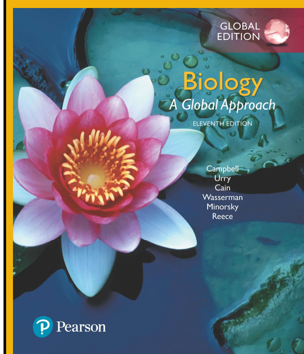


Chapter 5

Biological Macromolecules and Lipids

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

The Molecules of Life

- All living things are made up of four classes of large biological molecules: carbohydrates, lipids, proteins, and nucleic acids
- **Macromolecules** are large molecules and are complex
- Large biological molecules have unique properties that arise from the orderly arrangement of their atoms

Figure 5.1

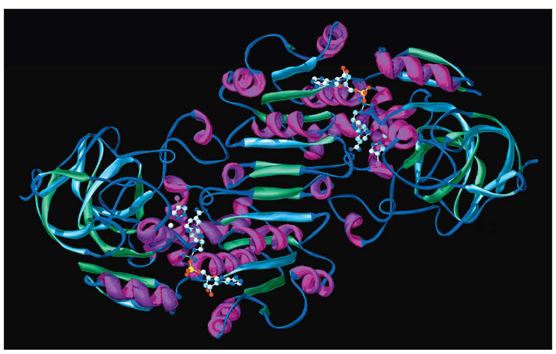


Figure 5.1a

The scientist in the foreground is using 3-D glasses to help her visualize the structure of the protein displayed on her screen.

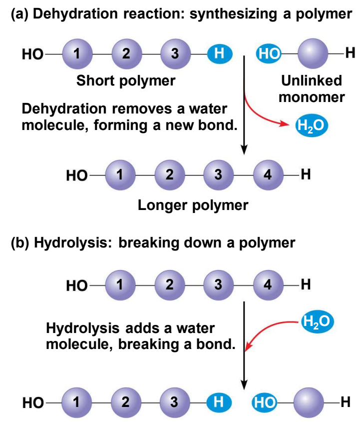
Concept 5.1: Macromolecules are polymers, built from monomers

- A **polymer** is a long molecule consisting of many similar building blocks
- The repeating units that serve as building blocks are called **monomers**
- Carbohydrates, proteins, and nucleic acids are polymers

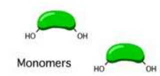
The Synthesis and Breakdown of Polymers

- **Enzymes** are specialized macromolecules that speed up chemical reactions such as those that make or break down polymers
- A **dehydration reaction** occurs when two monomers bond together through the loss of a water molecule
- Polymers are disassembled to monomers by **hydrolysis**, a reaction that is essentially the reverse of the dehydration reaction

Figure 5.2



Animation: Polymers



The Diversity of Polymers

- A cell has thousands of different macromolecules
- Macromolecules vary among cells of an organism, vary more within a species, and vary even more between species
- A huge variety of polymers can be built from a small set of monomers

Concept 5.2: Carbohydrates serve as fuel and building material

- **Carbohydrates** include sugars and the polymers of sugars
- The simplest carbohydrates are monosaccharides, or simple sugars
- Carbohydrate macromolecules are polysaccharides, polymers composed of many sugar building blocks

Sugars

- **Monosaccharides** have molecular formulas that are usually multiples of CH_2O
- Glucose ($C_6H_{12}O_6$) is the most common monosaccharide
- Monosaccharides are classified by
  - The location of the carbonyl group (as aldose or ketose)
  - The number of carbons in the carbon skeleton

Figure 5.3

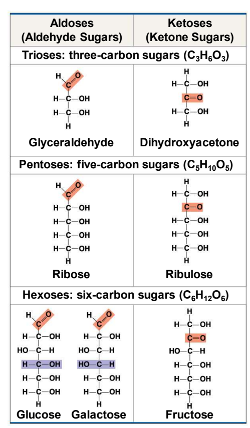


Figure 5.3a

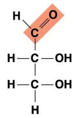
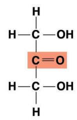
Aldose (Aldehyde Sugar)	Ketose (Ketone Sugar)
Trioses: three-carbon sugars ($C_3H_6O_3$)	
 Glyceraldehyde	 Dihydroxyacetone

Figure 5.3b

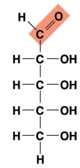
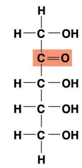
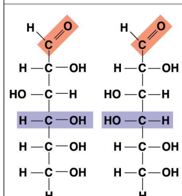
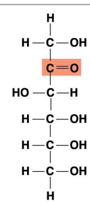
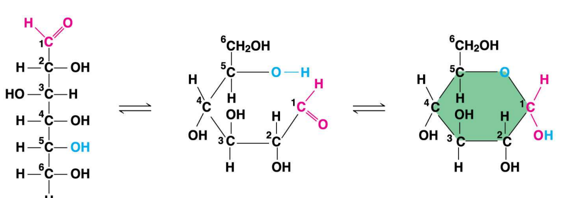
Aldose (Aldehyde Sugar)	Ketose (Ketone Sugar)
Pentoses: five-carbon sugars ($C_5H_{10}O_5$)	
 Ribose	 Ribulose

Figure 5.3c

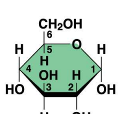
Aldose (Aldehyde Sugar)	Ketose (Ketone Sugar)
Hexoses: six-carbon sugars ($C_6H_{12}O_6$)	
 Glucose Galactose	 Fructose

- Though often drawn as linear skeletons, in aqueous solutions many sugars form rings
- Monosaccharides serve as a major fuel for cells and as raw material for building molecules

Figure 5.4



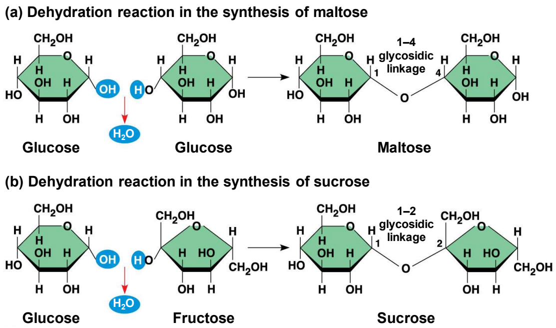
(a) Linear and ring forms



(b) Abbreviated ring structure

- A **disaccharide** is formed when a dehydration reaction joins two monosaccharides
- This covalent bond is called a **glycosidic linkage**

Figure 5.5



Animation: Disaccharides

Polysaccharides

- **Polysaccharides**, the polymers of sugars, have storage and structural roles
- The architecture and function of a polysaccharide are determined by its sugar monomers and the positions of its glycosidic linkages

Storage Polysaccharides

- **Starch**, a storage polysaccharide of plants, consists of glucose monomers
- Plants store surplus starch as granules within chloroplasts and other plastids
- The simplest form of starch is amylose

