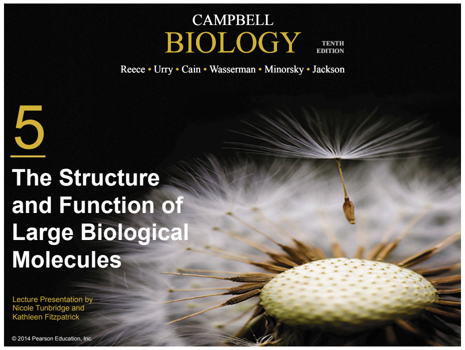


The Molecules of Life

- 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

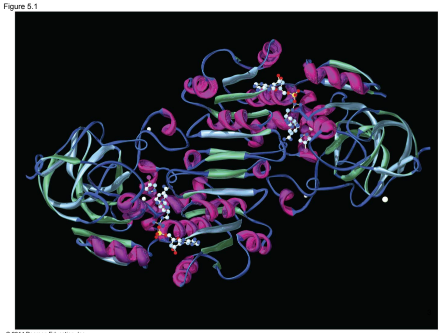
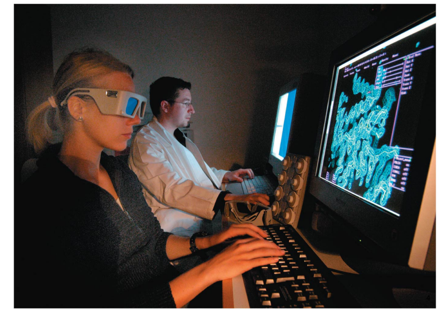


Figure 5.1a



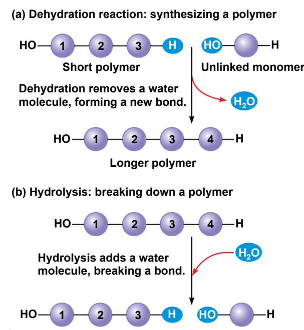
Concept 5.1: Macromolecules are polymers, built from monomers

- A **polymer** is a long molecule consisting of many similar building blocks
- The repeating units that serve as building blocks are called **monomers**
- Three of the four classes of life's organic molecules are polymers
  - Carbohydrates
  - Proteins
  - Nucleic acids

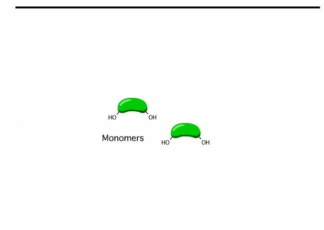
The Synthesis and Breakdown of Polymers

- **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

- Each 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

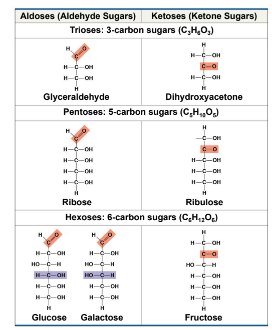


Figure 5.3a

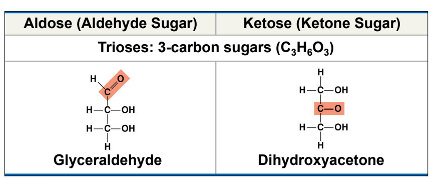


Figure 5.3b

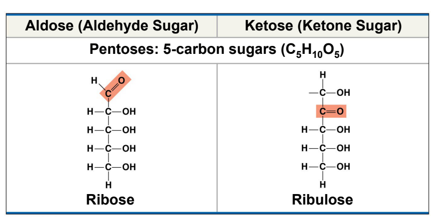
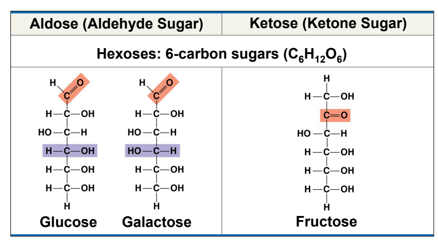
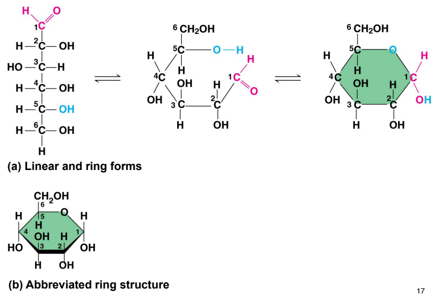


Figure 5.3c



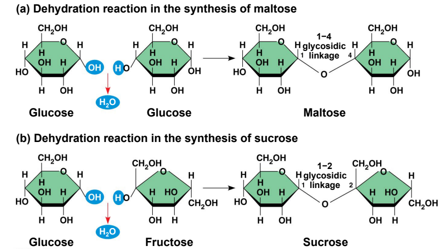
- Though often drawn as linear skeletons, in aqueous solutions many sugars form rings
- Monosaccharides serve as a major fuel for cells and as raw material for building molecules

Figure 5.4



- A **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 entirely of glucose monomers
- Plants store surplus starch as granules within chloroplasts and other plastids
- The simplest form of starch is amylose

