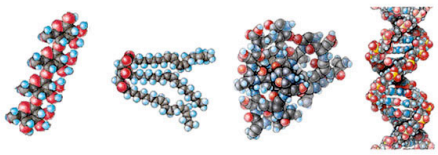
Chapter 3

The Chemical Building Blocks of Life

Terms

- ✓ Macromolecules - large molecules
- ✓ Polymers - small units linked together
- ✓ Monomers - single units
- ✓ Organic - carbon containing

Biological Macromolecules

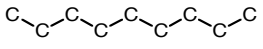


Carbohydrate (starch) | Lipid (triacylglycerol) | Protein (enzyme) | Nucleic acid (DNA)

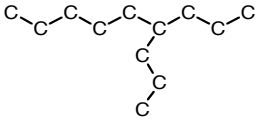
Biologically important compounds

- Lipids -- fats, oils, waxes
- Carbohydrates -- starch, cellulose, chitin, glycogen
- Nucleic acids -- DNA, RNA, ATP
- Proteins -- silk, hair, tendons, Jell-O

Carbon skeletons

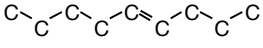


straight chain



branched chain

ring or cyclic structure



straight chain with double bonds

ring structure with double bonds

Primary Functional Groups

Group	Chemical formula	Structural Formula	Ball-and-Stick Model	Found in:
Hydroxyl	– OH	– OH		Alcohols
Carbonyl	C = O			Formaldehyde
Carboxyl	– COOH			Vinegar
Amino	$-NH_2$			Ammonia
Sulfhydryl	– SH	– S – H		Rubber
Phosphate	$-PO_4$			ATP
Methyl	$-CH_3$			Methane gas

Functional Groups

—OH alcohol, hydroxyl

aldehyde

ketone

carbonyl

—COOH carboxyl

Functional Groups (cont.)

—SH sulfhydryl

—NH_2 amino

—H_2PO_4 phosphate

hydrocarbon chain

Biological Reactions

Fueling reactions
(metabolism)
↓
Biosynthetic reactions
(making monomers)
↓
Polymerization reactions
(making polymers)
↓
Assembly reactions

Biological Molecules

fatty acids and glycerol → lipids

monosaccharides → polysaccharides

nucleotides → nucleic acids

amino acids → proteins

Monomers to Polymers

monomer + monomer + monomer → polymer!

(H_2O released at each bond)

Carbohydrates

✓ Monomers
- glucose
- fructose
- ribose and deoxyribose

✓ Polymers
- starch
- glycogen
- chitin
- peptidoglycan

Carbohydrate Families

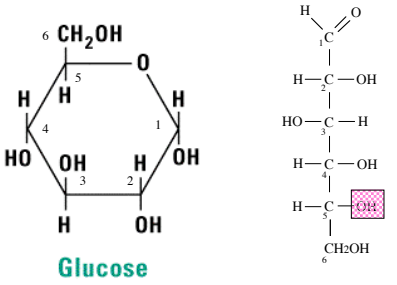
Storage

starch
glycogen

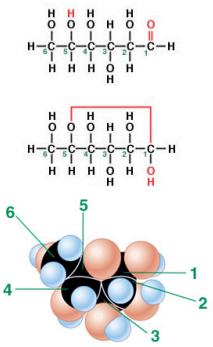
Structural

cellulose
chitin
peptidoglycan

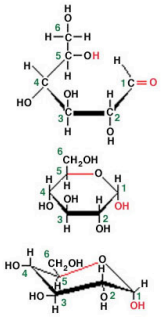
Carbohydrates



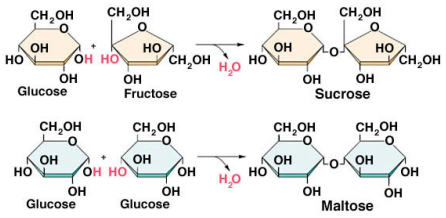
Glucose Molecular Structure (1)



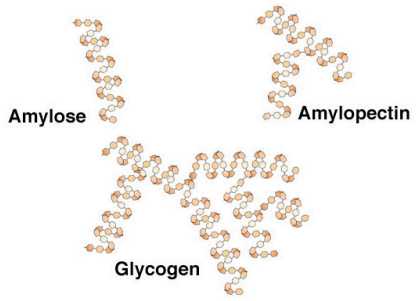
Glucose Molecular Structure (2)



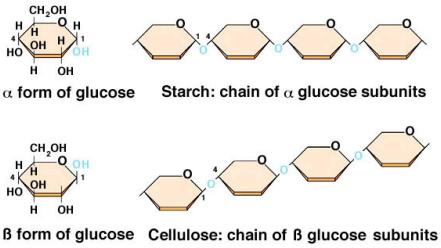
Disaccharides



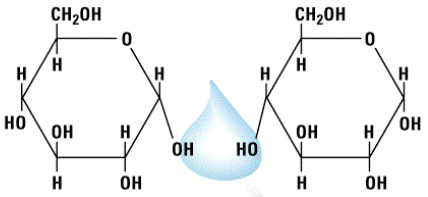
Starches



Comparison of Starch and Cellulose

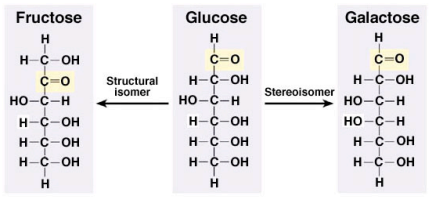


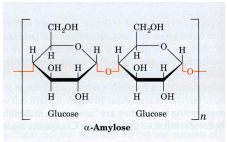
Glycosidic bonds are formed in a dehydration reaction between 2 carbohydrates.



