Introduction to Biochemistry

Atoms

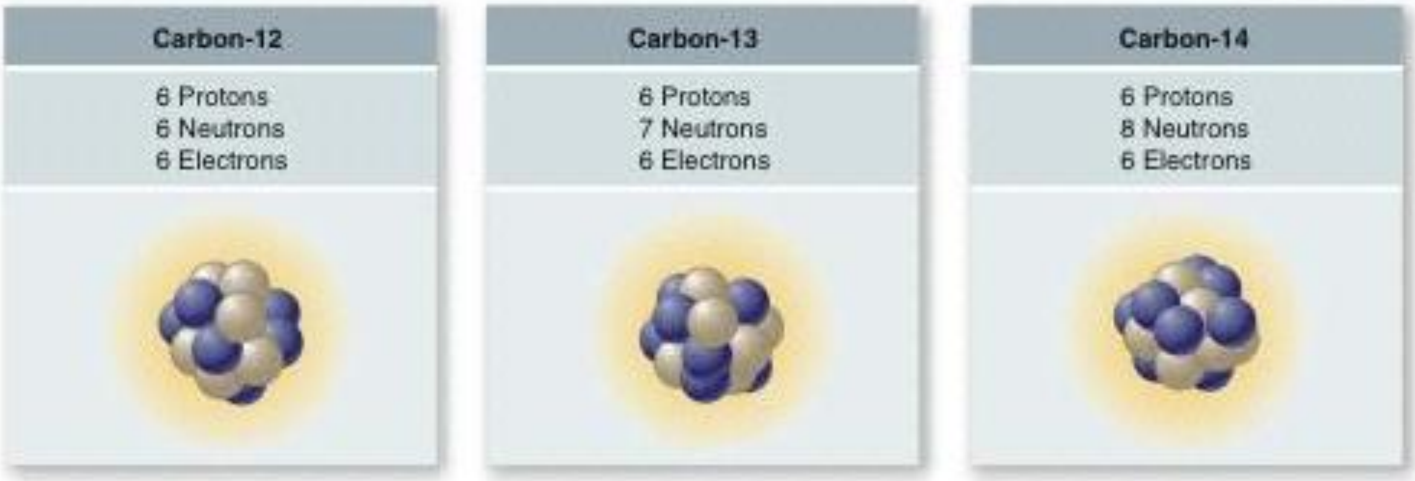
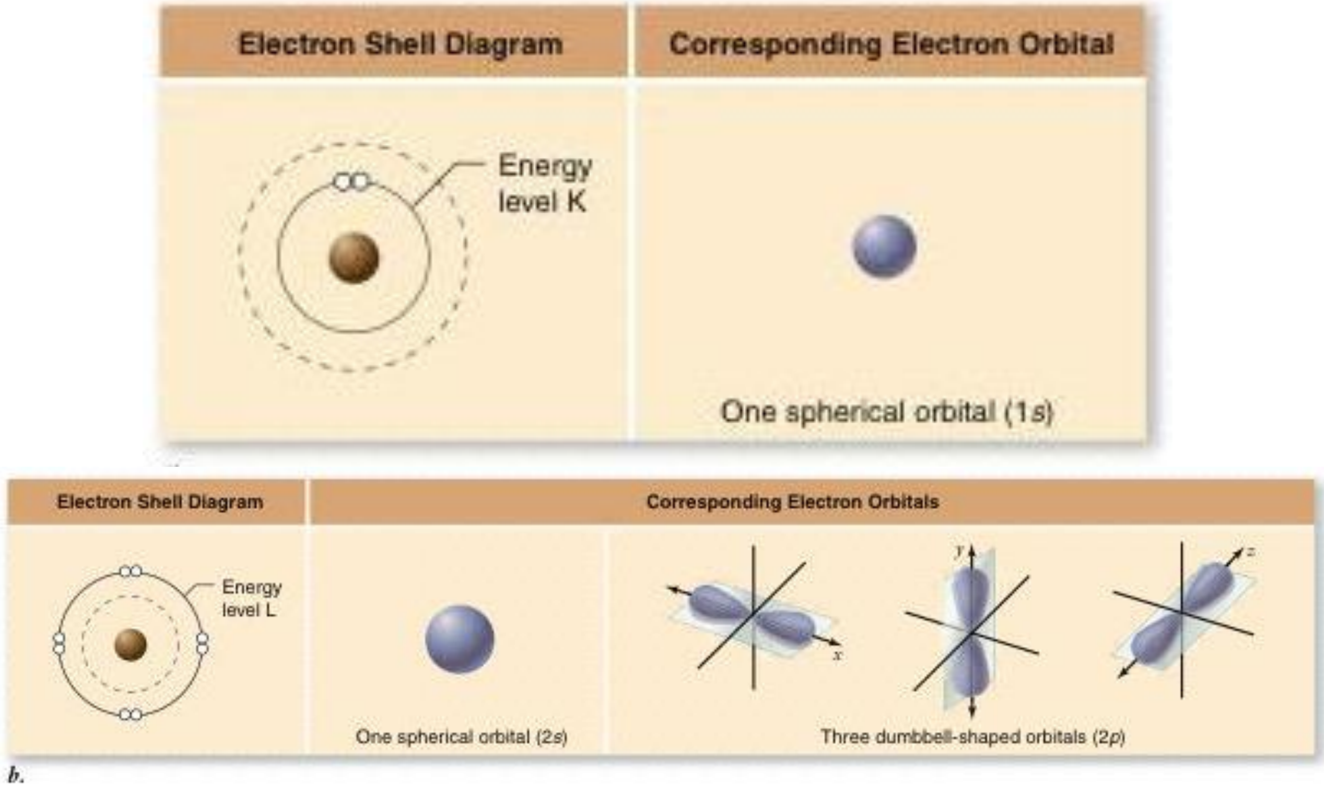


figure 2.3

THE THREE MOST ABUNDANT ISOTOPES OF CARBON. Isotopes of a particular element have different numbers of neutrons.

Electron orbitals



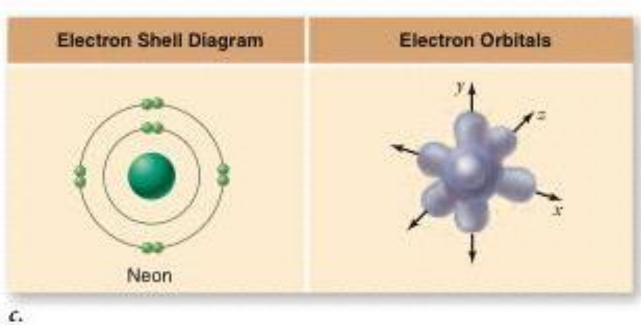


figure 2.4

ELECTRON ORBITALS. ***a.*** The lowest energy level or electron shell—the one nearest the nucleus—is level K. It is occupied by a single *s* orbital, referred to as 1*s*. ***b.*** The next highest energy level, L, is occupied by four orbitals: one *s* orbital (referred to as the 2*s* orbital) and three *p* orbitals (each referred to as a 2*p* orbital). Each orbital holds two paired electrons with opposite spin. Thus, the K level is populated by two electrons, and the L level is populated by a total of eight electrons. ***c.*** The neon atom shown has the L and K energy levels completely filled with electrons and is thus unreactive.

Energy Levels

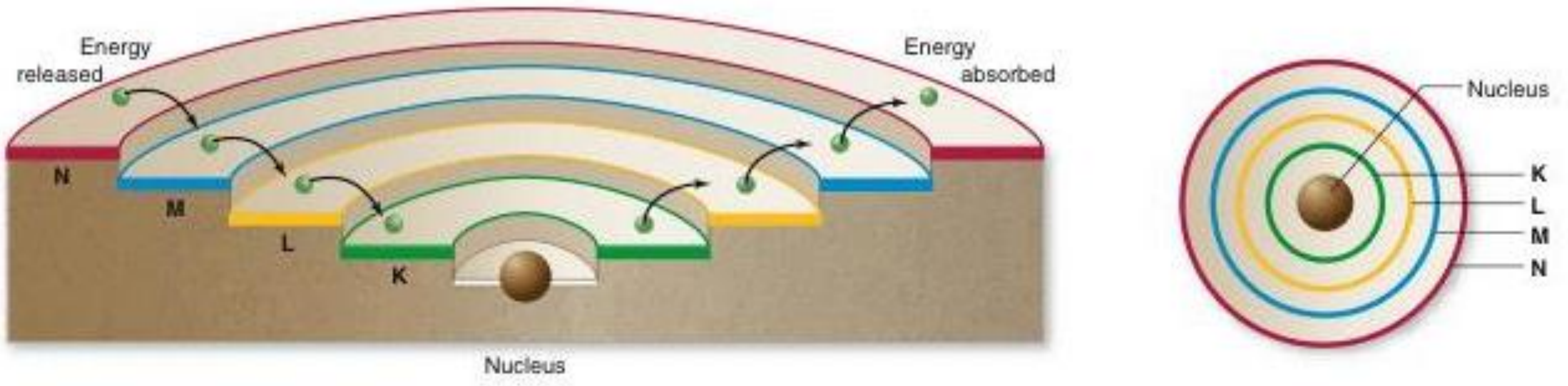


figure 2.5

ATOMIC ENERGY LEVELS. Electrons have energy of position. When an atom absorbs energy, an electron moves to a higher energy level, farther from the nucleus. When an electron falls to lower energy levels, closer to the nucleus, energy is released. The first two energy levels are the same as shown in the previous figure.