Figure 5.6

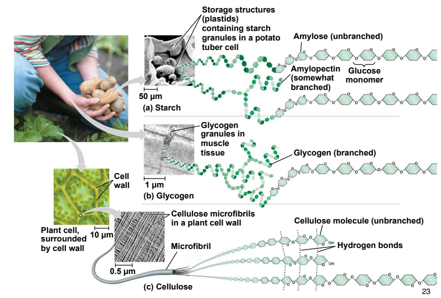


Figure 5.6a

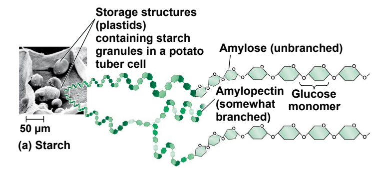
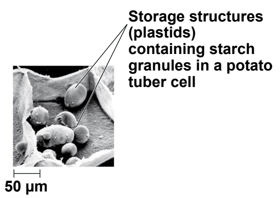
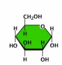


Figure 5.6aa



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

Figure 5.6b

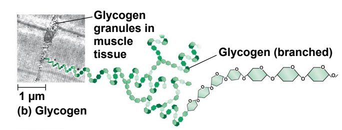
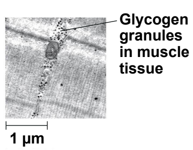


Figure 5.6ba



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 5.6c

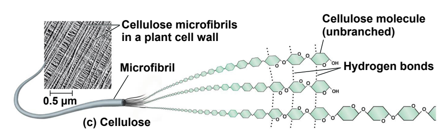


Figure 5.6ca

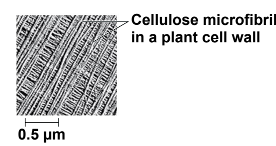
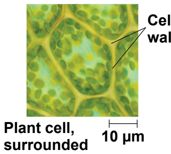


Figure 5.6d



Plant cell, surrounded by cell wall

Figure 5.7

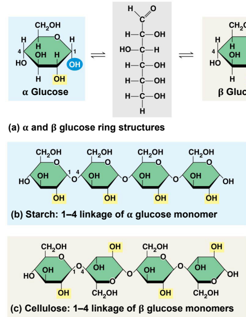
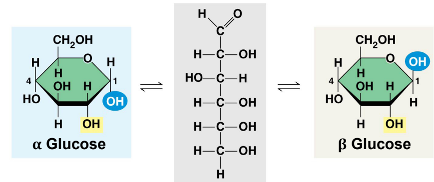
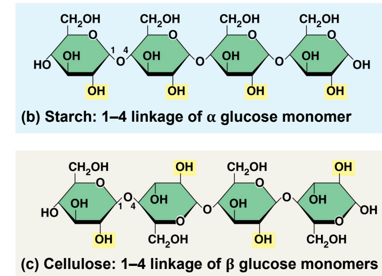


Figure 5.7a



(a) α and β glucose ring structures

Figure 5.7b



- 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

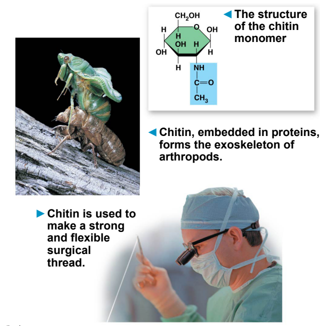
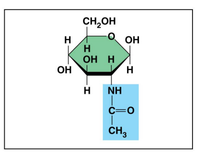


Figure 5.8a

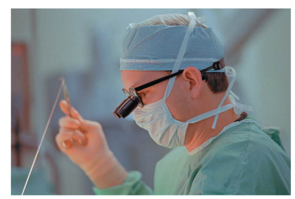


The structure of the chitin monomer

Figure 5.8b

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

Figure 5.8c



Chitin is used to make a strong and flexible surgical thread.

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 are hydrophobic because they consist mostly of hydrocarbons, which form nonpolar covalent bonds
- 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

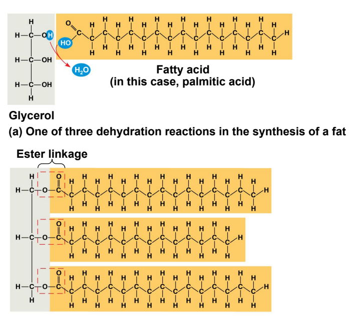
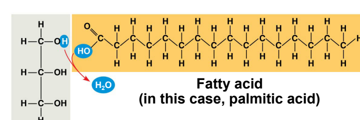


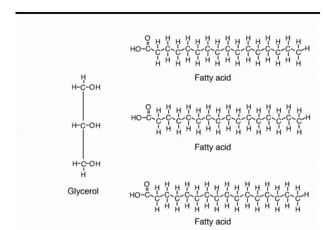
Figure 5.9a



Glycerol

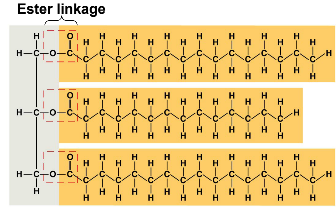
(a) One of three dehydration reactions in the synthesis of a fat

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

Figure 5.9b



(b) Fat molecule (triacylglycerol)

