteria; *Myc protein*, a transcription factor that stimulates cell proliferation and is overly active in some cancer cells.

(e) *G-proteins*, found in all cells, bind to trans membrane receptor proteins and transmit chemical signals inside the cell; *protein kinases* – found in all cells, regulate the activity of other proteins by adding phosphate groups to them at active sites; *receptors*, found in blood and lymph circulation as well as on other cells, bind to extracellular molecules (ligands) and ligand proteins, appropriate receptors and transmit chemical signals to the recipient cell; *MHC-II proteins*, found on macrophages and dendritic cells, bind to foreign particles and present them to WBCs to generate immune responses.

(f) *Insulin receptor* binds insulin to initiate glucose utilization and is found in cells requiring glucose; *acetylcholine receptor* binds the neurotransmitter acetylcholine to initiate nerve transmission and is found in neurons.

(g) *Antibodies*, globular proteins that recognize microorganisms, are found in white blood cells; *chitinase* degrades the fungal cell wall and is found in certain plant cells.

(h) *Ferritin,* a protein that binds and stores iron, is found in almost all cells; *gliadin*, a storage protein that is a source of amino acids in seeds, is found in kernels of wheat and other cereals.

3-13. (a) Although both amylose and amylopectin have the same repeating unit (α-Dglucose) amylase contains only $\alpha(1\rightarrow4)$ glycosidic bonds whereas amylopectin contains both $\alpha(1\rightarrow4)$ and $\alpha(1\rightarrow6)$ bonds which give rise to a branched polymer.

(b) As amylose contains only $\alpha(1\rightarrow4)$ bonds, it is more linear and therefore less space consuming compared to amylopectin. This is why amylose is the preferred storage polysaccharide in plants. Amylopectin is highly branched as it contains both $\alpha(1\rightarrow4)$ and $\alpha(1\rightarrow6)$ bonds. So, it is more soluble and more readily digested compared to amylose.

3-14. (a) A lipid is a molecule that is preferentially soluble in an organic solvent rather than in water. This definition is therefore based on the solubility properties of the molecule rather than on the chemical nature of the subunits or the bond that links subunits together, as is the case for proteins, nucleic acids, and carbohydrates.

(b) Laureate < Palmitate < Stearate < Oleate < Arachidonate

(c) The presence of an oleate will introduce a bend in one of the side chains that will closely approximate the shape of sphingomyelin, because the latter also has a double bond and hence a bend.

(d) Arachidate: 160 ATP, Laurate: 96 ATP, Palmitate: 128 ATP, and Stearate: 144 ATP

(e) Phosphatidyl serine: the phosphoserine group Sphingomyelin: the phosphocholine group Cholesterol: the hydroxyl group (only slightly hydrophilic) Triacylglycerol: the ester bonds between glycerol and the fatty acids.

3-15. (a) Some of the C=C double bonds in the fatty acids of the oils are changed to C–C single bonds in the hydrogenation process.

(b) Before, hydrogenation, vegetable oils are liquids at room temperature. Partial or complete hydrogenation of oils causes them to become solid at room temperature.

(c) Hydrogen atoms are added to polyunsaturated oils to create vegetable shortening. These hydrogen atoms are added to carbon atoms in C=C double bonds.

(d) Although the ingredients for making the shortening may be 100% polyunsaturated oils, to convert them into solid shortening they must be hydrogenated and thus become saturated fats in the final product.