dehydration

Isomers and Stereoisomers





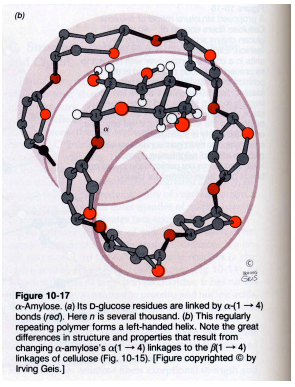


Figure 10-17
α-Amylose. (*a*) Its D-glucose residues are linked by α-(1 → 4) bonds (*red*). Here *n* is several thousand. (*b*) This regularly repeating polymer forms a left-handed helix. Note the great differences in structure and properties that result from changing α-amylose's α(1 → 4) linkages to the β(1 → 4) linkages of cellulose (Fig. 10-15). [Figure copyrighted © by Irving Geis.]

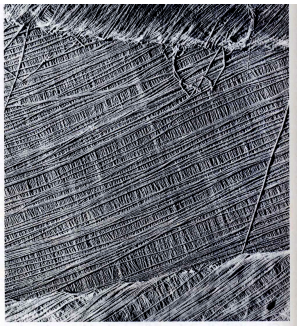


Figure 10-13
Electron micrograph of the cellulose fibers in the cell wall of the alga *Chaetomorpha*. Note that the cell wall consists of layers of parallel fibers. [Biophoto Associates.]

Lipid families

triglycerides

storage

phospholipids

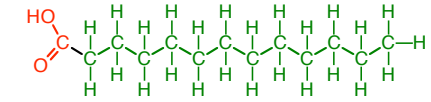
structural

sterols

structural, messenger

Fatty acids

✓ Carboxyl functional group attached to a hydrocarbon chain.

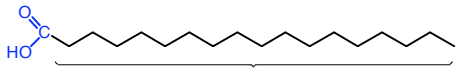


carboxylic acid

hydrocarbon chain

Saturated fatty acid

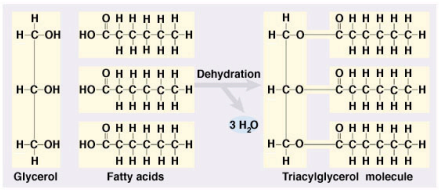
stearic acid--a saturated fatty acid



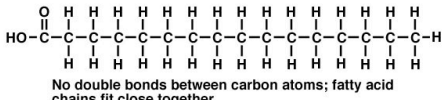
carboxylic acid

saturated hydrocarbon chain

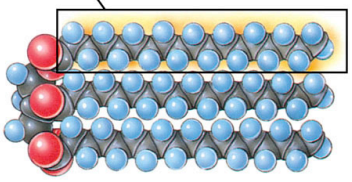
Triacylglycerol (Triglyceride)



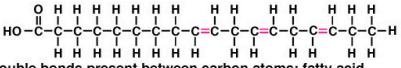
Saturated Fat



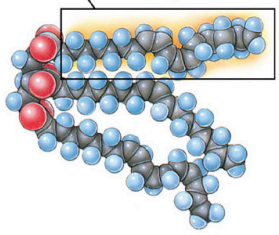
No double bonds between carbon atoms; fatty acid chains fit close together



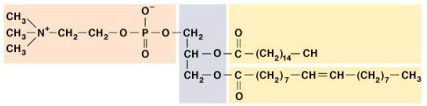
Unsaturated Fat



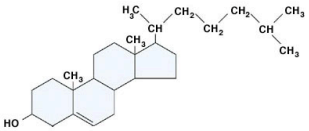
Double bonds present between carbon atoms; fatty acid chains do not fit close together



Other Primary Lipids (1)

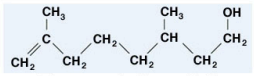


Phospholipid (phosphatidyl choline)

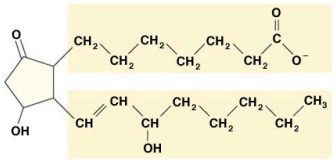


Steroid (cholesterol)

Other Primary Lipids (2)

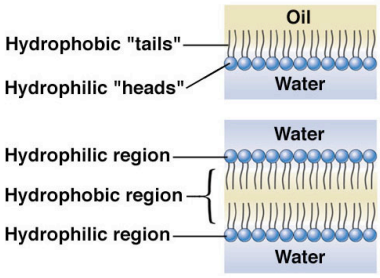


Terpene (citronellol)