- 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

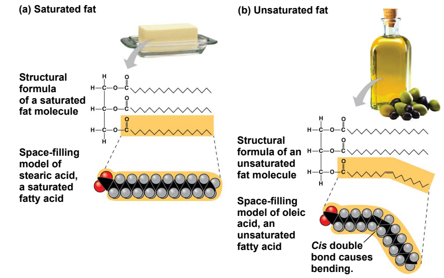


Figure 5.10a

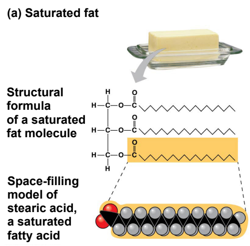


Figure 5.10aa

Figure 5.10b

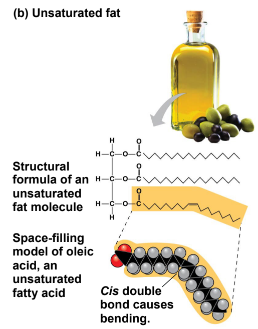


Figure 5.10ba

- 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

- Certain unsaturated fatty acids are not synthesized in the human body
- These must be supplied in the diet
- These essential fatty acids include the omega-3 fatty acids, which are required for normal growth and are thought to provide protection against 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

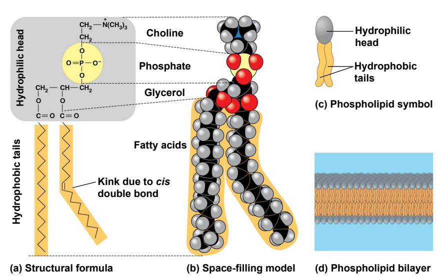


Figure 5.11a

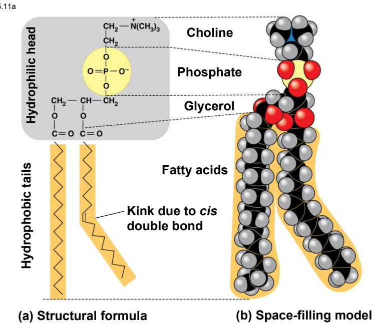
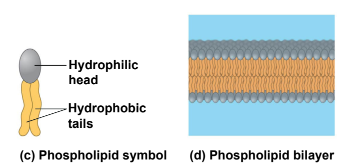


Figure 5.11b

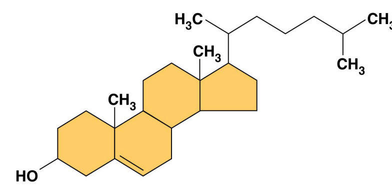


- When phospholipids are added to water, they self-assemble into double-layered structures called bilayers
- At the surface of a cell, phospholipids are also arranged in a bilayer, with the hydrophobic tails pointing toward the interior
- The structure of phospholipids results in a bilayer arrangement found in cell membranes
- The existence of cells depends on phospholipids

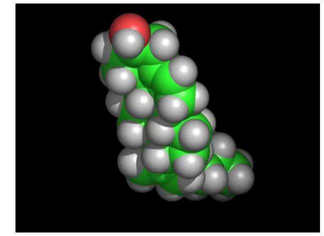
Steroids

- **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

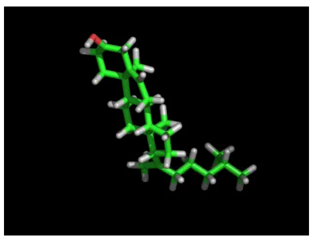
Figure 5.12



Video: Space-filling Model of Cholesterol



Video: Stick Model of Cholesterol

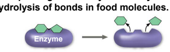


Concept 5.4: Proteins include a diversity of structures, resulting in a wide range of functions

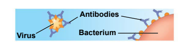
- Proteins account for more than 50% of the dry mass of most cells
- Some proteins speed up chemical reactions
- Other protein functions include defense, storage, transport, cellular communication, movement, or structural support

Figure 5.13a

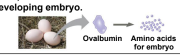
Enzymatic proteins
Function: Selective acceleration of chemical reactions
Example: Digestive enzymes catalyze the hydrolysis of bonds in food molecules.



Defensive proteins
Function: Protection against disease
Example: Antibodies inactivate and help destroy viruses and bacteria.



Storage proteins
Function: Storage of amino acids
Examples: Casein, the protein of milk, is the major source of amino acids for baby mammals. Plants have storage proteins in their seeds. Ovalbumin is the protein of egg white, used as an amino acid source for the developing embryo.



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.

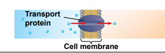


Figure 5.13aa

Enzymatic proteins
Function: Selective acceleration of chemical reactions
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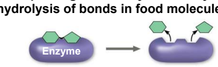

Figure 5.13ab

Defensive proteins
Function: Protection against disease
Example: Antibodies inactivate and help destroy viruses and bacteria.

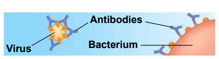

Figure 5.13ac

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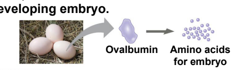


Figure 5.13aca

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.

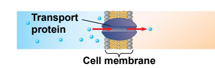
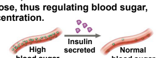


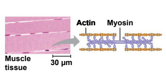
Figure 5.13b

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.

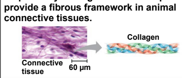


Figure 5.13ba

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.

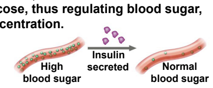


Figure 5.13bb

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.

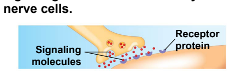


Figure 5.13bc

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.

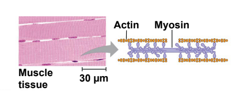
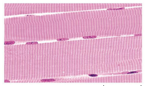


Figure 5.13bca



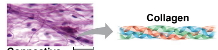
Muscle tissue
30 µm

Figure 5.13bd

Structural proteins

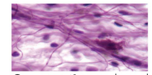
Function: Support

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.