Figure 5.6

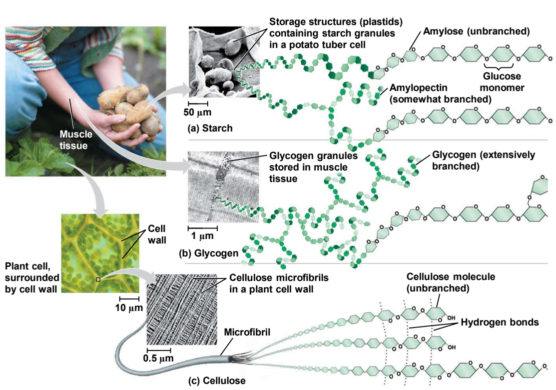


Figure 5.6a

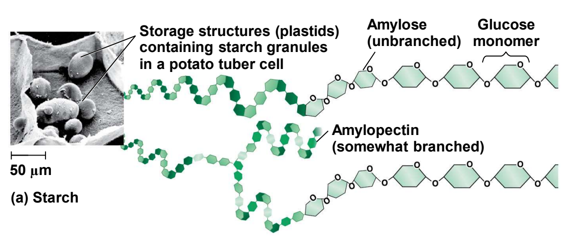


Figure 5.6aa

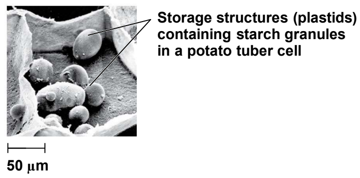


Figure 5.6b

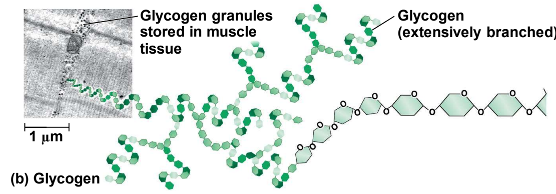


Figure 5.6ba

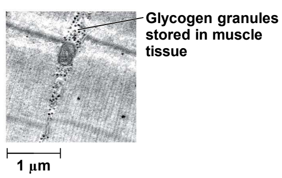


Figure 5.6c

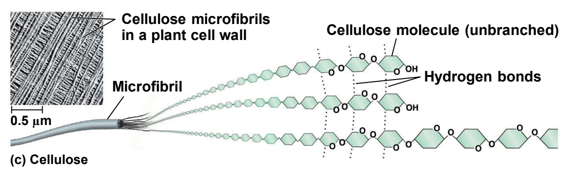


Figure 5.6ca

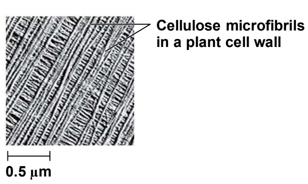
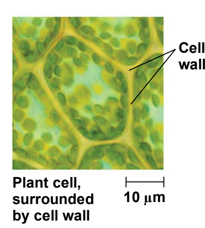
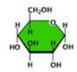


Figure 5.6d



Animation: Polysaccharides

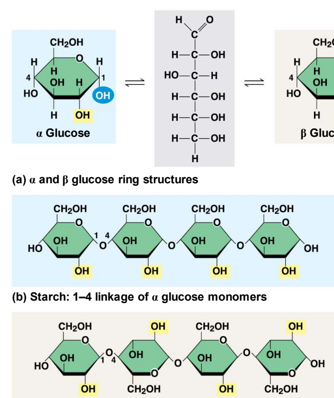


- **Glycogen** is a storage polysaccharide in animals
- Glycogen is stored mainly in liver and muscle cells
- Hydrolysis of glycogen in these cells releases glucose when the demand for sugar increases

Structural Polysaccharides

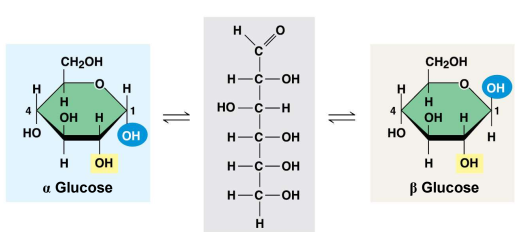
- The polysaccharide **cellulose** is a major component of the tough wall of plant cells
- Like starch, cellulose is a polymer of glucose, but the glycosidic linkages differ
- The difference is based on two ring forms for glucose: alpha (α) and beta (β)

Figure 5.7



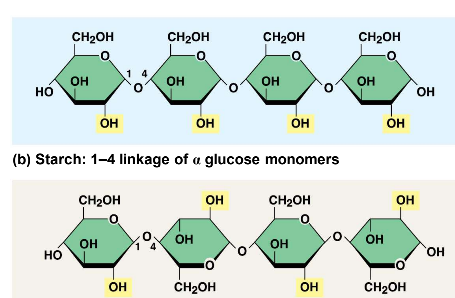
(c) Cellulose: 1–4 linkage of β glucose monomers

Figure 5.7a



(a) α and β glucose ring structures

Figure 5.7b



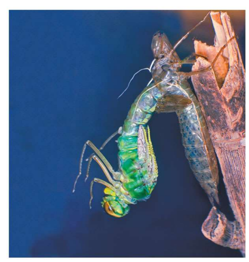
(c) Cellulose: 1–4 linkage of β glucose monomers

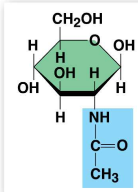
- Starch (α configuration) is largely helical
- Cellulose molecules (β configuration) are straight and unbranched
- Some hydroxyl groups on the monomers of cellulose can hydrogen-bond with hydroxyls of parallel cellulose molecules

- Enzymes that digest starch by hydrolyzing α linkages can't hydrolyze β linkages in cellulose
- The cellulose in human food passes through the digestive tract as "insoluble fiber"
- Some microbes use enzymes to digest cellulose
- Many herbivores, from cows to termites, have symbiotic relationships with these microbes

- **Chitin**, another structural polysaccharide, is found in the exoskeleton of arthropods
- Chitin also provides structural support for the cell walls of many fungi

Figure 5.8





◄ The structure of the chitin monomer

◄ Chitin, embedded in proteins, forms the exoskeleton of arthropods.

Figure 5.8a

Chitin, embedded in proteins, forms the exoskeleton of arthropods.

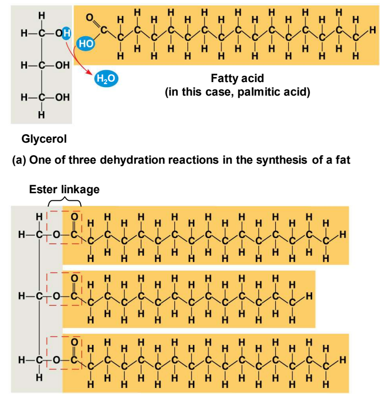
Concept 5.3: Lipids are a diverse group of hydrophobic molecules

- **Lipids** are the one class of large biological molecules that does not include true polymers
- The unifying feature of lipids is that they mix poorly, if at all, with water
- Lipids consist mostly of hydrocarbon regions
- The most biologically important lipids are fats, phospholipids, and steroids

Fats

- **Fats** are constructed from two types of smaller molecules: glycerol and fatty acids
- Glycerol is a three-carbon alcohol with a hydroxyl group attached to each carbon
- A **fatty acid** consists of a carboxyl group attached to a long carbon skeleton

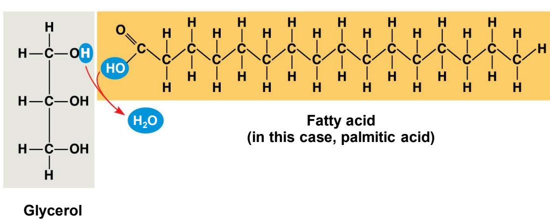
Figure 5.9



(a) One of three dehydration reactions in the synthesis of a fat

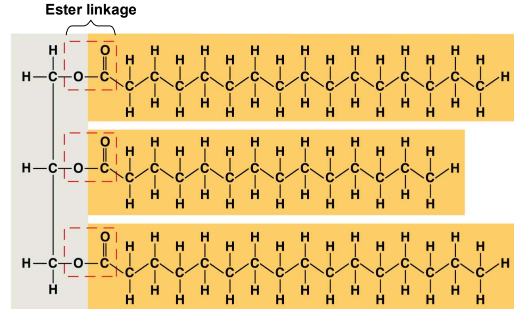
(b) Fat molecule (triacylglycerol)

Figure 5.9a



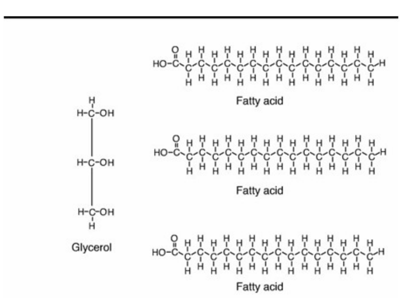
(a) One of three dehydration reactions in the synthesis of a fat

Figure 5.9b



(b) Fat molecule (triacylglycerol)