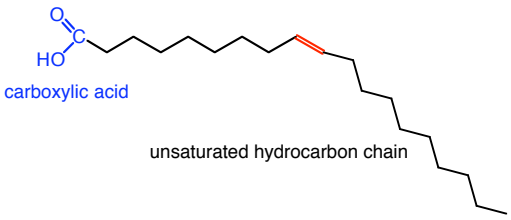
Prostaglandin (PGE)

Phospholipids



Unsaturated fatty acid

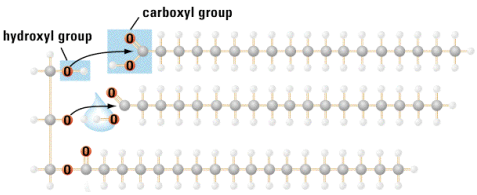
oleic acid--an unsaturated fatty acid



carboxylic acid

unsaturated hydrocarbon chain

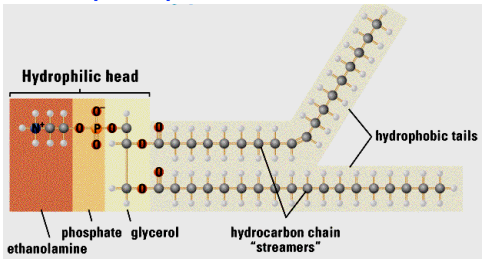
Triglycerides



Glycerol

Three fatty acids

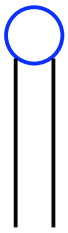
Phospholipids



Phosphate group

2 fatty acids

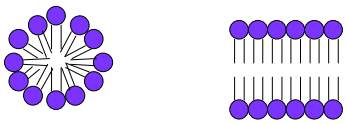
Phospholipids are amphipathic molecules

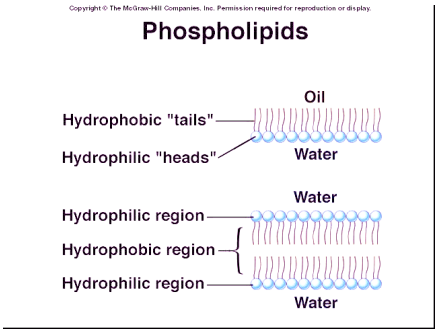


Hydrophilic head

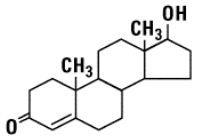
Hydrophobic tails

Phospholipids form micelles and bilayers





Steroids



Steroids contain 4 rings of carbon atoms

Others include: cholesterol,progesterone, estradiol, & corticosterone

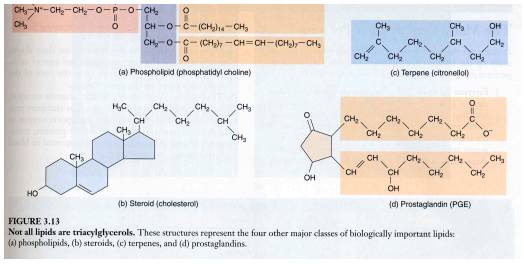


FIGURE 3.13
Not all lipids are triacylglycerols. These structures represent the four other major classes of biologically important lipids: (a) phospholipids, (b) steroids, (c) terpenes, and (d) prostaglandins.

Biological Molecules Small and Large

Nucleic Acids and Proteins

Introduction

- ✓ **Proteins** are instrumental in about everything that an organism does.
  - ✒ These functions include structural support, storage, transport of other substances, intercellular signaling, movement, and defense against foreign substances.
  - ✒ Proteins are the overwhelming enzymes in a cell and regulate metabolism by selectively accelerating chemical reactions.
- ✓ Humans have tens of thousands of different proteins, each with their own structure and function.

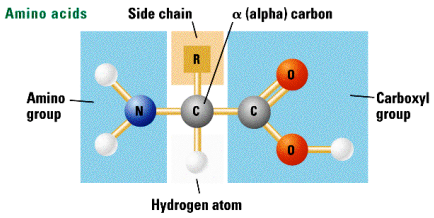
- ✓ Proteins are the most structurally complex molecules known.
  - ✒ Each type of protein has a complex three-dimensional shape or conformation.
- ✓ All protein polymers are constructed from the same set of 20 monomers, called amino acids.
- ✓ Polymers of proteins are called **polypeptides**.
- ✓ A protein consists of one or more polypeptides folded and coiled into a specific conformation.

A polypeptide is a polymer of amino acids connected in a specific sequence

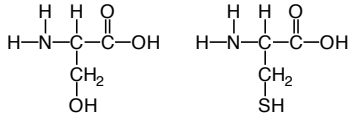
- ✓ **Amino acids** consist of four components attached to a central carbon, the *alpha carbon*.
- ✓ These components include a hydrogen atom, a carboxyl group, an amino group, and a variable R group (or side chain).
  - ✒ Differences in R groups produce the 20 different amino acids.

- ✓ The twenty different R groups may be as simple as a hydrogen atom (as in the amino acid glutamine) to a carbon skeleton with various functional groups attached.
- ✓ The physical and chemical characteristics of the R group determine the unique characteristics of a particular amino acid.