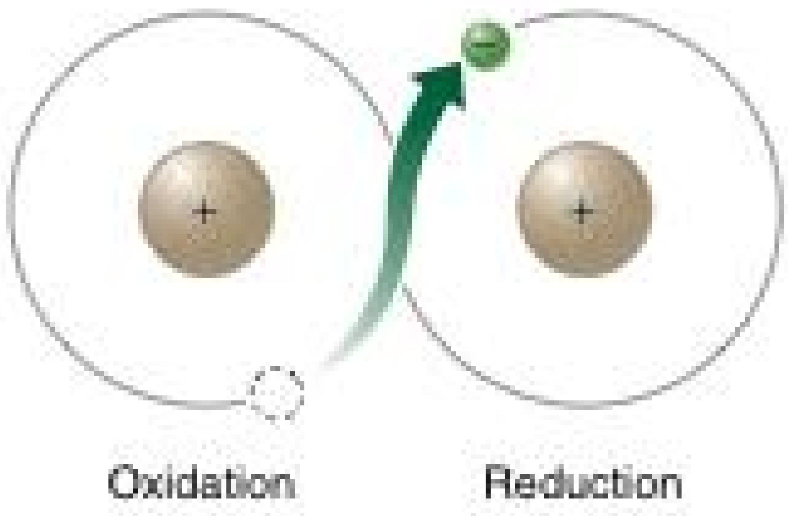
Redox Reactions

Redox can involve loss or gain of an electron or a hydrogen (contains an electron)

$C_6H_{12}O_6 + 6O_2 \text{ ---> } 6CO_2 + 6H_2O$

Carbon loses hydrogen therefore is oxidized.

Oxygen gains hydrogen therefore is reduced.



Electronegativities

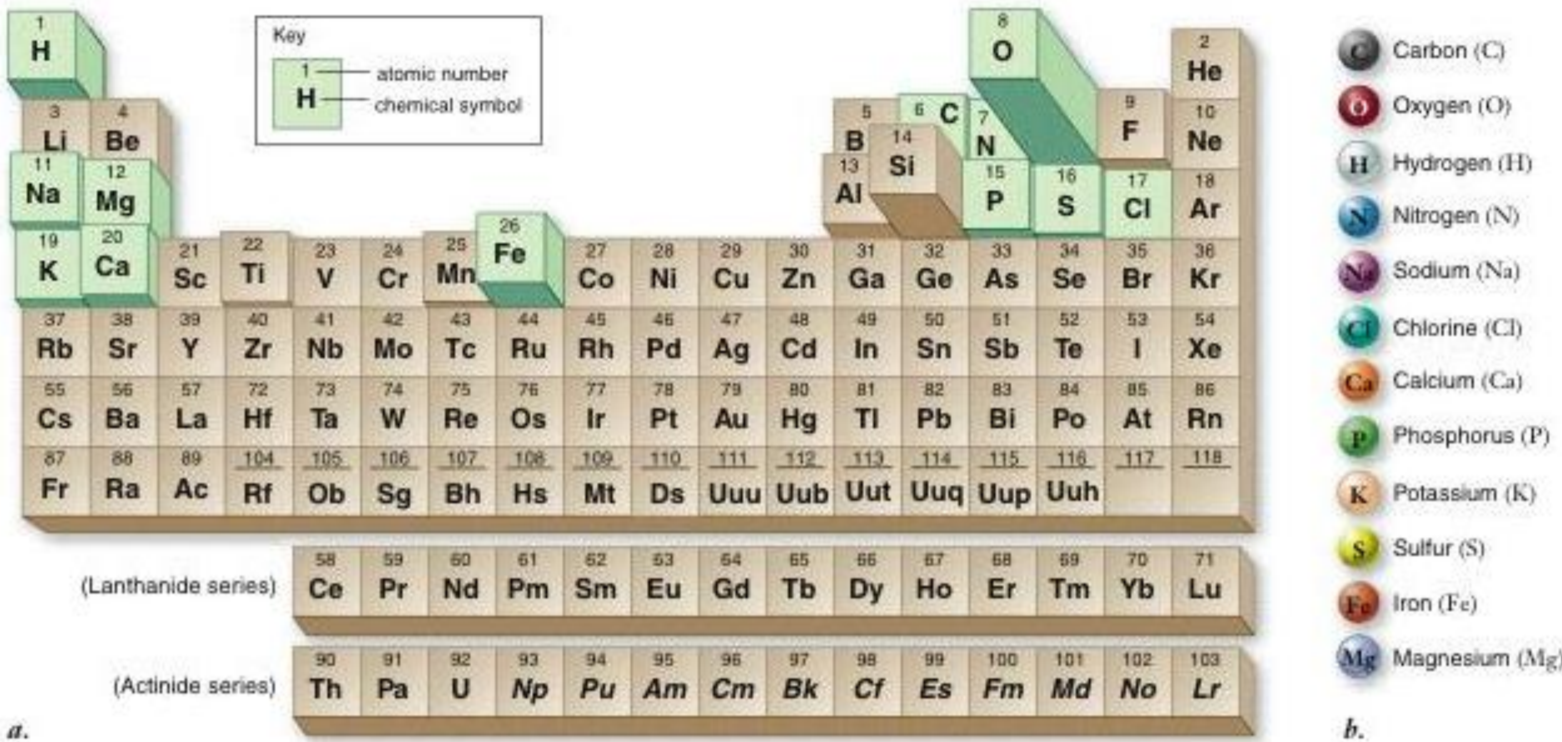


figure 2.6

PERIODIC TABLE OF THE ELEMENTS. ***a.*** In this representation, the frequency of elements that occur in the Earth's crust is indicated by the height of the block. Elements shaded in green are found in living systems in more than trace amounts. ***b.*** Common elements found in living systems are shown in colors that will be used throughout the text.

Biochemistry

- There are several different types of bonds that are important to understand for Biology.
- Covalent= shares electrons
- Ionic = swaps electrons
- Polar Covalent= somewhere in between.
- The reality is that most bonds have both ionic and covalent characteristics= polar.

TABLE 2.1 Bonds and Interactions

Name	Basis of interaction	Strength
Covalent bond	Sharing of electron pairs	Strong
Ionic bond	Attraction of opposite charges	↑
Hydrogen bond	Sharing of H atom	
Hydrophobic interaction	Forcing of hydrophobic portions of molecules together in presence of polar substances	↓
van der Waals attraction	Weak attractions between atoms due to oppositely polarized electron clouds	Weak