Animation: Fats



- Fats separate from water because water molecules hydrogen-bond to each other and exclude the fats
- In a fat, three fatty acids are joined to glycerol by an ester linkage, creating a **triacylglycerol**, or triglyceride
- The fatty acids in a fat can be all the same or of two or three different kinds

- Fatty acids vary in length (number of carbons) and in the number and locations of double bonds
- **Saturated fatty acids** have the maximum number of hydrogen atoms possible and no double bonds
- **Unsaturated fatty acids** have one or more double bonds

Figure 5.10

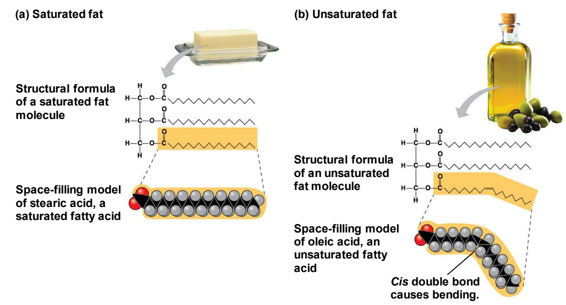


Figure 5.10a

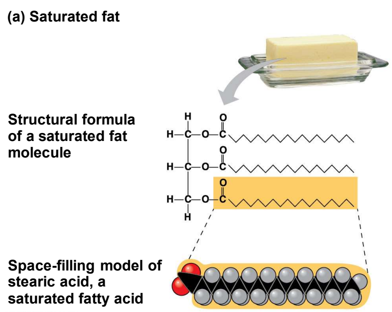


Figure 5.10aa

Figure 5.10b

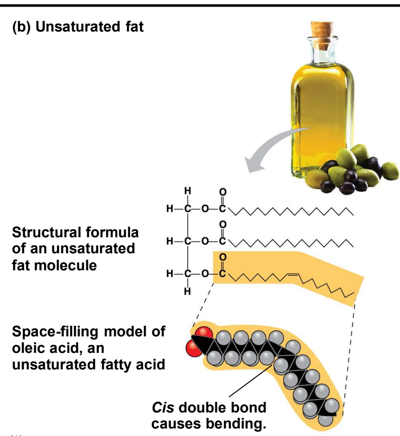


Figure 5.10ba

- Fats made from saturated fatty acids are called saturated fats and are solid at room temperature
- Most animal fats are saturated
- Fats made from unsaturated fatty acids are called unsaturated fats or oils and are liquid at room temperature
- Plant fats and fish fats are usually unsaturated

- A diet rich in saturated fats may contribute to cardiovascular disease through plaque deposits
- Hydrogenation is the process of converting unsaturated fats to saturated fats by adding hydrogen
- Hydrogenating vegetable oils also creates unsaturated fats with *trans* double bonds
- These ***trans* fats** may contribute more than saturated fats to cardiovascular disease

- The major function of fats is energy storage
- Humans and other mammals store their long-term food reserves in adipose cells
- Adipose tissue also cushions vital organs and insulates the body

Phospholipids

- In a **phospholipid**, two fatty acids and a phosphate group are attached to glycerol
- The two fatty acid tails are hydrophobic, but the phosphate group and its attachments form a hydrophilic head

Figure 5.11

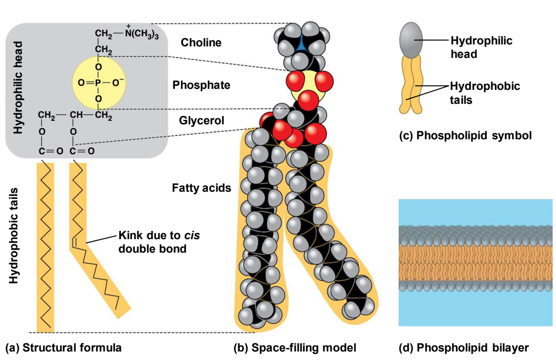


Figure 5.11a

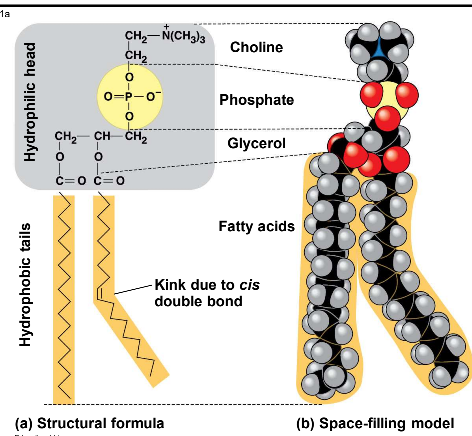
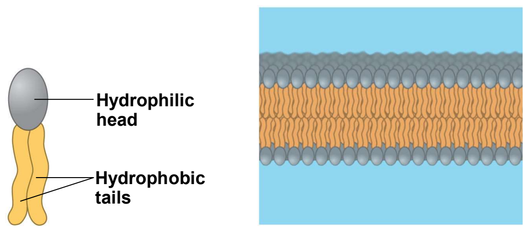


Figure 5.11b



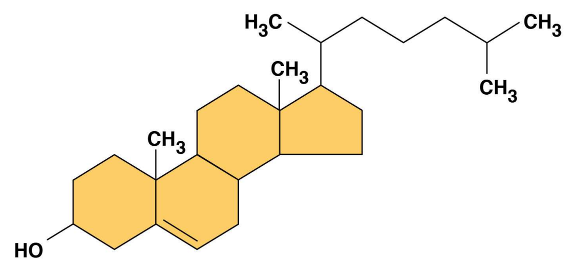
(c) Phospholipid symbol (d) Phospholipid bilayer

- When phospholipids are added to water, they self-assemble into double-layered sheets called bilayers
- At the surface of a cell, phospholipids are also arranged in a bilayer, with the hydrophobic tails pointing toward the interior
- The phospholipid bilayer forms a boundary between the cell and its external environment

Steroids

- **Steroids** are lipids characterized by a carbon skeleton consisting of four fused rings
- **Cholesterol**, a type of steroid, is a component in animal cell membranes and a precursor from which other steroids are synthesized
- A high level of cholesterol in the blood may contribute to cardiovascular disease

Figure 5.12



Video: Space-filling Model of Cholesterol

Video: Stick Model of Cholesterol

Concept 5.4: Proteins include a diversity of structures, resulting in a wide range of functions

- Proteins account for more than 50% of the dry mass of most cells
- Some proteins speed up chemical reactions
- Other protein functions include defense, storage, transport, cellular communication, movement, and structural support

Figure 5.13a

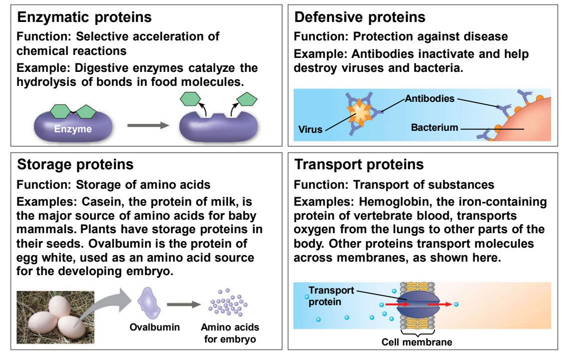


Figure 5.13aa

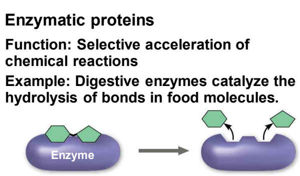


Figure 5.13ab

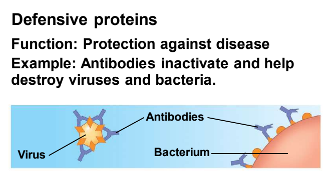


Figure 5.13ac

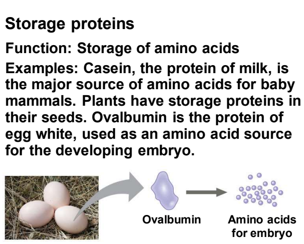


Figure 5.13aca

Figure 5.13ad

Transport proteins

Function: Transport of substances

Examples: Hemoglobin, the iron-containing protein of vertebrate blood, transports oxygen from the lungs to other parts of the body. Other proteins transport molecules across membranes, as shown here.