Basic structure of an amino acid



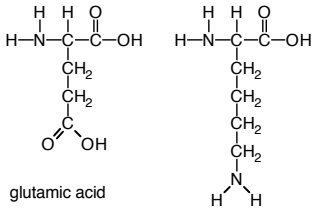
Polar, non-ionizable amino acids



serine cysteine

Contain alcohol (-OH), sulfhydryl (-SH) groups

Polar, ionizable amino acids

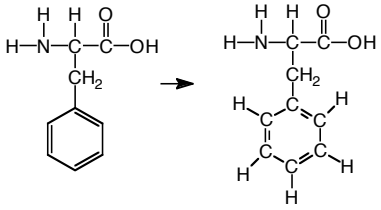


glutamic acid

lysine

Contain carboxyl (-COOH) and amino ($-NH_2$) groups

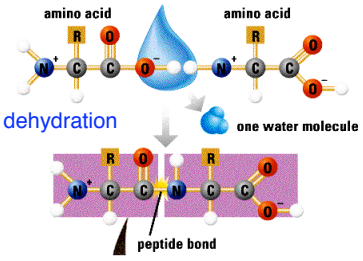
Nonpolar amino acids



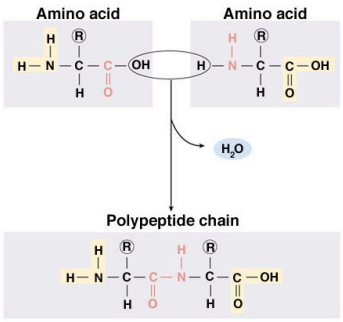
Phenylalanine

Contain only carbon (C) and hydrogen (H) atoms

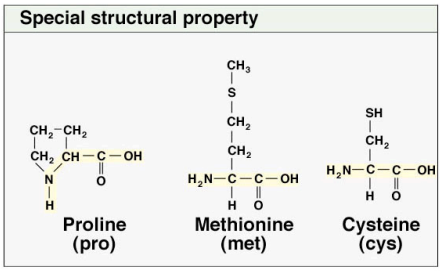
Amino Acids to Proteins



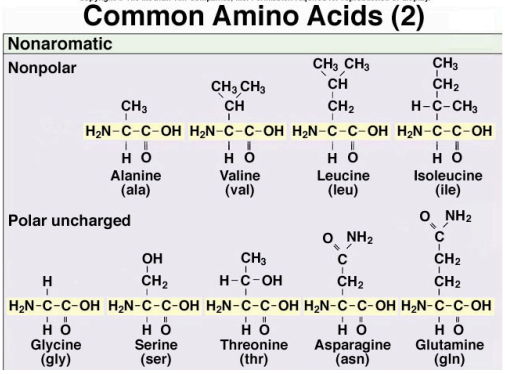
Peptide Bond



Common Amino Acids (1)

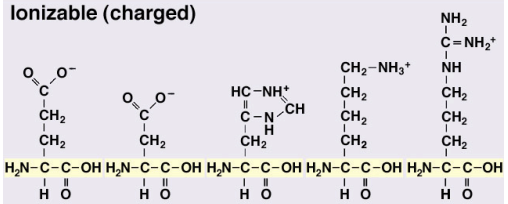


Common Amino Acids (2)



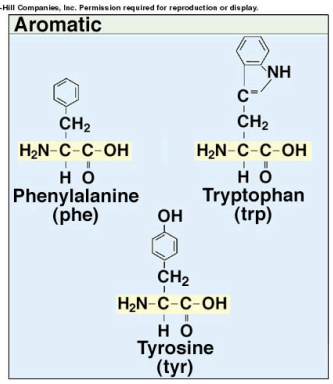
Common Amino Acids (3)

Nonaromatic
Ionizable (charged)



Common Amino Acids (4)

Aromatic



✓ One group of amino acids has hydrophobic R groups.

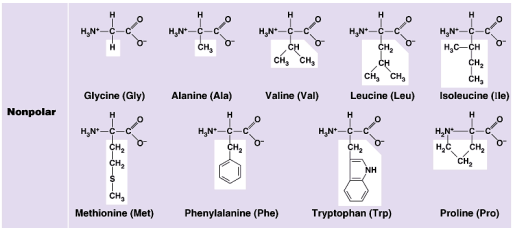


Fig. 5.15a

✓ Another group of amino acids has polar R groups, making them hydrophilic.

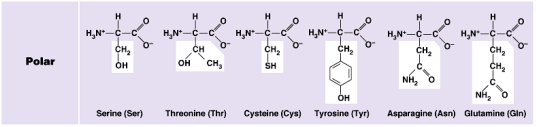


Fig. 5.15b

✓ The last group of amino acids includes those with functional groups that are charged (ionized) at cellular pH.

- Some R groups are bases, others are acids.