Ionic Bonds

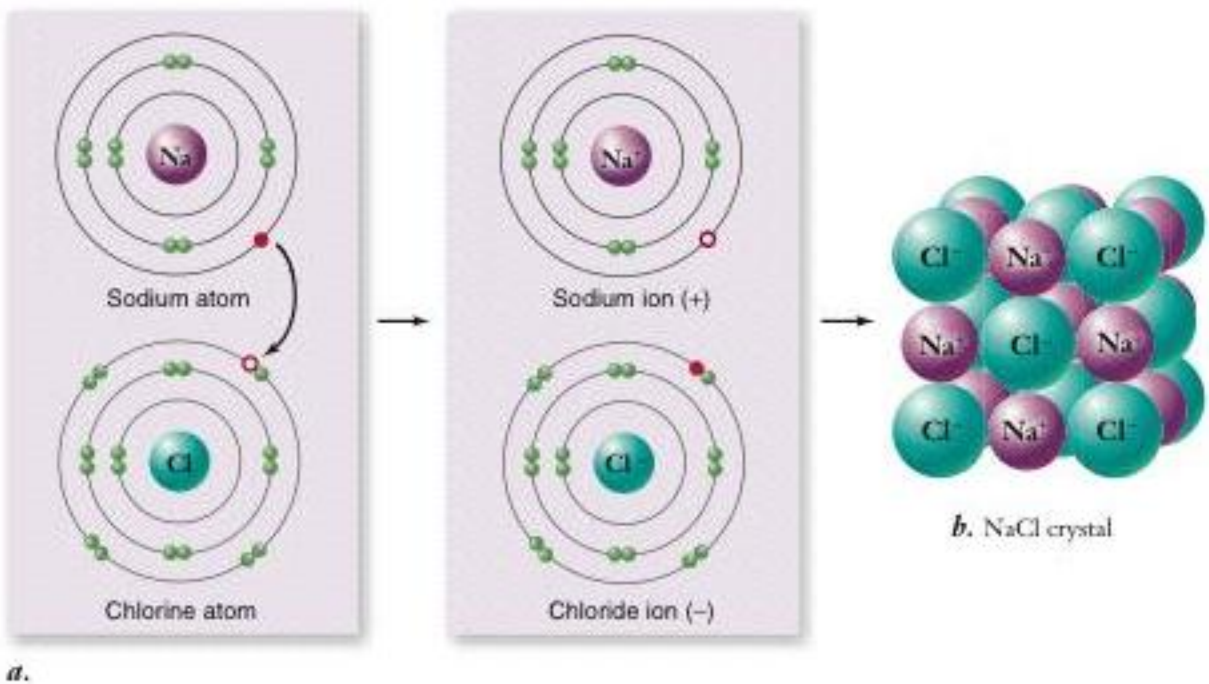
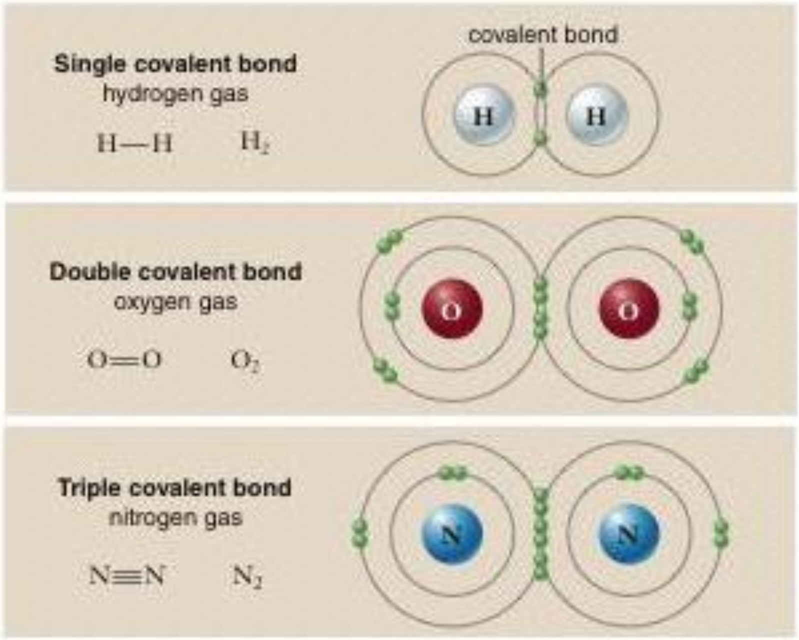


figure 2.8

THE FORMATION OF IONIC BONDS BY SODIUM CHLORIDE.

a. When a sodium atom donates an electron to a chlorine atom, the sodium atom becomes a positively charged sodium ion, and the chlorine atom becomes a negatively charged chloride ion. ***b.*** The electrostatic attraction of oppositely charged ions leads to the formation of a lattice of Na^+ and Cl^-.

Covalent Bonds



Covalent bonds are represented in chemical formulas as lines connecting atomic symbols, where each line between two bonded atoms represents the sharing of one pair of electrons. The *structural formulas* of hydrogen gas and oxygen gas are H—H and O═O, respectively, and their *molecular formulas* are H_2 and O_2. The structural formula for N_2 is N≡N.

Electronegativity

Electronegativity, symbol χ, is the chemical property that describes the ability of an atom (or, more rarely, a functional group) to attract electrons (or electron density) towards itself in a covalent bond.

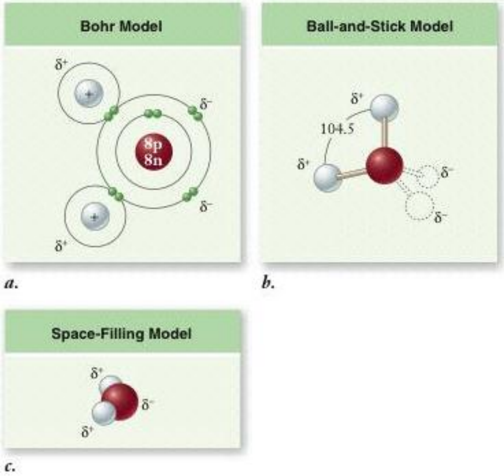
TABLE 2.2	Relative Electronegativities of Some Important Atoms
Atom	Electronegativity
O	3.5
N	3.0
C	2.5
H	2.1

Bond Strength

- While it takes more energy to break ionic bonds in a dry environment, in living things molecules are in aqueous environments.
- Therefore in Biology: Covalent bonds are stronger than Ionic bonds, and H-bonds are weaker than both.
- Keep in mind that in large numbers H-bonds can be strong.

Polar Covalent Bonds

- Because Oxygen has an electronegativity value of 3.44 and Hydrogen has a value of 2.1, the difference is significant enough that at any given time the electrons are more likely to be found closer to the O.
- Oxygen is a well known electron thief.
- While there is no official charge on either atom, we have a "partial charge" δ^{+} , δ^{-}



Hydrogen Bonds

- Because Hydrogen has such a low electronegativity value, when it is bonded to something with a stronger value the polarization allows the δ^+ charge of the H to form a weak bond with the δ^- charge of another polar molecule.
- Which elements bonded with H will tend to form H-bonds?

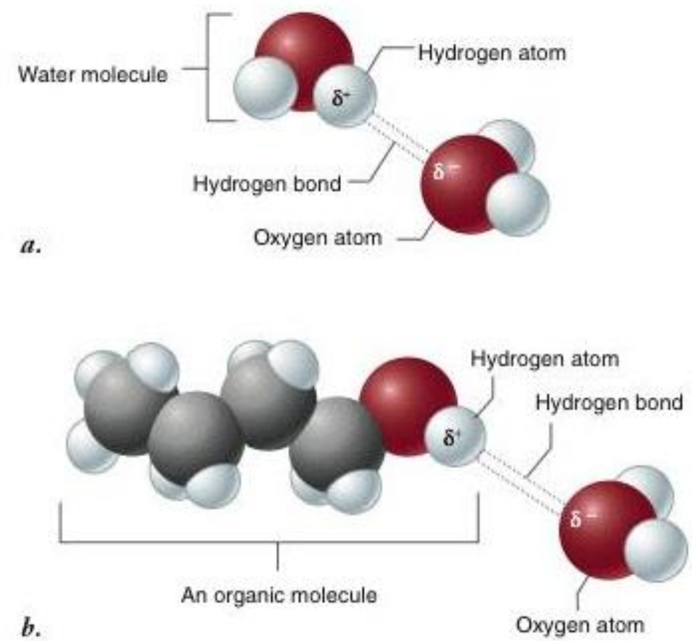
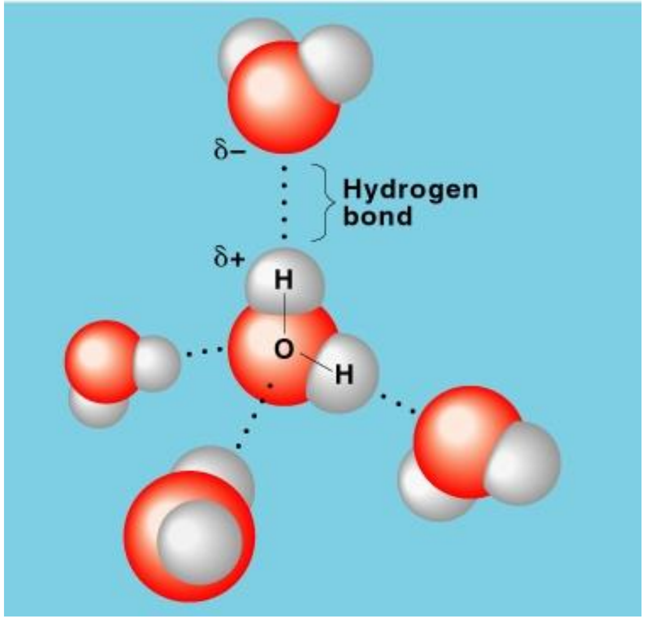


figure 2.11

STRUCTURE OF A HYDROGEN BOND. ***a.*** Hydrogen bond between two water molecules. ***b.*** Hydrogen bond between an organic molecule (*n*-butanol) and water. H in *n*-butanol forms a hydrogen bond with oxygen in water. This kind of hydrogen bond is possible any time H is bound to a more electronegative atom (see table 2.2).

Water!

- A Single Water Molecule can form up to 4 H-bonds with other molecules at a time, and when combined with other water molecules that can make 4 of their own H-bonds, the net strength of those bonds is significant.



Water Phase Changes

- When going from a liquid to a gas, H-bonds have to be broken- it requires an increase in energy.
- When Water evaporates is takes energy from the environment, which in turn cools off the environment. (sweating cools us)
- When water freezes, it is releasing energy to the environment.