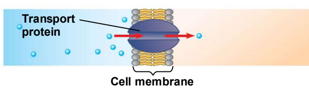
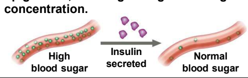


Figure 5.13b

Hormonal proteins

Function: Coordination of an organism's activities

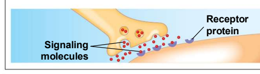
Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.



Receptor proteins

Function: Response of cell to chemical stimuli

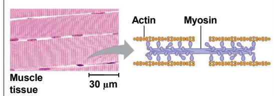
Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.



Contractile and motor proteins

Function: Movement

Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.



Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.

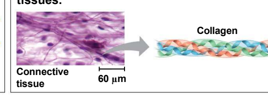


Figure 5.13ba

Hormonal proteins

Function: Coordination of an organism's activities

Example: Insulin, a hormone secreted by the pancreas, causes other tissues to take up glucose, thus regulating blood sugar concentration.

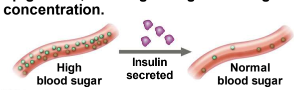


Figure 5.13bb

Receptor proteins

Function: Response of cell to chemical stimuli

Example: Receptors built into the membrane of a nerve cell detect signaling molecules released by other nerve cells.

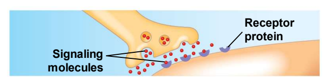


Figure 5.13bc

Contractile and motor proteins

Function: Movement

Examples: Motor proteins are responsible for the undulations of cilia and flagella. Actin and myosin proteins are responsible for the contraction of muscles.

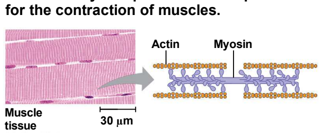


Figure 5.13bca

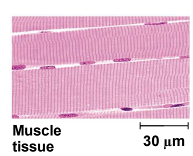


Figure 5.13bd

Structural proteins

Function: Support

Examples: Keratin is the protein of hair, horns, feathers, and other skin appendages. Insects and spiders use silk fibers to make their cocoons and webs, respectively. Collagen and elastin proteins provide a fibrous framework in animal connective tissues.

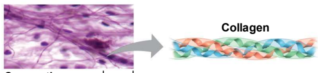
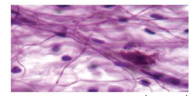
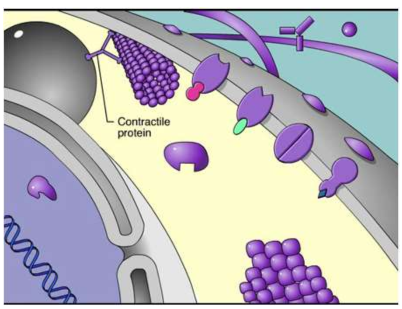


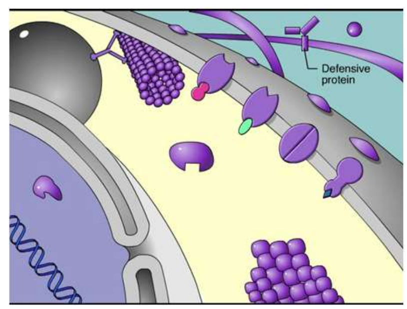
Figure 5.13bda



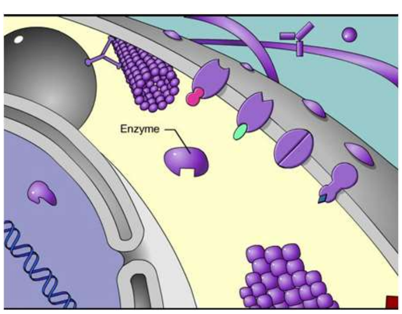
Animation: Contractile Proteins



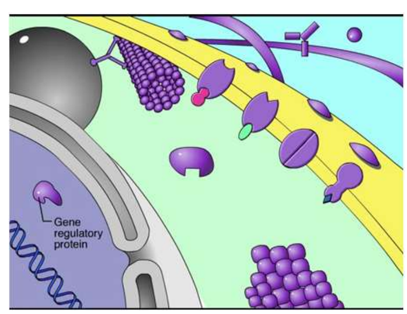
Animation: Defensive Proteins



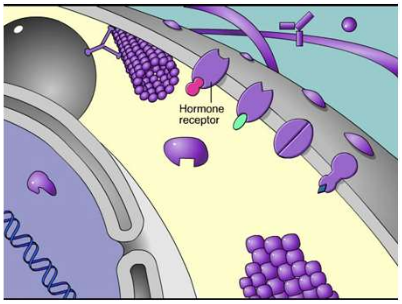
Animation: Enzymes



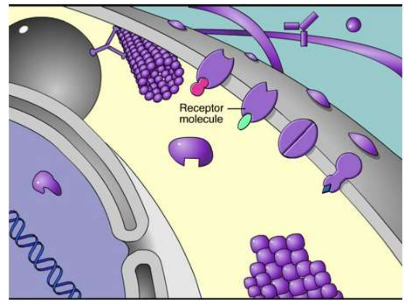
Animation: Gene Regulatory Proteins



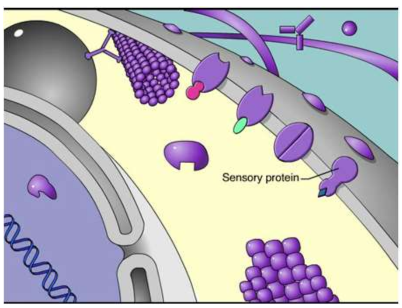
Animation: Hormonal Proteins



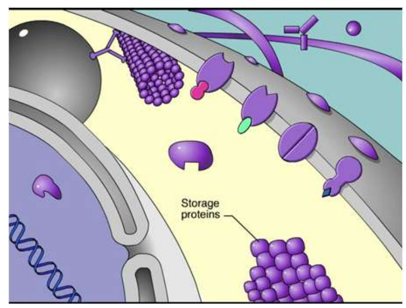
Animation: Receptor Proteins



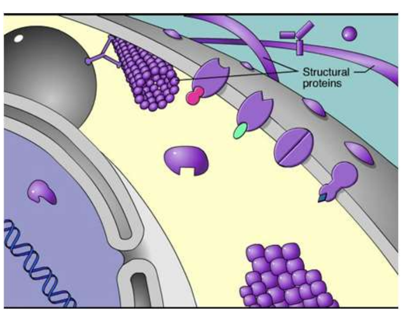
Animation: Sensory Proteins



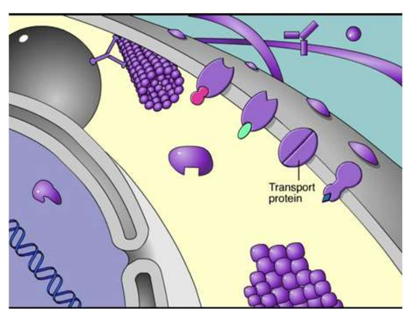
Animation: Storage Proteins



Animation: Structural Proteins



Animation: Transport Proteins



- Enzymes are proteins that act as **catalysts** to speed up chemical reactions
- Enzymes can perform their functions repeatedly, functioning as workhorses that carry out the processes of life

- Proteins are all constructed from the same set of 20 amino acids
- **Polypeptides** are unbranched polymers built from these amino acids
- A **protein** is a biologically functional molecule that consists of one or more polypeptides

Amino Acid Monomers

- **Amino acids** are organic molecules with amino and carboxyl groups
- Amino acids differ in their properties due to differing side chains, called R groups