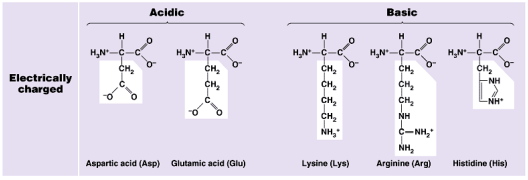


Fig. 5.15c

✓ Amino acids are joined together when a dehydration reaction removes a hydroxyl group from the carboxyl end of one amino acid and a hydrogen from the amino group of another.

- The resulting covalent bond is called a **peptide bond**.

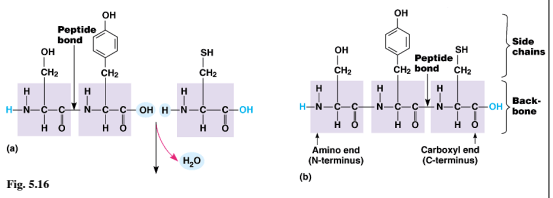


Fig. 5.16

- ✓ Repeating the process over and over creates a long polypeptide chain.
  - ✒ At one end is an amino acid with a free amino group the (the N-terminus) and at the other is an amino acid with a free carboxyl group the (the C-terminus).
- ✓ The repeated sequence (N-C-C) is the polypeptide backbone.
- ✓ Attached to the backbone are the various R groups.
- ✓ Polypeptides range in size from a few monomers to thousands.

A protein's function depends on its specific conformation

- ✓ A functional proteins consists of one or more polypeptides that have been precisely twisted, folded, and coiled into a unique shape.
- ✓ It is the order of amino acids that determines what the three-dimensional conformation will be.

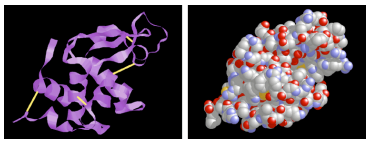


Fig. 5.17

- ✓ A protein's specific conformation determines its function.
- ✓ In almost every case, the function depends on its ability to recognize and bind to some other molecule.
  - ✒ For example, antibodies bind to particular foreign substances that fit their binding sites.
  - ✒ Enzyme recognize and bind to specific substrates, facilitating a chemical reaction.
  - ✒ Neurotransmitters pass signals from one cell to another by binding to receptor sites on proteins in the membrane of the receiving cell.

- ✓ The folding of a protein from a chain of amino acids occurs spontaneously.
- ✓ The function of a protein is an emergent property resulting from its specific molecular order.
- ✓ Three levels of structure: primary, secondary, and tertiary structure, are used to organize the folding within a single polypeptide.
- ✓ Quarternary structure arises when two or more polypeptides join to form a protein.

- ✓ The **primary structure** of a protein is its unique sequence of amino acids.
  - ✒ Lysozyme, an enzyme that attacks bacteria, consists on a polypeptide chain of 129 amino acids.
  - ✒ The precise primary structure of a protein is determined by inherited genetic information.

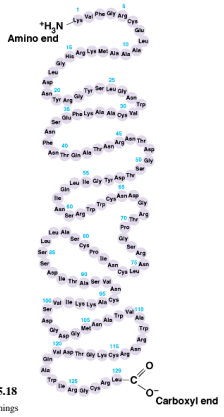
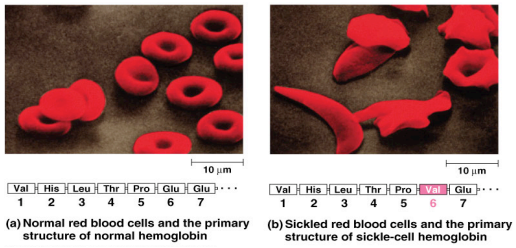


Fig. 5.18

- ✓ Even a slight change in primary structure can affect a protein's conformation and ability to function.
- ✓ In individuals with sickle cell disease, abnormal hemoglobins, oxygen-carrying proteins, develop because of a single amino acid substitution.
  - ✒ These abnormal hemoglobins crystallize, deforming the red blood cells and leading to clogs in tiny blood vessels.



(a) Normal red blood cells and the primary structure of normal hemoglobin

(b) Sickled red blood cells and the primary structure of sickle-cell hemoglobin

Fig. 5.19

✓ The **secondary structure** of a protein results from hydrogen bonds at regular intervals along the polypeptide backbone.

- Typical shapes that develop from secondary structure are coils (an alpha helix) or folds (beta pleated sheets).

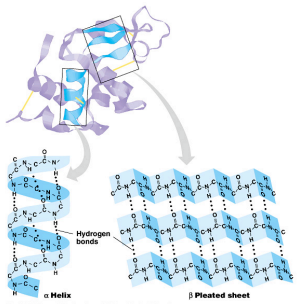


Fig. 5.20

✓ The structural properties of silk are due to beta pleated sheets.

- The presence of so many hydrogen bonds makes each silk fiber stronger than steel.

Fig. 5.21

✓ **Tertiary structure** is determined by a variety of interactions among R groups and between R groups and the polypeptide backbone.

- These interactions include hydrogen bonds among polar and/or charged areas, ionic bonds between charged R groups, and **hydrophobic interactions** and **van der Waals interactions** among hydrophobic R groups.