Solutions

- Ions Dissociate in water.
- Covalent molecules that form H-bonds with each other can break the H-bonds and separate into individual molecules. (dissolving sugar in water- each sucrose molecule gets surrounded and shielded by water molecules)

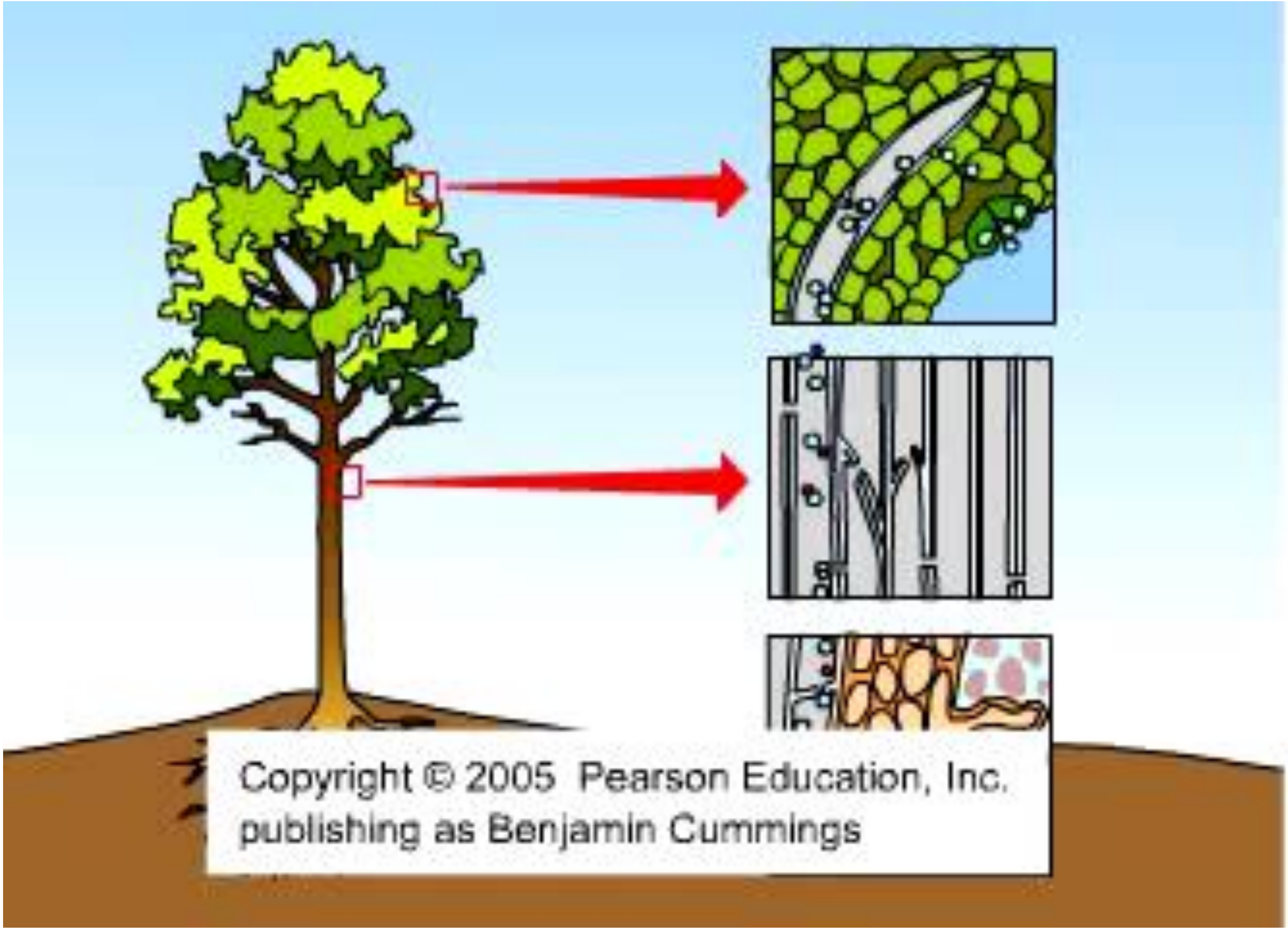
figure 2.14

WHY SALT DISSOLVES IN WATER. When a crystal of table salt dissolves in water, individual Na^+ and Cl^- ions break away from the salt lattice and become surrounded by water molecules. Water molecules orient around Cl^- ions so that their partial positive poles face toward the negative Cl^- ion; water molecules surrounding Na^+ ions orient in the opposite way, with their partial negative poles facing the positive Na^+ ion. Surrounded by hydration shells, Na^+ and Cl^- ions never reenter the salt lattice.

Water

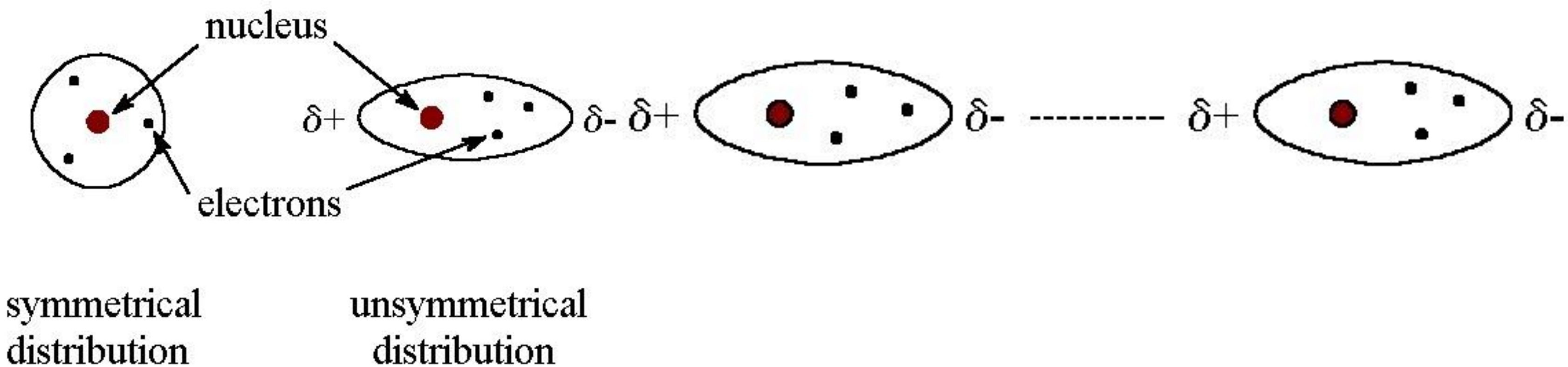
TABLE 2.3	The Properties of Water	
Property	**Explanation**	**Example of Benefit to Life**
Cohesion	Hydrogen bonds hold water molecules together.	Leaves pull water upward from the roots; seeds swell and germinate.
High specific heat	Hydrogen bonds absorb heat when they break and release heat when they form, minimizing temperature changes.	Water stabilizes the temperature of organisms and the environment.
High heat of vaporization	Many hydrogen bonds must be broken for water to evaporate.	Evaporation of water cools body surfaces.
Lower density of ice	Water molecules in an ice crystal are spaced relatively far apart because of hydrogen bonding.	Because ice is less dense than water, lakes do not freeze solid, allowing fish and other life in lakes to survive the winter.
Solubility	Polar water molecules are attracted to ions and polar compounds, making them soluble.	Many kinds of molecules can move freely in cells, permitting a diverse array of chemical reactions.

An example of waters special properties in action



Other weak intermolecular forces

- Other Van der Walls interactions
- “London Forces”



http://www.youtube.com/watch?v=gzm7yD-JuyM

pH

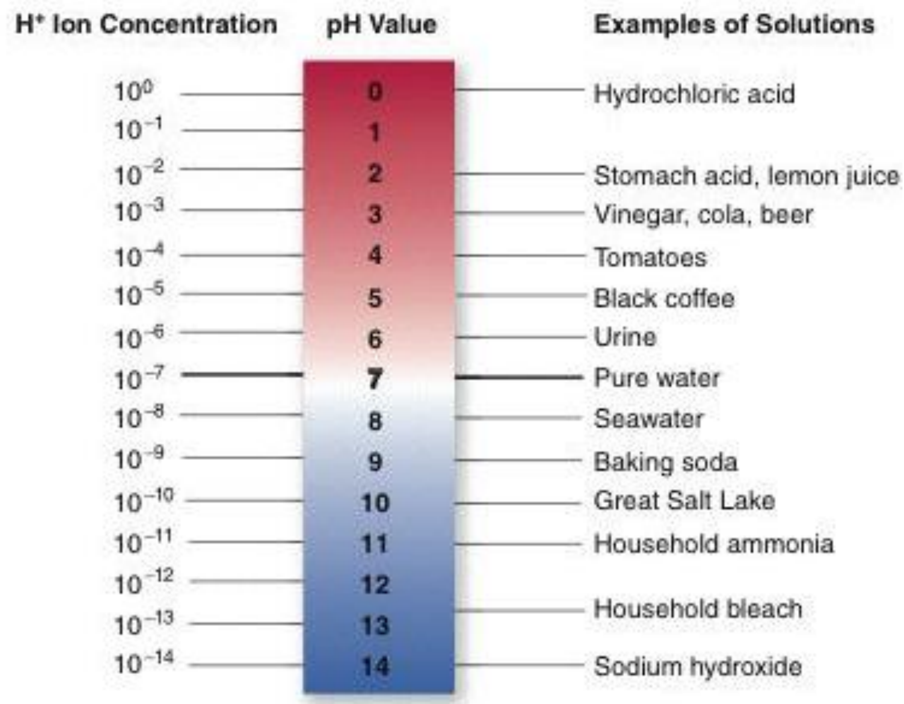


figure 2.15

THE pH SCALE. The pH value of a solution indicates its concentration of hydrogen ions. Solutions with a pH less than 7 are acidic, whereas those with a pH greater than 7 are basic. The scale is logarithmic, so that a pH change of 1 means a 10-fold change in the concentration of hydrogen ions. Thus, lemon juice is 100 times more acidic than tomato juice, and seawater is 10 times more basic than pure water, which has a pH of 7.