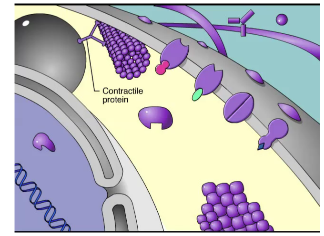
Connective tissue
60 µm

Figure 5.13bda

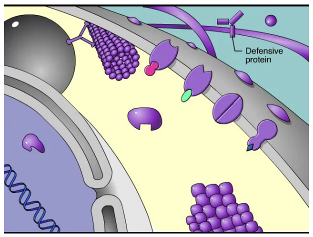


Connective tissue
60 µm

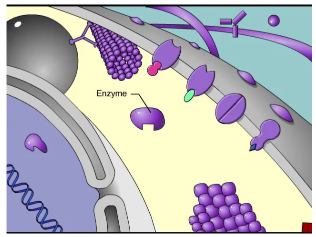
Animation: Contractile Proteins



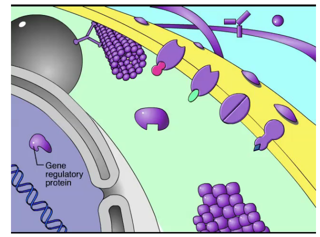
Animation: Defensive Proteins



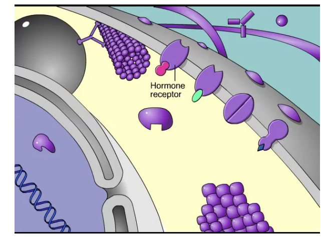
Animation: Enzymes



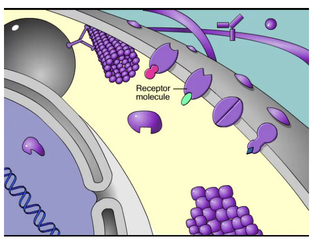
Animation: Gene Regulatory Proteins



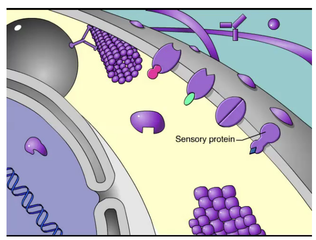
Animation: Hormonal Proteins



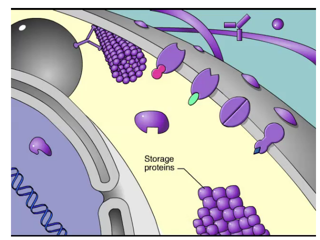
Animation: Receptor Proteins



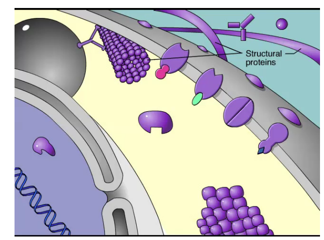
Animation: Sensory Proteins



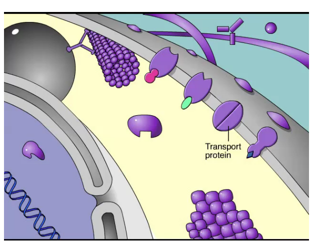
Animation: Storage Proteins



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

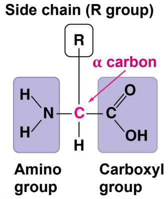


Figure 5.14

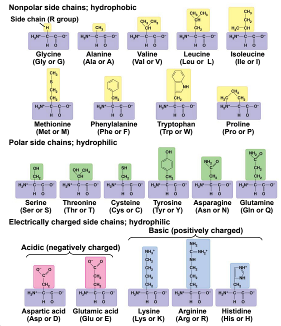


Figure 5.14a

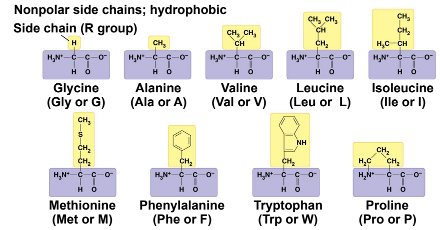


Figure 5.14b

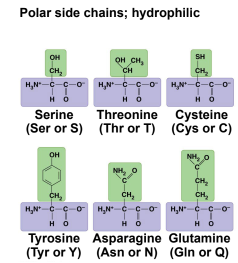
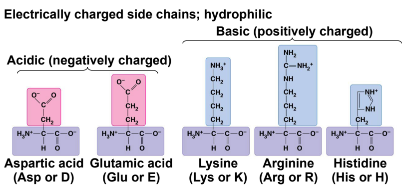


Figure 5.14c



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 a thousand 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

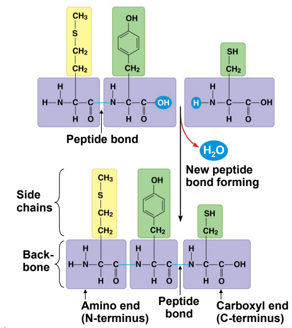


Figure 5.15a

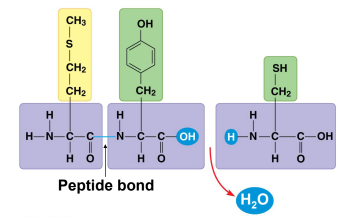
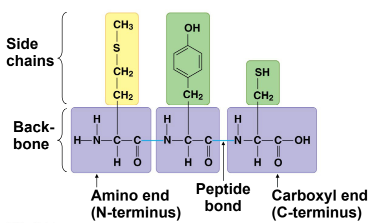