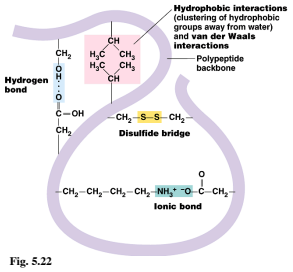


Fig. 5.22

✓ While these three interactions are relatively weak, **disulfide bridges**, strong covalent bonds that form between the sulfhydryl groups (SH) of cysteine monomers, stabilize the structure.

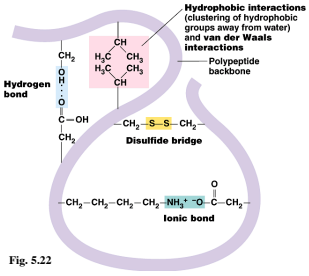


Fig. 5.22

✓ **Quarternary structure** results from the aggregation of two or more polypeptide subunits.

- Collagen is a fibrous protein of three polypeptides that are supercoiled like a rope.
  - This provides the structural strength for their role in connective tissue.
- Hemoglobin is a globular protein with two copies of two kinds of polypeptides.

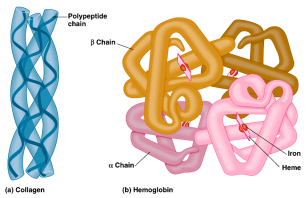


Fig. 5.23

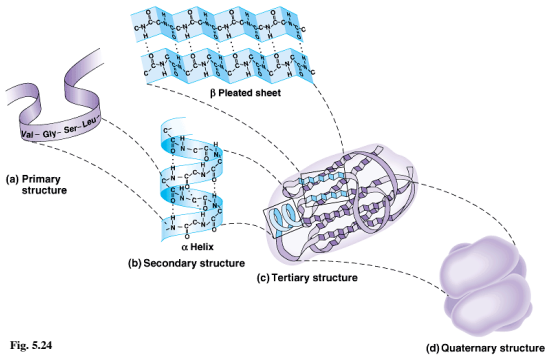


Fig. 5.24

- ✓ A protein's conformation can change in response to the physical and chemical conditions.
- ✓ Alterations in pH, salt concentration, temperature, or other factors can unravel or **denature** a protein.
  - These forces disrupt the hydrogen bonds, ionic bonds, and disulfide bridges that maintain the protein's shape.
- ✓ Some proteins can return to their functional shape after denaturation, but others cannot, especially in the crowded environment of the cell.

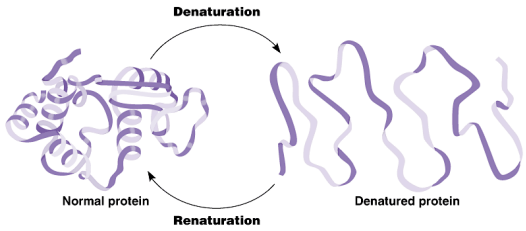


Fig. 5.25

- ✓ In spite of the knowledge of the three-dimensional shapes of over 10,000 proteins, it is still difficult to predict the conformation of a protein from its primary structure alone.
  - Most proteins appear to undergo several intermediate stages before reaching their "mature" configuration.

- The folding of many proteins is protected by **chaperonin** proteins that shield out bad influences.

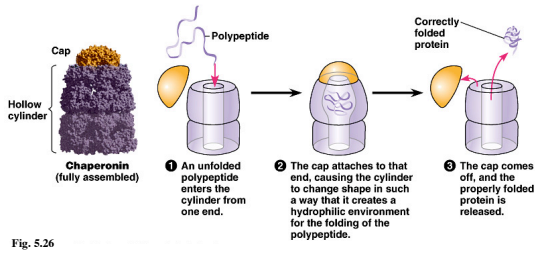
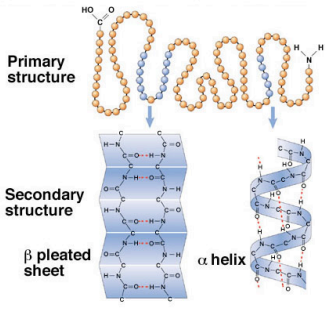


Fig. 5.26

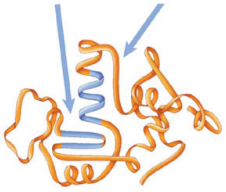
- ✓ A new generation of supercomputers is being developed to generate the conformation of any protein from its amino acid sequence or even its gene sequence.
  - Part of the goal is to develop general principles that govern protein folding.
- ✓ At present, scientists use **X-ray crystallography** to determine protein conformation.
  - This technique requires the formation of a crystal of the protein being studied.
  - The pattern of diffraction of an X-ray by the atoms of the crystal can be used to determine the location of the atoms and to build a computer model of its structure.