Figure 5.UN01

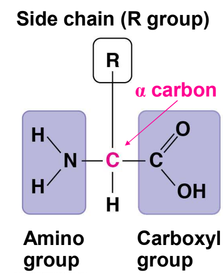


Figure 5.14

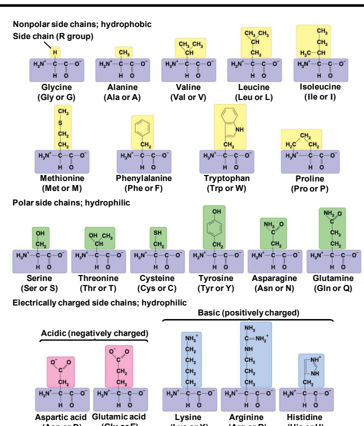


Figure 5.14a

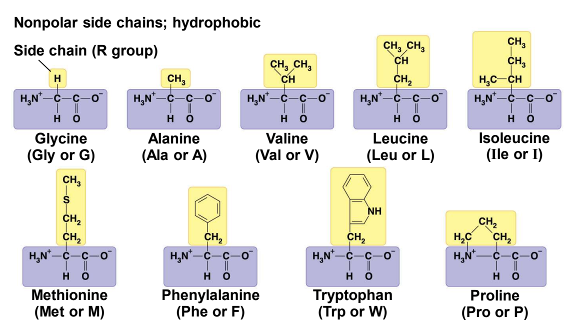


Figure 5.14b

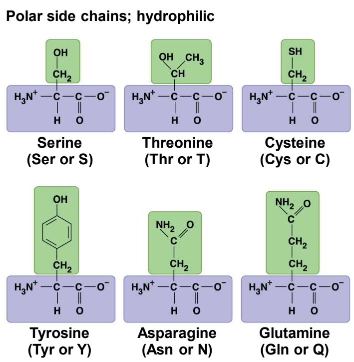
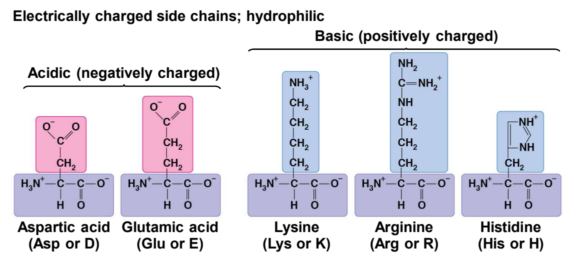


Figure 5.14c



Polypeptides (Amino Acid Polymers)

- Amino acids are linked by covalent bonds called **peptide bonds**
- A polypeptide is a polymer of amino acids
- Polypeptides range in length from a few to more than 1,000 monomers
- Each polypeptide has a unique linear sequence of amino acids, with a carboxyl end (C-terminus) and an amino end (N-terminus)

Figure 5.15

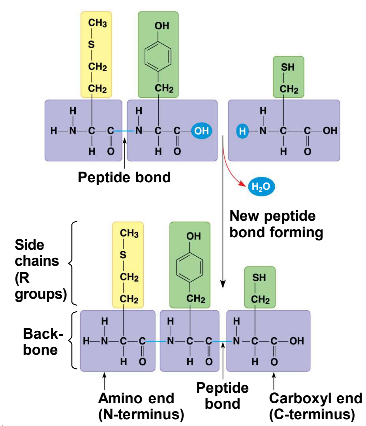


Figure 5.15a

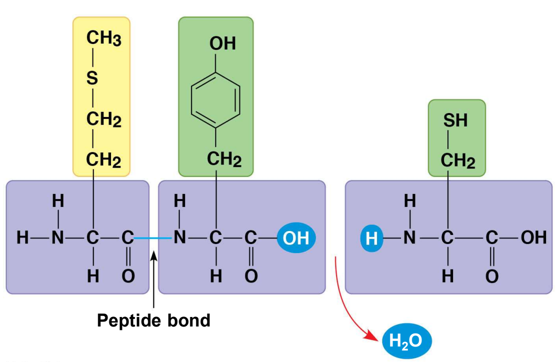
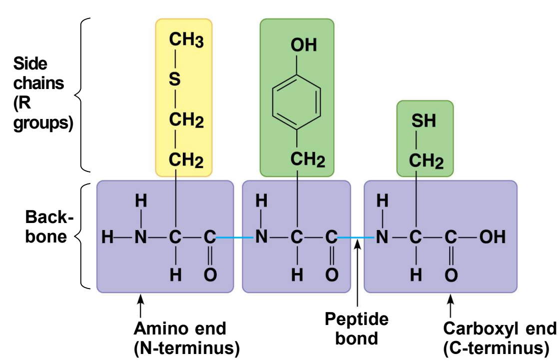


Figure 5.15b



Protein Structure and Function

- The specific activities of proteins result from their intricate three-dimensional architecture
- A functional protein consists of one or more polypeptides precisely twisted, folded, and coiled into a unique shape

Figure 5.16

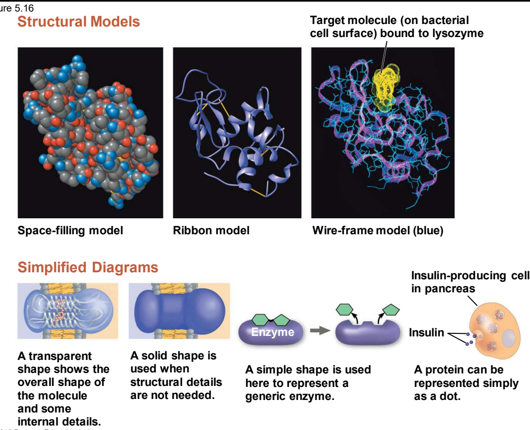


Figure 5.16a

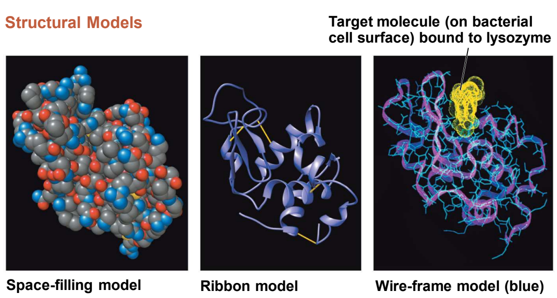
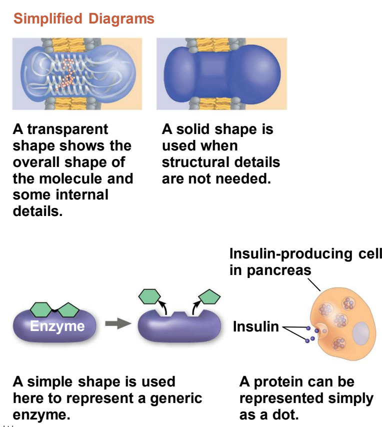
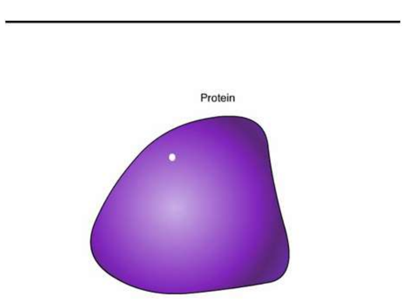


Figure 5.16b

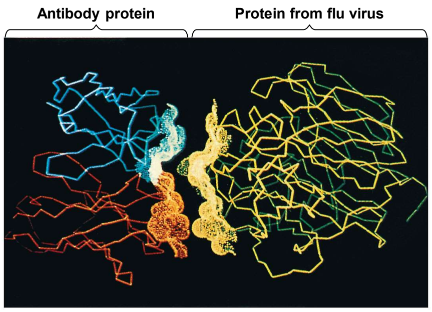


Animation: Protein Structure Introduction



- The sequence of amino acids determines a protein's three-dimensional structure
- A protein's structure determines how it works
- The function of a protein usually depends on its ability to recognize and bind to some other molecule

Figure 5.17



Four Levels of Protein Structure

- The primary structure of a protein is its unique sequence of amino acids
- Secondary structure, found in most proteins, consists of coils and folds in the polypeptide chain
- Tertiary structure is determined by interactions among various side chains (R groups)
- Quaternary structure results when a protein consists of multiple polypeptide chains