Buffering Capacity

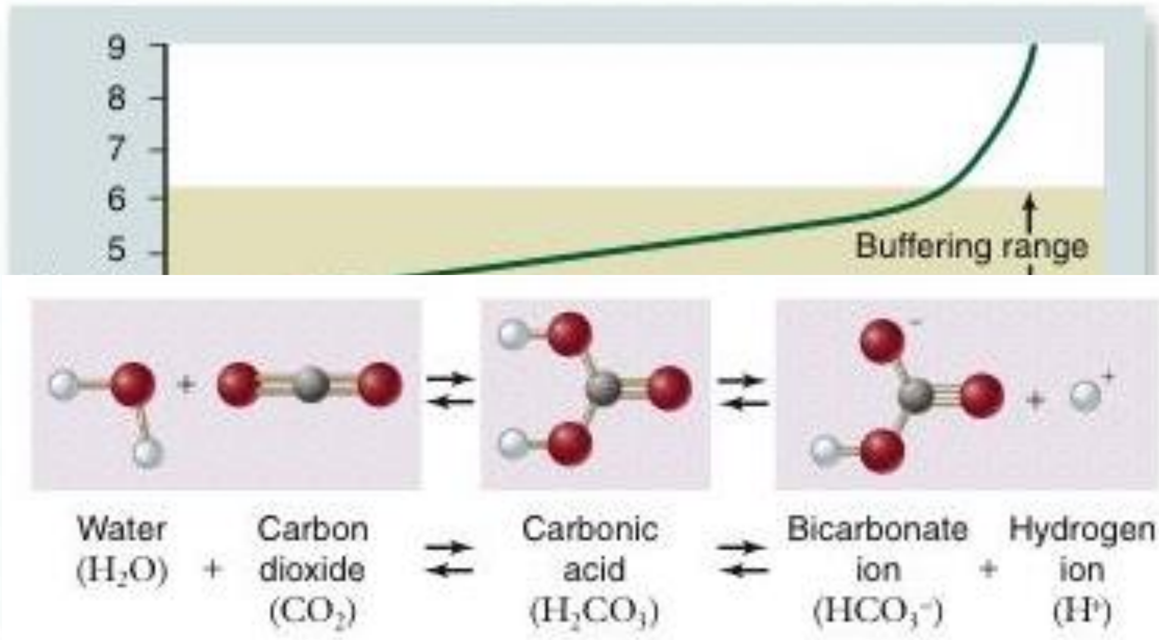


figure 2.16

BUFFERS MINIMIZE CHANGES IN pH. Adding a base to a solution neutralizes some of the acid present, and so raises the pH. Thus, as the curve moves to the right, reflecting more and more base, it also rises to higher pH values. A buffer makes the curve rise or fall very slowly over a portion of the pH scale, called the "buffering range" of that buffer.

Organic Chemistry

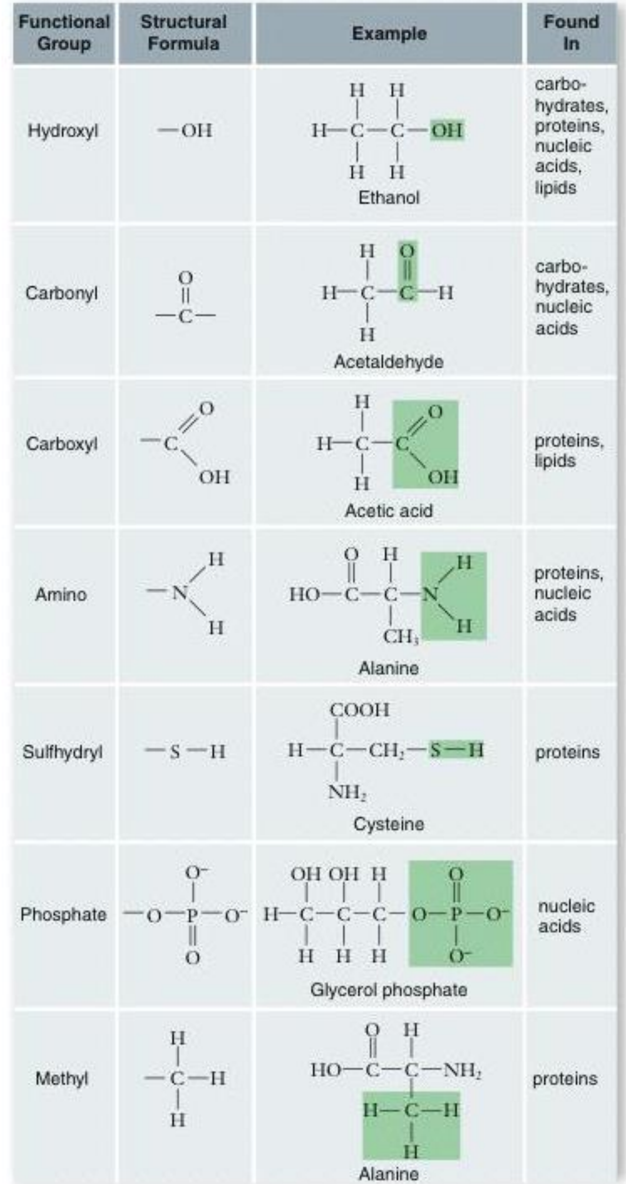


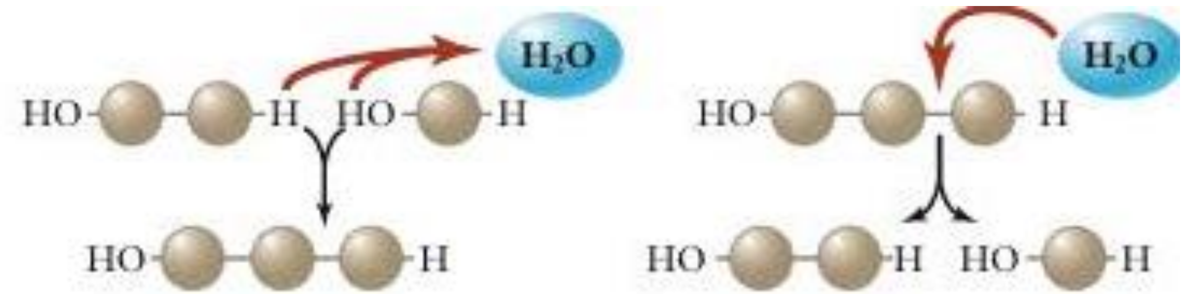
figure 3.1

THE PRIMARY FUNCTIONAL CHEMICAL GROUPS. These groups tend to act as units during chemical reactions and confer specific chemical properties on the molecules that possess them. Amino groups, for example, make a molecule more basic, whereas carboxyl groups make a molecule more acidic. These functional groups are also not limited to the examples in the "Found In" column but are widely distributed in biological molecules.