Levels of Protein Structure (1)

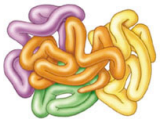


Levels of Protein Structure (2)

Tertiary structure



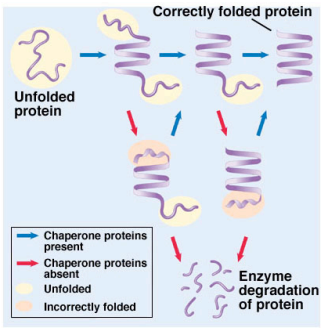
Quaternary structure

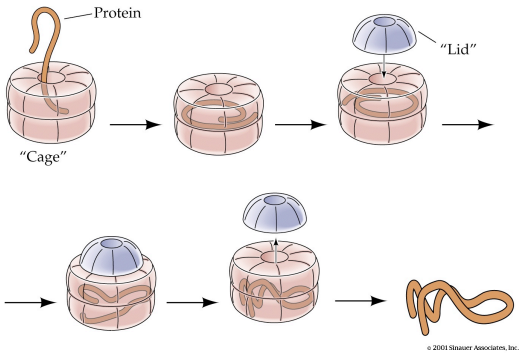


Protein Structure

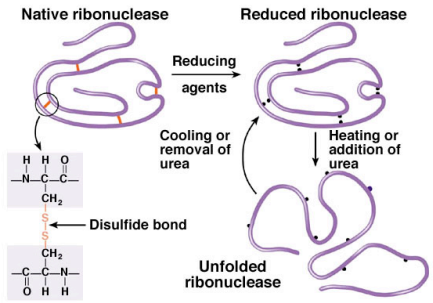
- ✓ Primary
  - ✒Linear arrangement of amino acids.
- ✓ Secondary
  - ✒3-dimensional □-helix and □-pleated sheet.
- ✓ Tertiary
  - ✒Hydrophobic, ionic interactions, disulfide bonds
- ✓ Quaternary
  - ✒Two or more polypeptides forming a functional protein.

Protein Folding

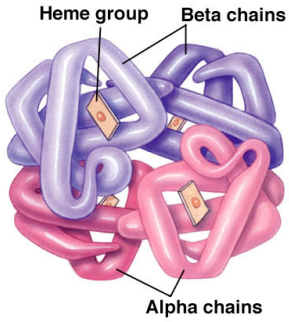


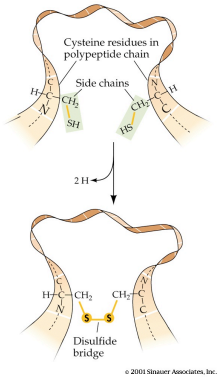


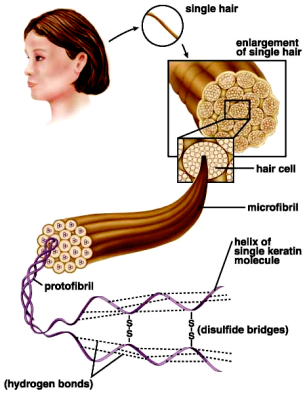
Protein Unfolding and Refolding

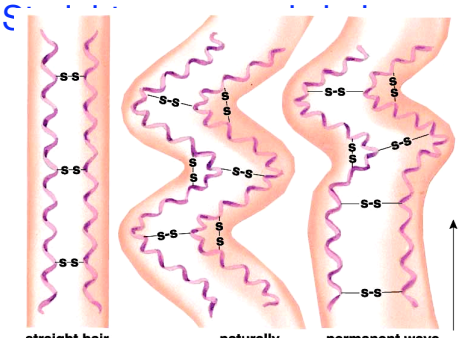


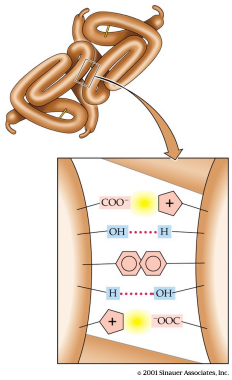
Hemoglobin Molecule







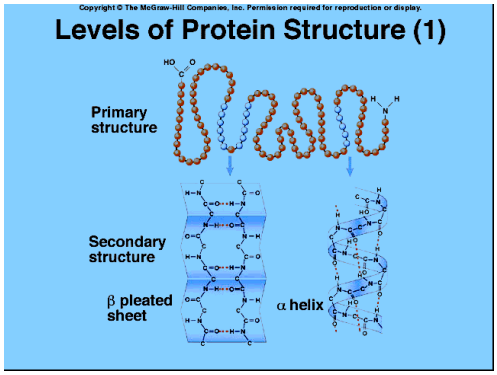




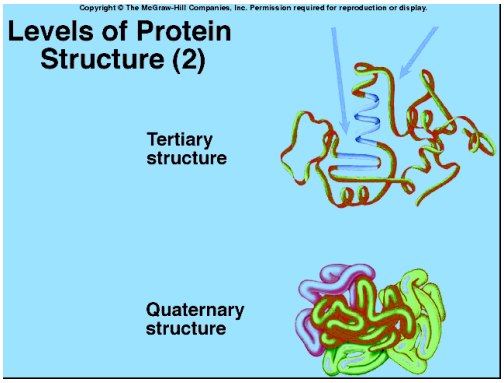
Non-covalent protein interactions

Salt bridges
Hydrogen bonds
Hydrophobic interaction

Levels of Protein Structure (1)