Figure 5.18a

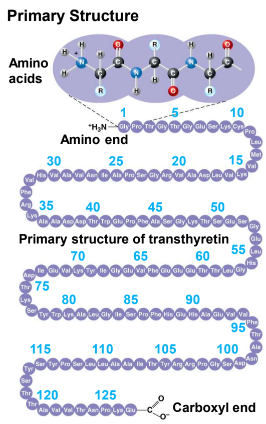


Figure 5.18aa

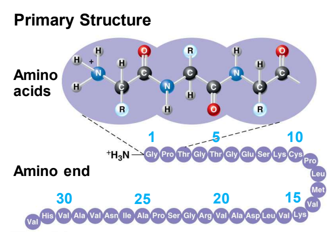


Figure 5.18b

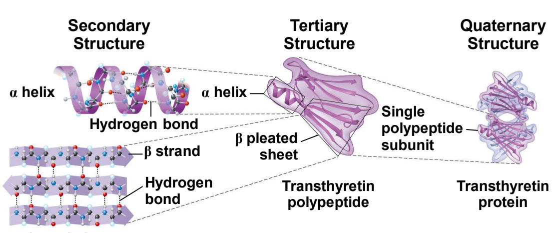


Figure 5.18ba

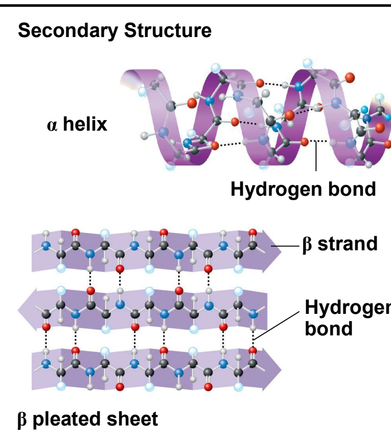


Figure 5.18bb

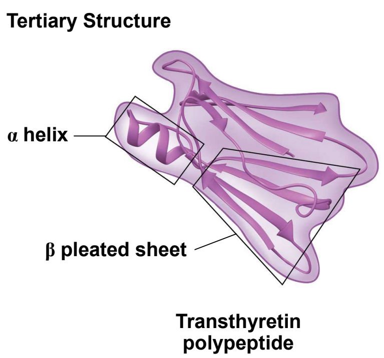


Figure 5.18bc

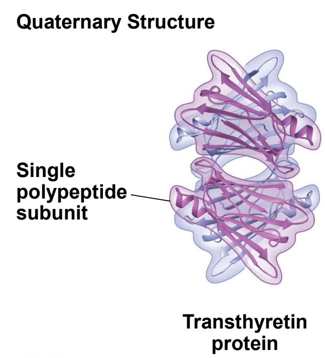


Figure 5.18c

Figure 5.18d

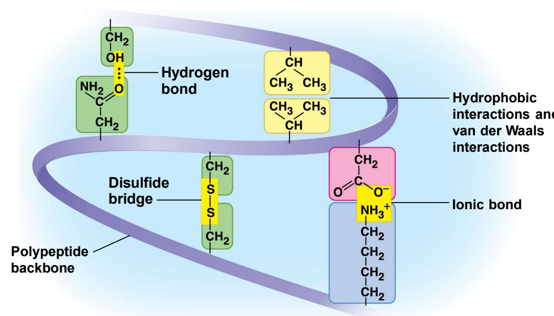


Figure 5.18e

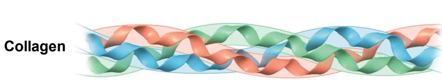
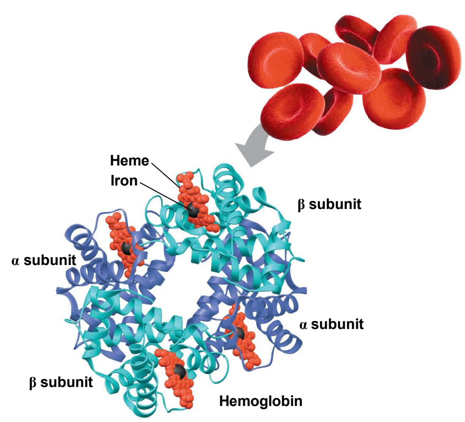
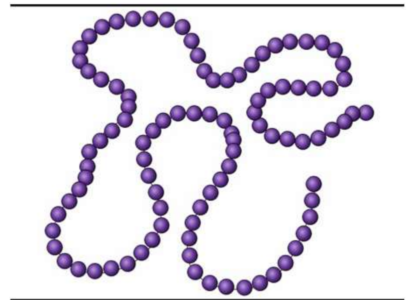


Figure 5.18f



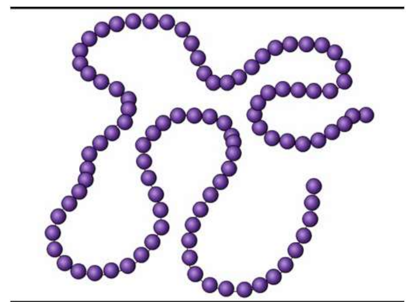
- The **primary structure** of a protein is its sequence of amino acids
- Primary structure is like the order of letters in a long word
- Primary structure is determined by inherited genetic information

Animation: Primary Protein Structure

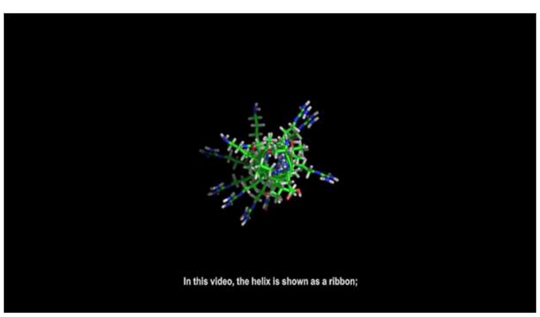


- The coils and folds of **secondary structure** result from hydrogen bonds between repeating constituents of the polypeptide backbone
- Typical secondary structures are a coil called an **α helix** and a folded structure called a **β pleated sheet**

Animation: Secondary Protein Structure

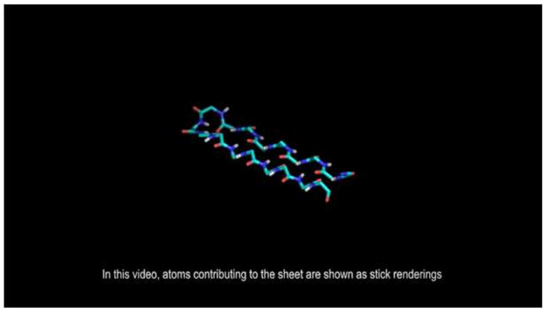


Video: An Idealized α Helix

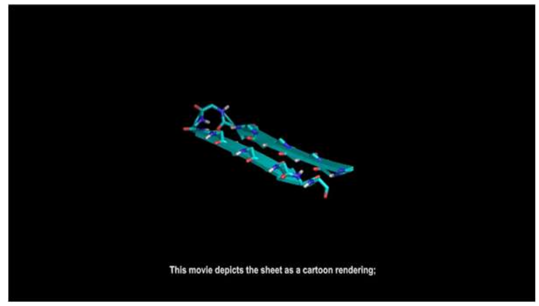


Video: An Idealized α Helix: No Sidechains

Video: An Idealized β Pleated Sheet

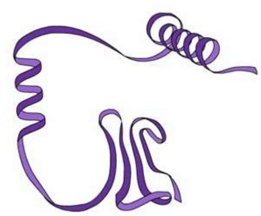


Video: An Idealized β Pleated Sheet Cartoon



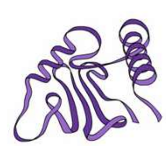
- **Tertiary structure**, the overall shape of a polypeptide, results from interactions between R groups, rather than interactions between backbone constituents
- These interactions include hydrogen bonds, ionic bonds, **hydrophobic interactions**, and van der Waals interactions
- Strong covalent bonds called **disulfide bridges** may reinforce the protein's structure