Macromolecules

TABLE 3.1	Macromolecules		
Macromolecule	**Subunit**	**Function**	**Example**
CARBOHYDRATES			
Starch, glycogen	Glucose	Energy storage	Potatoes
Cellulose	Glucose	Plant cell walls	Paper; strings of celery
Chitin	Modified glucose	Structural support	Crab shells
NUCLEIC ACIDS			
DNA	Nucleotides	Encodes genes	Chromosomes
RNA	Nucleotides	Needed for gene expression	Messenger RNA
PROTEINS			
Functional	Amino acids	Catalysis; transport	Hemoglobin
Structural	Amino acids	Support	Hair; silk
LIPIDS			
Fats	Glycerol and three fatty acids	Energy storage	Butter; corn oil; soap
Phospholipids	Glycerol, two fatty acids, phosphate, and polar R groups	Cell membranes	Phosphatidylcholine
Prostaglandins	Five-carbon rings with two nonpolar tails	Chemical messengers	Prostaglandin E (PGE)
Steroids	Four fused carbon rings	Membranes; hormones	Cholesterol; estrogen
Terpenes	Long carbon chains	Pigments; structural support	Carotene; rubber

Constructing and Breaking Macromolecules



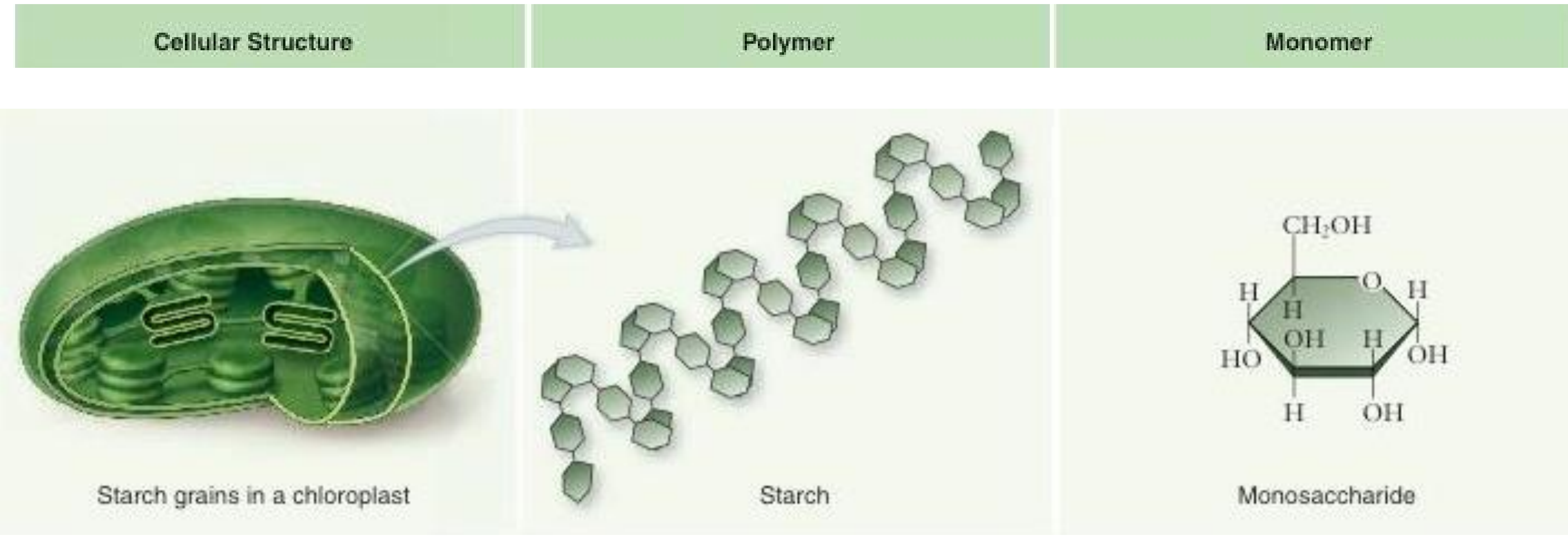
a. Dehydration synthesis ***b.*** Hydrolysis

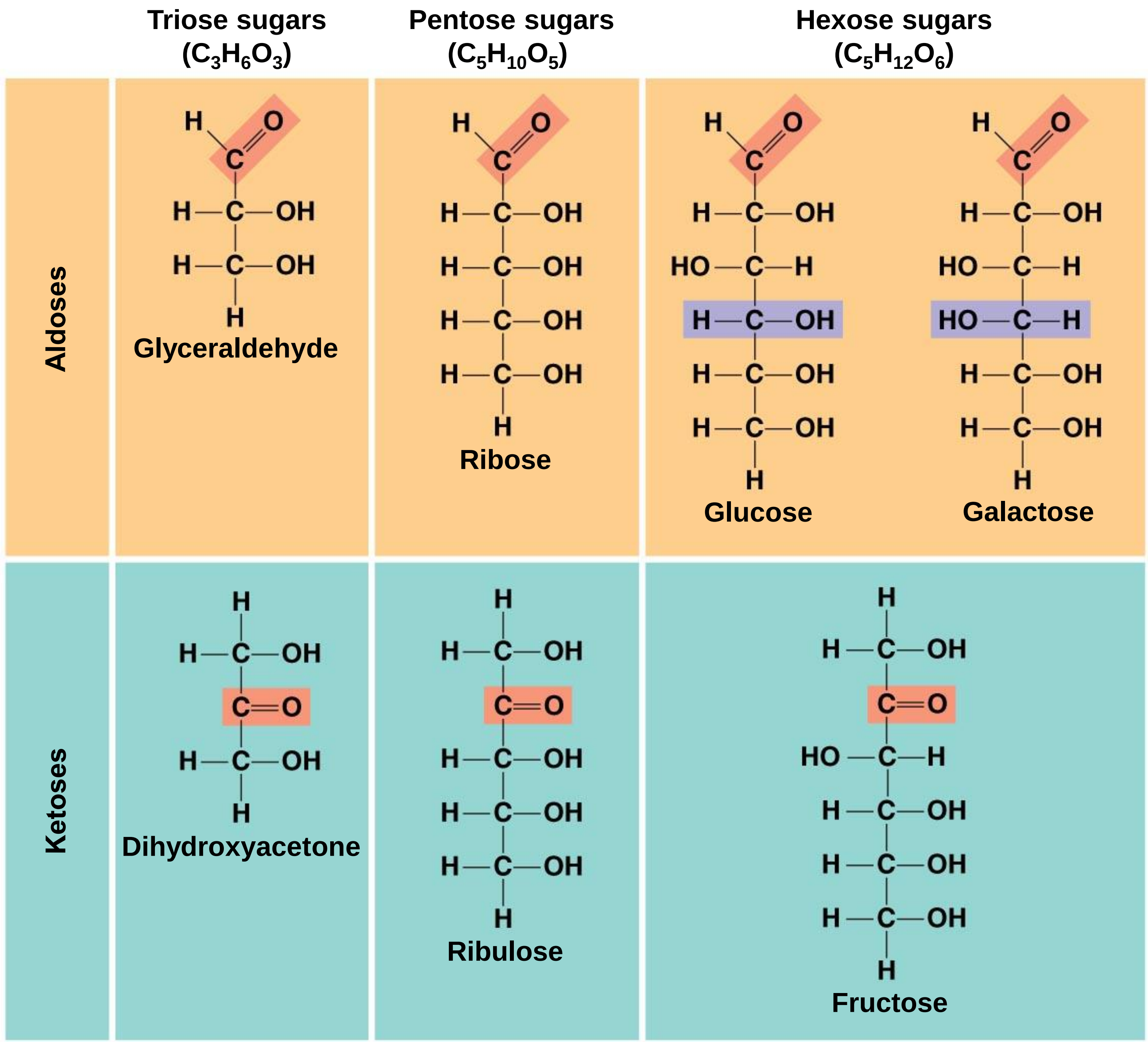
figure 3.4

MAKING AND BREAKING MACROMOLECULES.
a. Biological macromolecules are polymers formed by linking monomers together by dehydration synthesis. This process releases a water molecule for every bond formed. ***b.*** Breaking the bond between subunits involves a process called hydrolysis, which reverses the loss of a water molecule by dehydration.

Carbohydrates

- Most abundant of the four macromolecules
- Has purposes ranging from energy storage to structural components.
- Have a 1:2:1 ratio

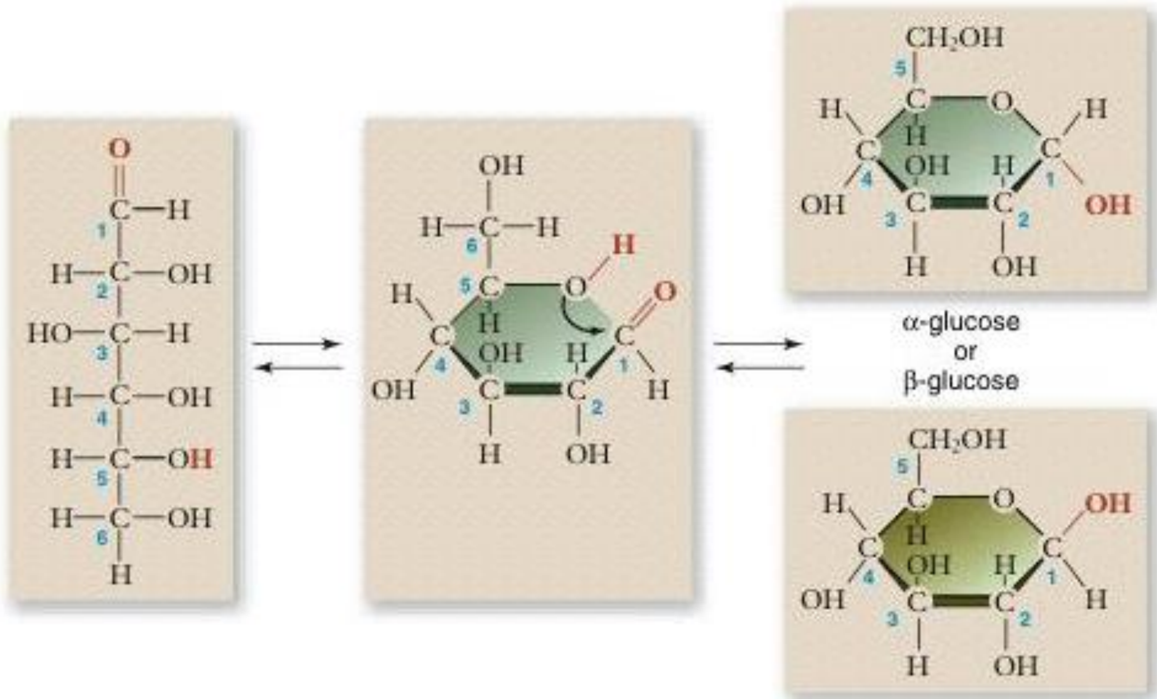



Triose sugars
($C_3H_6O_3$)
Pentose sugars
($C_5H_{10}O_5$)
Hexose sugars
($C_5H_{12}O_6$)
Aldoses
Ketoses
Glyceraldehyde
Ribose
Glucose
Galactose
Dihydroxyacetone
Ribulose
Fructose