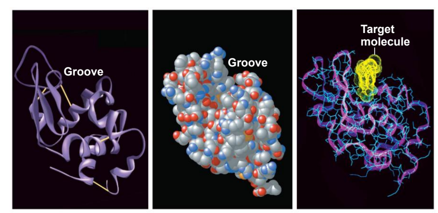
Figure 5.15b



Protein Structure and Function

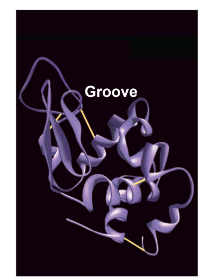
- The specific activities of proteins result from their intricate three-dimensional architecture
- A functional protein consists of one or more polypeptides precisely twisted, folded, and coiled into a unique shape

Figure 5.16



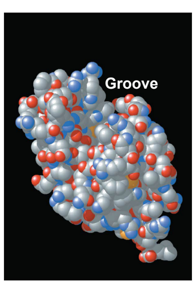
(a) A ribbon model (b) A space-filling model (c) A wireframe model

Figure 5.16a



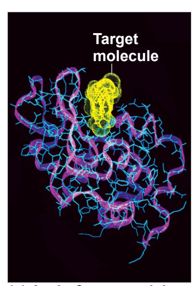
(a) A ribbon model

Figure 5.16b



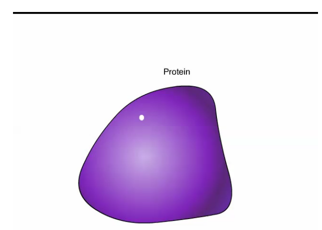
(b) A space-filling model

Figure 5.16c



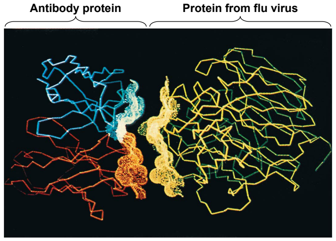
(c) A wireframe model

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

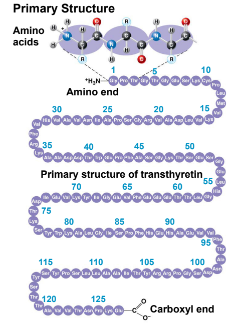
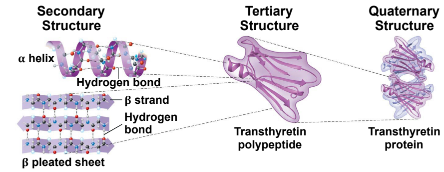
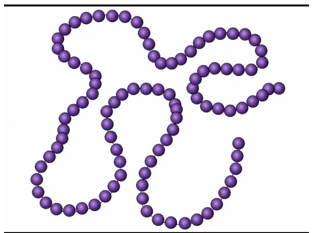


Figure 5.18b

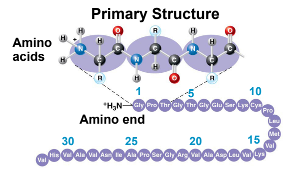


Animation: Primary Protein Structure



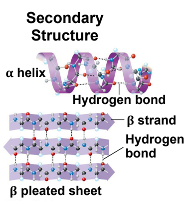
- The **primary structure** of a protein is its sequence of amino acids
- Primary structure is like the order of letters in a long word
- Primary structure is determined by inherited genetic information

Figure 5.18aa

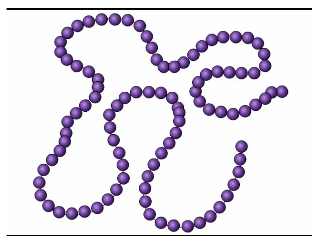


- The coils and folds of **secondary structure** result from hydrogen bonds between repeating constituents of the polypeptide backbone
- Typical secondary structures are a coil called an **α helix** and a folded structure called a **β pleated sheet**

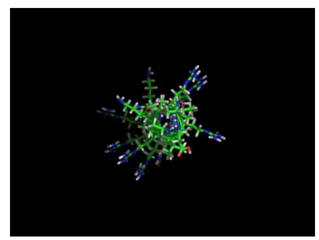
Figure 5.18ba



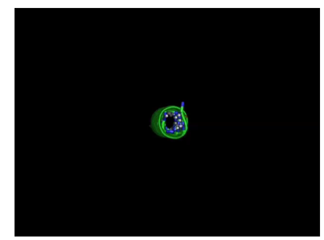
Animation: Secondary Protein Structure



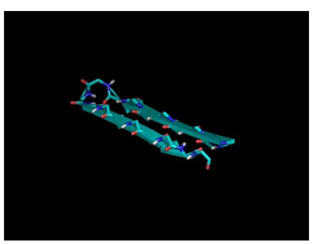
Video: An Idealized α Helix



Video: An Idealized α Helix: No Sidechains



Video: An Idealized β Pleated Sheet



Video: An Idealized β Pleated Sheet Cartoon

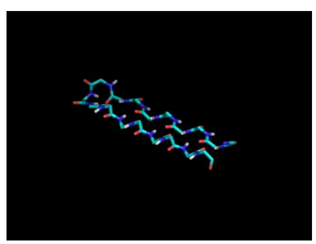
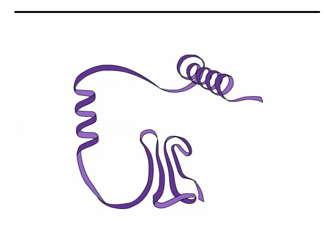