Animation: Tertiary Protein Structure



- **Quaternary structure** results when two or more polypeptide chains form one macromolecule
- Collagen is a fibrous protein consisting of three polypeptides coiled like a rope
- Hemoglobin is a globular protein consisting of four polypeptides: two α and two β subunits

Animation: Quaternary Protein Structure



Sickle-Cell Disease: A Change in Primary Structure

- A slight change in primary structure can affect a protein's structure and ability to function
- **Sickle-cell disease**, an inherited blood disorder, results from a single amino acid substitution in the protein hemoglobin
- The abnormal hemoglobin molecules cause the red blood cells to aggregate into chains and to deform into a sickle shape

Figure 5.19

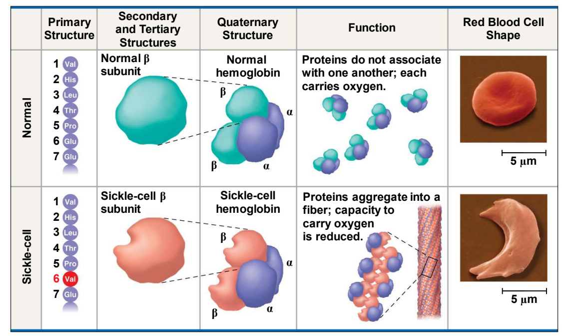


Figure 5.19a

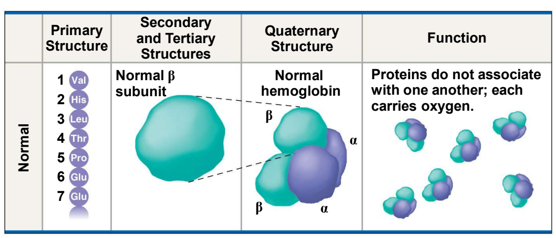


Figure 5.19aa

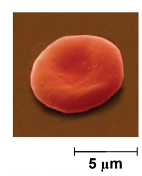


Figure 5.19b

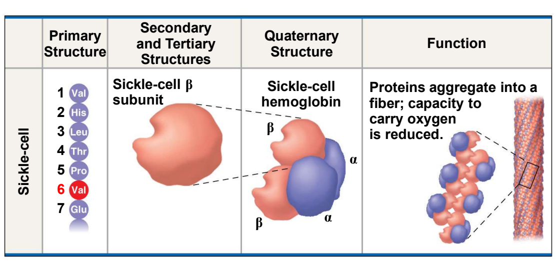
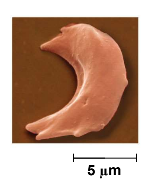


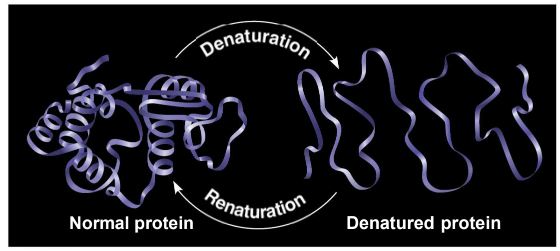
Figure 5.19ba



What Determines Protein Structure?

- In addition to primary structure, physical and chemical conditions can affect structure
- Alterations in pH, salt concentration, temperature, or other environmental factors can cause a protein to unravel
- This loss of a protein's native structure is called **denaturation**
- A denatured protein is biologically inactive

Figure 5.20

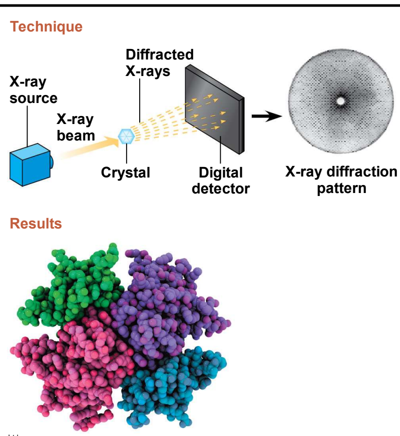


Protein Folding in the Cell

- It is hard to predict a protein's structure from its primary structure
- Most proteins probably go through several stages on their way to a stable structure
- Diseases such as Alzheimer's, Parkinson's, and mad cow disease are associated with misfolded proteins

- Scientists use **X-ray crystallography** to determine a protein's structure
- Another method is nuclear magnetic resonance (NMR) spectroscopy, which does not require protein crystallization
- Bioinformatics is another approach to prediction of protein structure from amino acid sequences

Figure 5.21



Concept 5.5: Nucleic acids store, transmit, and help express hereditary information

- The amino acid sequence of a polypeptide is programmed by a unit of inheritance called a **gene**
- Genes consist of DNA, a **nucleic acid** made of monomers called nucleotides

Slide 144

MA1 Monday 6Jul2020
Mamoon Al-Rshaidat, 7/6/2020

The Roles of Nucleic Acids

- There are two types of nucleic acids
  - **Deoxyribonucleic acid (DNA)**
  - **Ribonucleic acid (RNA)**
- DNA provides directions for its own replication
- DNA directs synthesis of messenger RNA (mRNA) and, through mRNA, controls protein synthesis
- This process is called **gene expression**

Figure 5.22_1

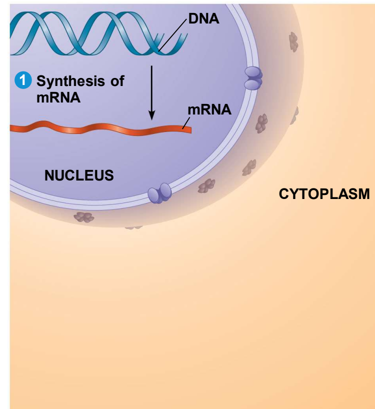


Figure 5.22_2

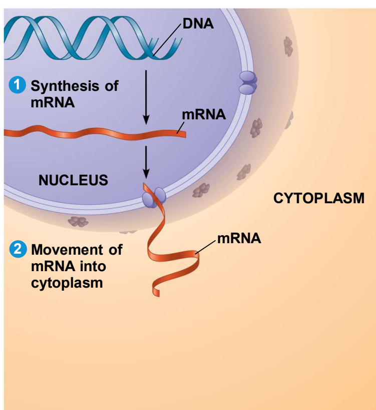
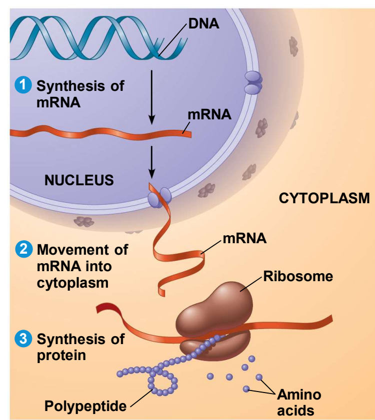


Figure 5.22_3



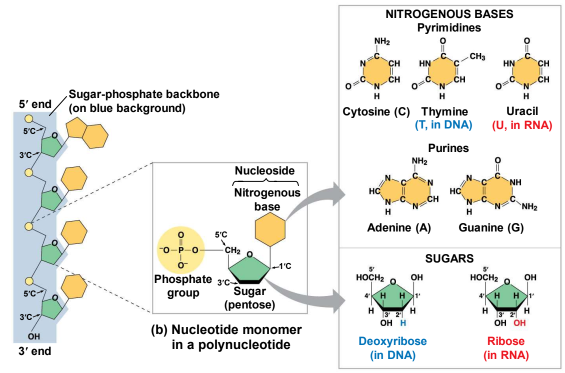
- Each gene along a DNA molecule directs synthesis of a messenger RNA (mRNA)
- The mRNA molecule interacts with the cell's protein-synthesizing machinery to direct production of a polypeptide
- The flow of genetic information can be summarized as DNA → RNA → protein