Levels of Protein Structure (2)



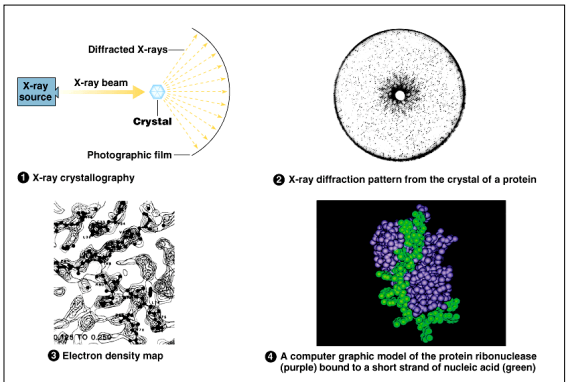
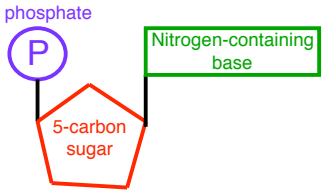
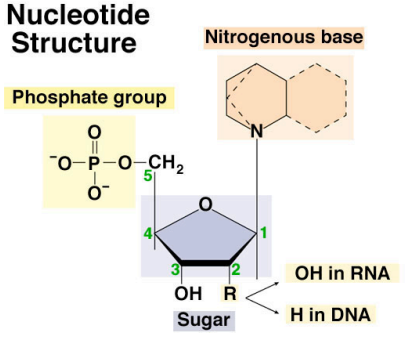


Fig. 5.27

Basic structure of a nucleotide

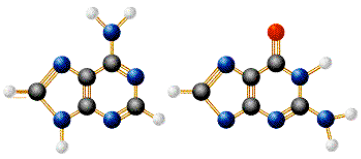


Nucleotide Structure

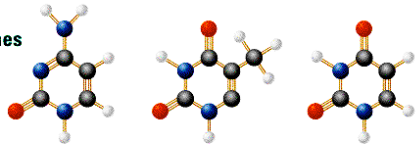


Nucleotides

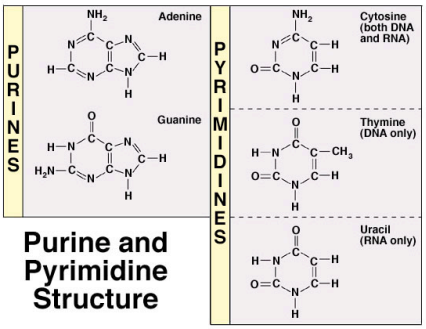
Purines



Pyrimidines

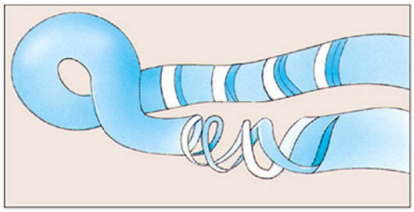


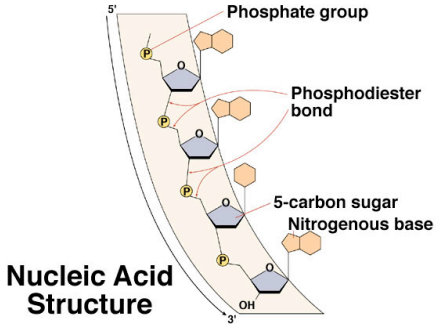
cytosine (C) thymine (T) (only in DNA) uracil (U) (only in RNA)



Purine and Pyrimidine Structure

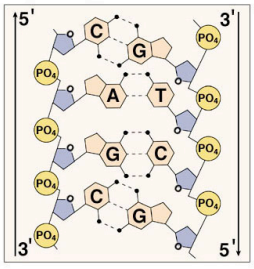
DNA Molecule



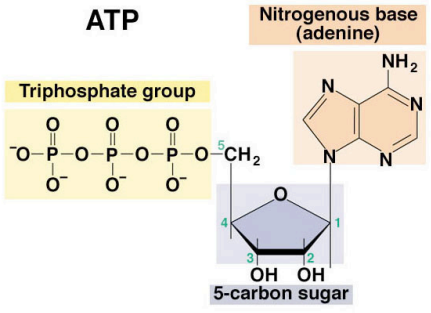


Nucleic Acid Structure

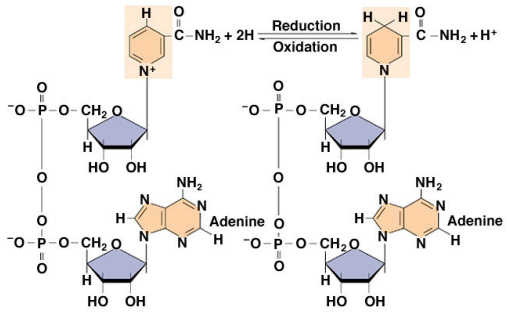
DNA Base-Pairing and Hydrogen Bonds



ATP



Nicotinamide



Nucleotides to Nucleic Acids