Figure 5.18c

Animation: Tertiary Protein Structure



- **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

Figure 5.18bb

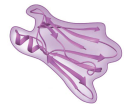
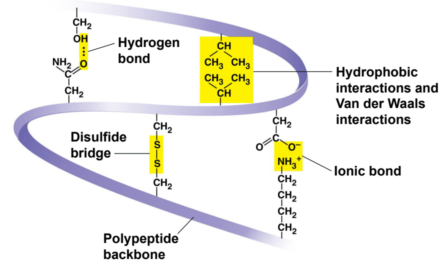
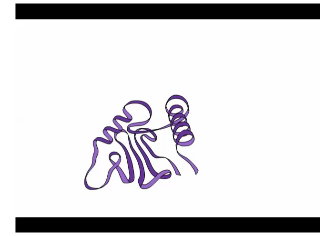


Figure 5.18d



Animation: Quaternary 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 alpha and two beta chains

Figure 5.18bc

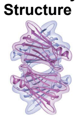


Figure 5.18e

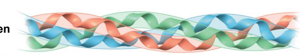
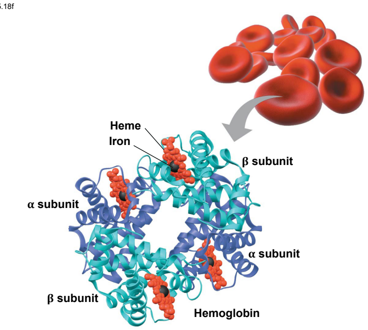


Figure 5.18f



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

Figure 5.19

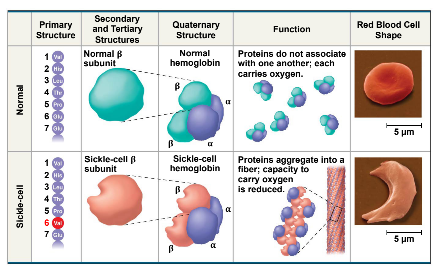


Figure 5.19a

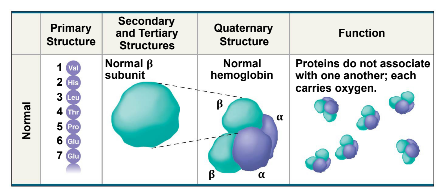


Figure 5.19aa

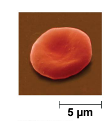


Figure 5.19b

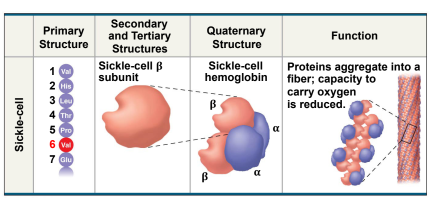


Figure 5.19ba

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 5.20-1

Figure 5.20-2

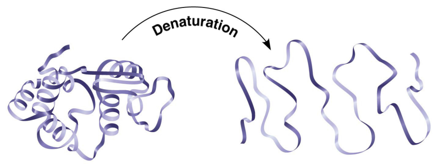
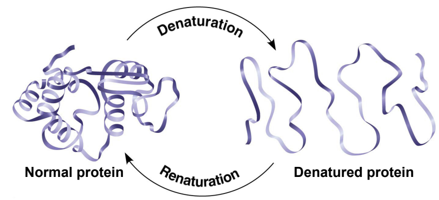


Figure 5.20-3



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
- **Chaperonins** are protein molecules that assist the proper folding of other proteins
- Diseases such as Alzheimer's, Parkinson's, and mad cow disease are associated with misfolded proteins

Figure 5.21

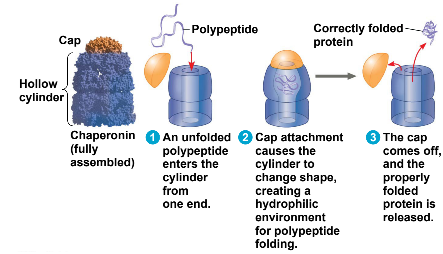


Figure 5.21a

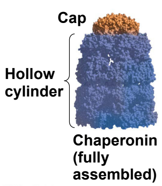


Figure 5.21b-1

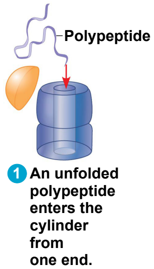


Figure 5.21b-2

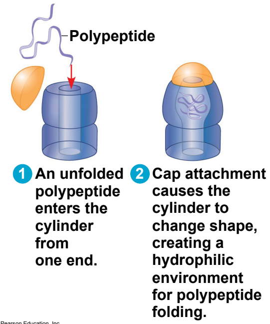
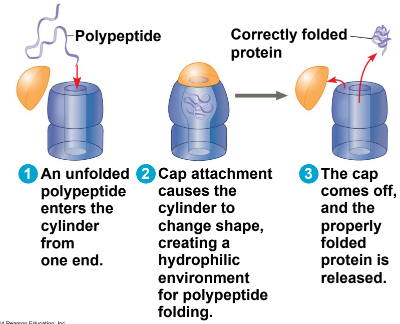