The Components of Nucleic Acids

- Nucleic acids are polymers called **polynucleotides**
- Each polynucleotide is made of monomers called **nucleotides**
- Each nucleotide consists of a nitrogenous base, a pentose sugar, and one or more phosphate groups
- The portion of a nucleotide without the phosphate group is called a nucleoside

- Nucleoside = nitrogenous base + sugar
- There are two families of nitrogenous bases
  - **Pyrimidines** (cytosine, thymine, and uracil) have a single six-membered ring
  - **Purines** (adenine and guanine) have a six-membered ring fused to a five-membered ring
- In DNA, the sugar is **deoxyribose**; in RNA, the sugar is **ribose**
- Nucleotide = nucleoside + phosphate group

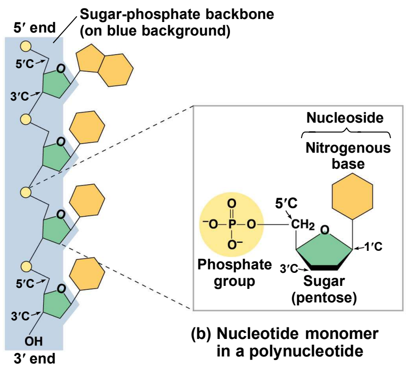
Figure 5.23



(a) Polynucleotide, or nucleic acid

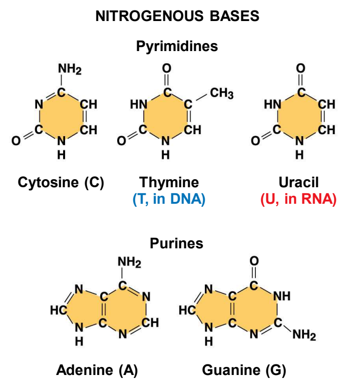
(c) Nucleoside components

Figure 5.23a



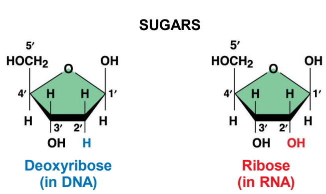
(a) Polynucleotide, or nucleic acid

Figure 5.23b



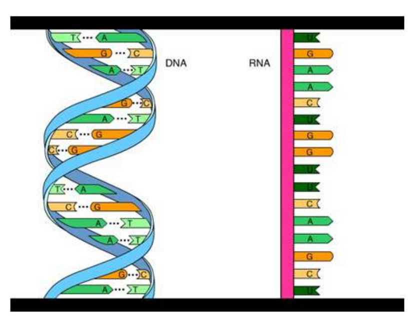
(c) Nucleoside components

Figure 5.23c



(c) Nucleoside components

Animation: DNA and RNA Structure



Nucleotide Polymers

- Nucleotides are linked together by a phosphodiester linkage to build a polynucleotide
- A phosphodiester linkage consists of a phosphate group that links the sugars of two nucleotides
- These links create a backbone of sugar-phosphate units with nitrogenous bases as appendages
- The sequence of bases along a DNA or mRNA polymer is unique for each gene

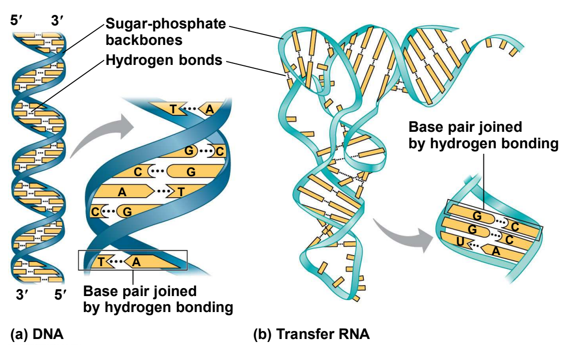
The Structures of DNA and RNA Molecules

- DNA molecules have two polynucleotides spiraling around an imaginary axis, forming a **double helix**
- The backbones run in opposite 5′ → 3′ directions from each other, an arrangement referred to as **antiparallel**
- One DNA molecule includes many genes

- Only certain bases in DNA pair up and form hydrogen bonds:
  - adenine (A) always with thymine (T)
  - guanine (G) always with cytosine (C)
- This is called **complementary base pairing**
- This feature of DNA structure makes it possible to generate two identical copies of each DNA molecule in a cell preparing to divide

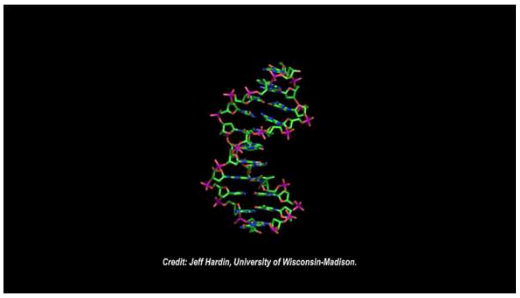
- **RNA**, in contrast to DNA, is single-stranded
- Complementary pairing can also occur between two RNA molecules or between parts of the same molecule
- In RNA, thymine is replaced by uracil (U), so A and U pair
- While DNA always exists as a double helix, RNA molecules are more variable in form

Figure 5.24

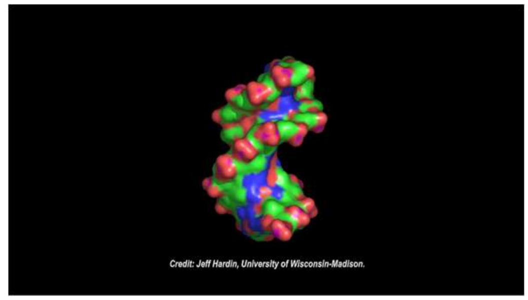


Animation: DNA Double Helix

Video: Stick Model of DNA (Deoxyribonucleic Acid)



Video: Surface Model of DNA (Deoxyribonucleic Acid)



Chapter Summary

- Functional groups from Chapter 4
  (PDF file found in E-Learning)
- Macromolecular of Life
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic Acids

Figure 5.UN04

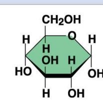
Components	Examples	Functions
 Monosaccharide monomer	Monosaccharides: glucose, fructose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
	Disaccharides: lactose, sucrose	
	Polysaccharides: - Cellulose (plants) - Starch (plants) - Glycogen (animals) - Chitin (animals and fungi)	- Strengthens plant cell walls - Stores glucose for energy - Stores glucose for energy - Strengthens exoskeletons and fungal cell walls

Figure 5.UN05

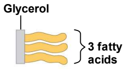
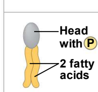
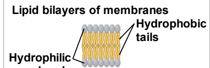
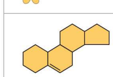
Components	Examples	Functions
Glycerol 	Triacylglycerols (fats or oils): glycerol + three fatty acids	Important energy source 
	Phospholipids: glycerol + phosphate group + two fatty acids	Lipid bilayers of membranes 
 Steroid backbone	Steroids: four fused rings with attached chemical groups	- Component of cell membranes (cholesterol) - Signaling molecules that travel through the body (hormones)

Figure 5.UN06

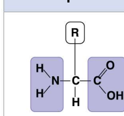
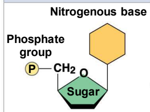
Components	Examples	Functions
 Amino acid monomer (20 types)	- Enzymes - Defensive proteins - Storage proteins - Transport proteins - Hormones - Receptor proteins - Motor proteins - Structural proteins	- Catalyze chemical reactions - Protect against disease - Store amino acids - Transport substances - Coordinate organismal responses - Receive signals from outside cell - Function in cell movement - Provide structural support

Figure 5.UN07

Components	Examples	Functions
 Nucleotide (monomer of a polynucleotide)	DNA: ▪ Sugar = deoxyribose ▪ Nitrogenous bases = C, G, A, T ▪ Usually double-stranded	Stores hereditary information
	RNA: ▪ Sugar = ribose ▪ Nitrogenous bases = C, G, A, U ▪ Usually single-stranded	Various functions in gene expression, including carrying instructions from DNA to ribosomes