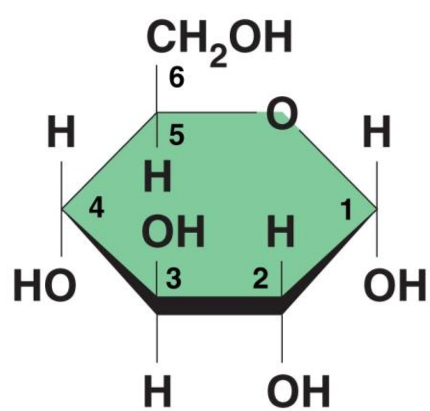
Different Sugar Conformations

figure 3.6

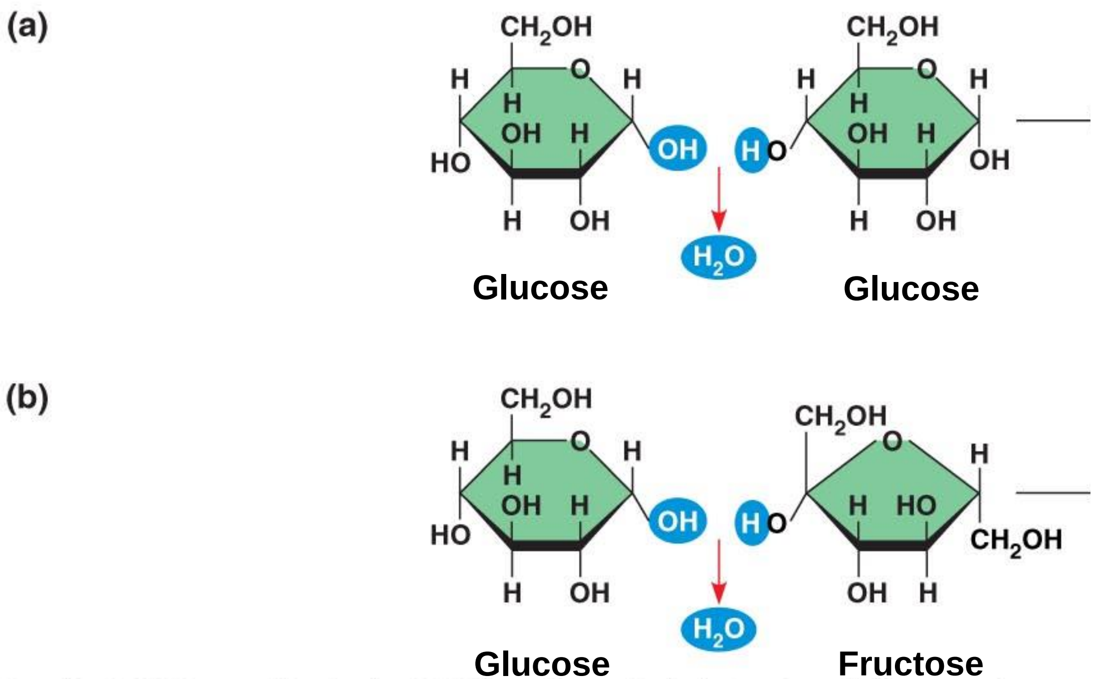
STRUCTURE OF THE GLUCOSE MOLECULE. Glucose is a linear, six-carbon molecule that forms a six-membered ring in solution. Ring closure occurs such that two forms can result: α-glucose and β-glucose. These structures differ only in the position of the OH bound to carbon 1. The structure of the ring can be represented in many ways; the ones shown here are the most common, with the carbons conventionally numbered (in *blue*) so that the forms can be compared easily. The bold lines represent portions of the molecule that are projecting out of the page toward you.