Figure 5.21b-3



- 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 5.22

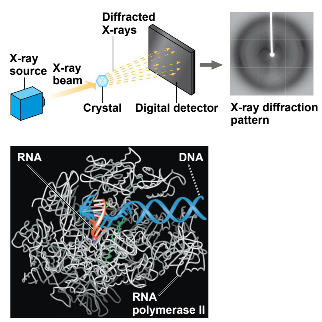


Figure 5.22a

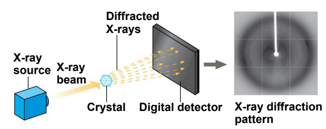
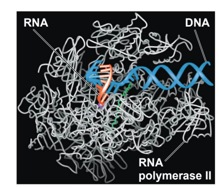


Figure 5.22b



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

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 5.23-1

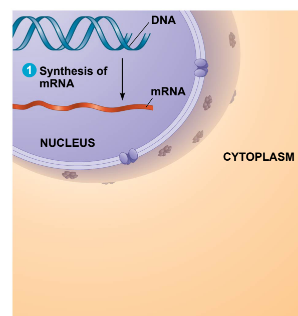


Figure 5.23-2

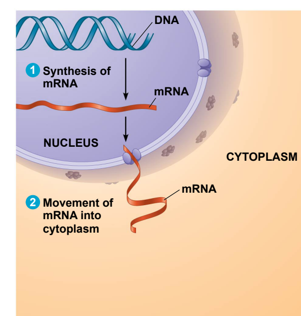
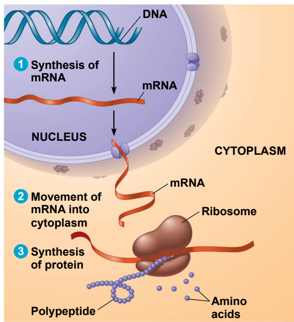


Figure 5.23-3



- 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 5.24

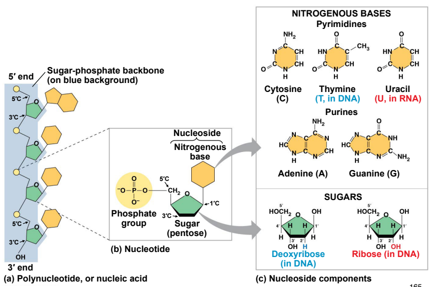


Figure 5.24a

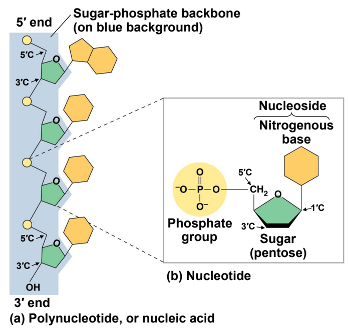


Figure 5.24b

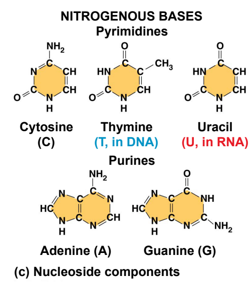
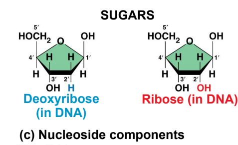
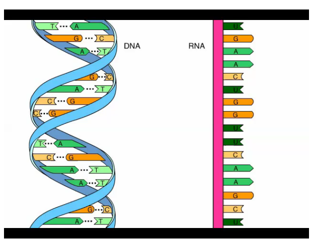


Figure 5.24c



Animation: DNA and RNA Structure



Nucleotide Polymers

- Nucleotides are linked together to build a polynucleotide
- Adjacent nucleotides are joined by a phosphodiester linkage, which 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

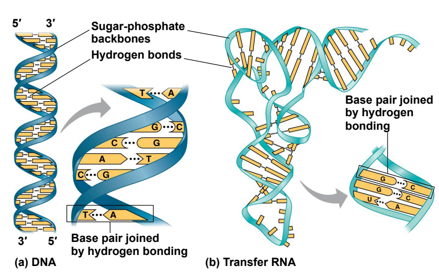
The Structures of DNA and RNA Molecules

- 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

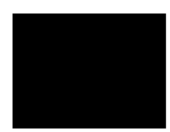
- Only certain bases in DNA pair up and form hydrogen bonds: adenine (A) always with thymine (T), and guanine (G) always with cytosine (C)
- This is called complementary base pairing
- This feature of DNA structure makes it possible to generate two identical copies of each DNA molecule in a cell preparing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

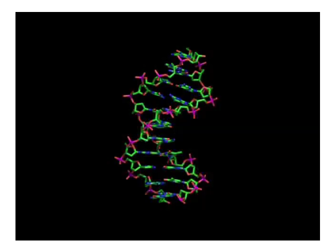
Figure 5.25



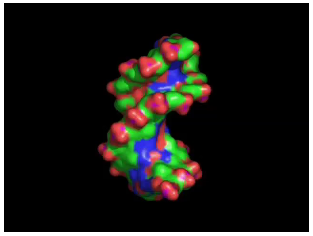
Animation: DNA Double Helix



Video: Stick Model of DNA (Deoxyribonucleic Acid)



Video: Surface Model of DNA (Deoxyribonucleic Acid)



Concept 5.6: Genomics and proteomics have transformed biological inquiry and applications

- Once the structure of DNA and its relationship to amino acid sequence was understood, biologists sought to "decode" genes by learning their base sequences
- The first chemical techniques for DNA sequencing were developed in the 1970s and refined over the next 20 years

- It is enlightening to sequence the full complement of DNA in an organism's genome
- The rapid development of faster and less expensive methods of sequencing was a side effect of the Human Genome Project
- Many genomes have been sequenced, generating reams of data

- Bioinformatics uses computer software and other computational tools to deal with the data resulting from sequencing many genomes
- Analyzing large sets of genes or even comparing whole genomes of different species is called **genomics**
- A similar analysis of large sets of proteins including their sequences is called **proteomics**

Figure 5.26

MAKE CONNECTIONS
Contributions of Genomics and Proteomics to Biology

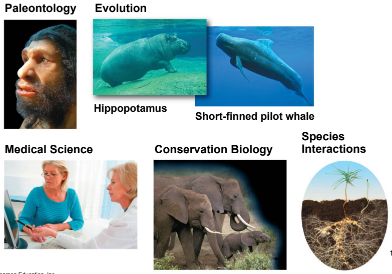


Figure 5.26a

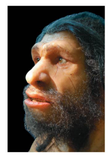


Figure 5.26b

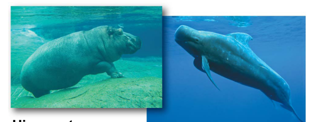


Figure 5.26ba

Figure 5.26bb

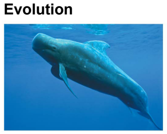


Figure 5.26c

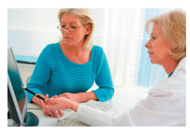


Figure 5.26d

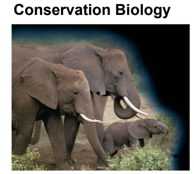


Figure 5.26e

DNA and Proteins as Tape Measures of Evolution

- Sequences of genes and their protein products document the hereditary background of an organism
- Linear sequences of DNA molecules are passed from parents to offspring
- We can extend the concept of "molecular genealogy" to relationships between species
- Molecular biology has added a new measure to the toolkit of evolutionary biology

Figure 5.UN02a

Species	Alignment of Amino Acid Sequences of β-globin
Human	1 VHLTPEEKSA VTALWGKVNV DEVGGEALGR LLVVYPWTQR FFESFGDLST
Monkey	1 VHLTPEEKNA VTTLWGKVNV DEVGGEALGR LLLVYPWTQR FFESFGDLSS
Gibbon	1 VHLTPEEKSA VTALWGKVNV DEVGGEALGR LLVVYPWTQR FFESFGDLST
Human	51 PDAVMGNPKV KAHGKKVLGA FSDGLAHLDN LKGTFATLSE LHCDKLHVDP
Monkey	51 PDAVMGNPKV KAHGKKVLGA FSDGLNHLDN LKGTFAQLSE LHCDKLHVDP
Gibbon	51 PDAVMGNPKV KAHGKKVLGA FSDGLAHLDN LKGTFAQLSE LHCDKLHVDP
Human	101 ENFRLLGNVL VCVLAHHFGK EFTPPVQAAY QKVVAGVANA LAHKYH
Monkey	101 ENFKLLGNVL VCVLAHHFGK EFTPQVQAAY QKVVAGVANA LAHKYH
Gibbon	101 ENFRLLGNVL VCVLAHHFGK EFTPQVQAAY QKVVAGVANA LAHKYH

Figure 5.UN02b

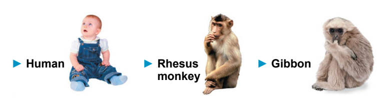


Figure 5.UN03

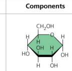
Large Biological Molecules	Components	Examples	Functions
Carbohydrates serve as fuel and building material (pp. 68–72)	 Monosaccharide monomer	**Monosaccharides:** glucose, fructose **Disaccharides:** lactose, sucrose	Fuel; carbon sources that can be converted to other molecules or combined into polymers
		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.UN04

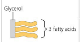
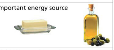
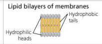
Large Biological Molecules	Components	Examples	Functions
Lipids are a diverse group of hydrophobic molecules (pp. 72–75)		**Triacylglycerols** (fats or oils): glycerol + 3 fatty acids	Important energy source 
		**Phospholipids:** glycerol + phosphate group + 2 fatty acids	Lipid bilayers of membranes 
	 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.UN05

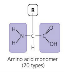
Large Biological Molecules	Components	Examples	Functions
Proteins include a diversity of structures, resulting in a wide range of functions (pp. 75–84)	 Amino acid monomer (20 types)	• Enzymes • Structural proteins • Hormones • Receptor proteins • Motor proteins • Defensive proteins	• Catalyze chemical reactions • Provide structural support • Coordinate organismal responses • Receive signals from outside cell • Function in cell movement • Protect against disease

Figure 5.UN06

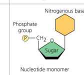
Large Biological Molecules	Components	Examples	Functions
Nucleic acids store, transmit, and help express hereditary information (pp. 84–87)	 Nucleotide monomer	**DNA:**  • Sugar = deoxyribose • Nitrogenous bases = C, G, A, T • Usually double-stranded	Stores hereditary information
		RNA:  • Sugar = ribose • Nitrogenous bases = C, G, A, U • Usually single-stranded	Various functions in gene expression, including carrying instructions from DNA to ribosomes

Figure 5.UN07