In organic chemistry the carbons are labeled 1-6



Monosaccharide + Monosaccharide = Disaccharide



Polysaccharides

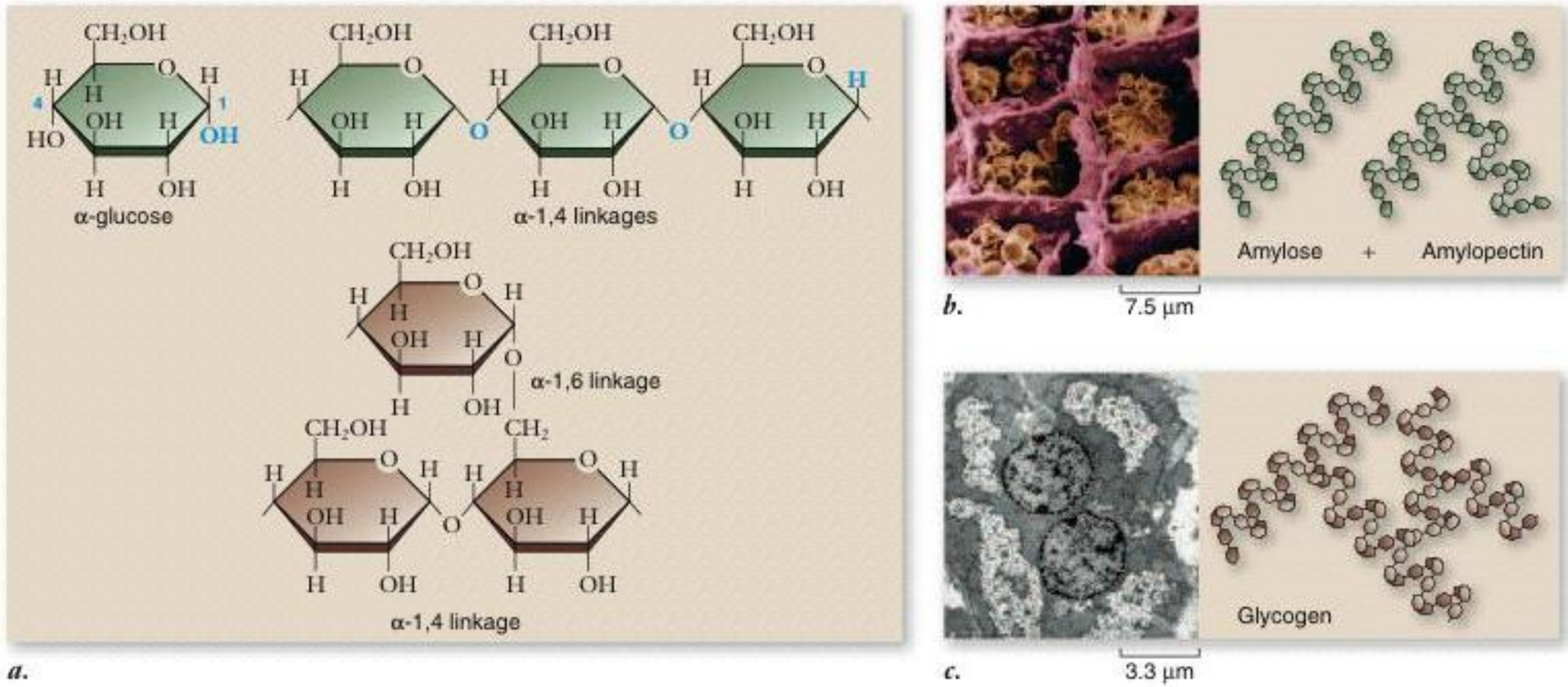


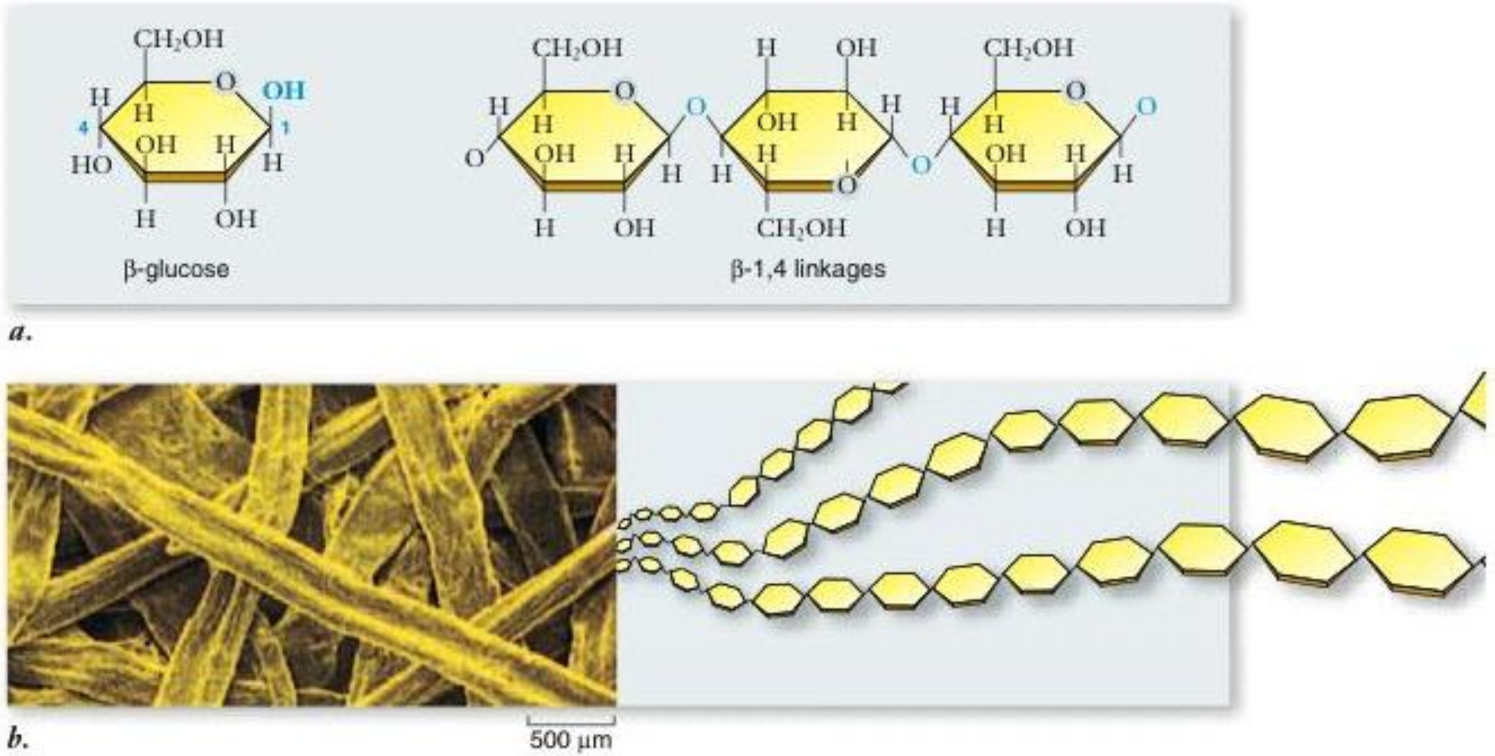
figure 3.9

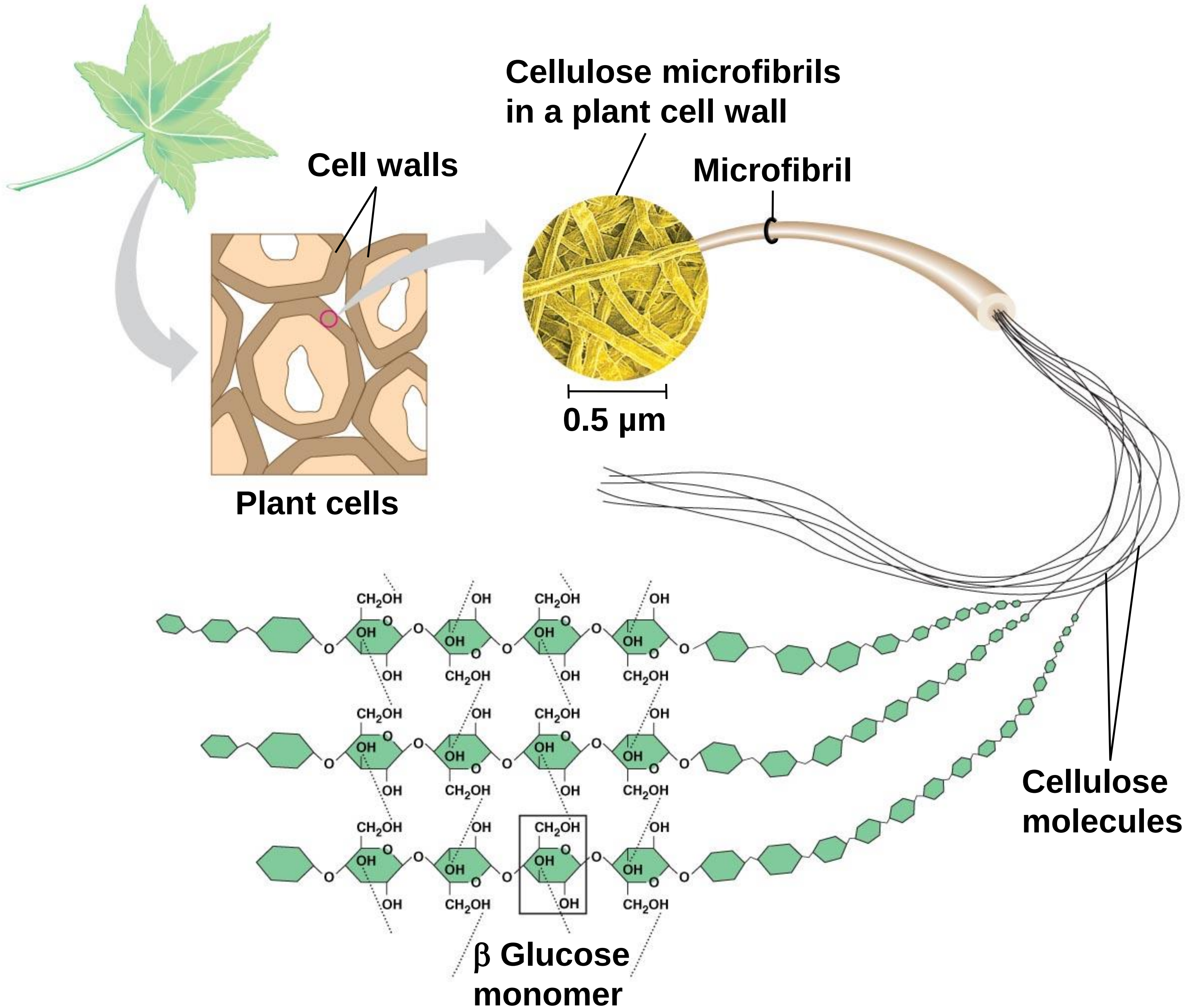
POLYMERS OF GLUCOSE: STARCH AND GLYCOGEN.

a. Starch chains consist of polymers of α-glucose subunits joined by α-1,4 glycosidic linkages. These chains can be branched by forming similar α-1,6 glycosidic bonds. These storage polymers then differ primarily in their degree of branching. ***b.*** Starch is found in plants and is composed of amylose and amylopectin, which are unbranched and branched, respectively. The branched form is insoluble and forms starch granules in plant cells. ***c.*** Glycogen is found in animal cells and is highly branched and also insoluble, forming glycogen granules.

figure 3.10

POLYMERS OF GLUCOSE: CELLULOSE. Starch chains consist of α-glucose subunits, and cellulose chains consist of β-glucose subunits. ***a.*** Thus the bonds between adjacent glucose molecules in cellulose are β-1,4 glycosidic linkages. ***b.*** Cellulose is unbranched and forms long fibers. Cellulose fibers can be very strong and are quite resistant to metabolic breakdown, which is one reason wood is such a good building material.




Cellulose microfibrils in a plant cell wall
Cell walls
Microfibril
0.5 µm
Plant cells
CH₂OH
OH
O
β Glucose monomer
Cellulose molecules

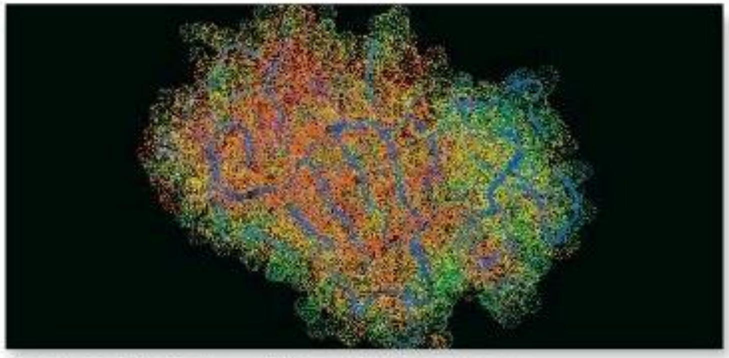
Chitin: Found in the exoskeleton of insects

(a) **The structure of chitin.**

(b) **Chitin forms the exoskeleton of arthropods. This cicada is molting, shedding its old exoskeleton and emerging in adult form.**

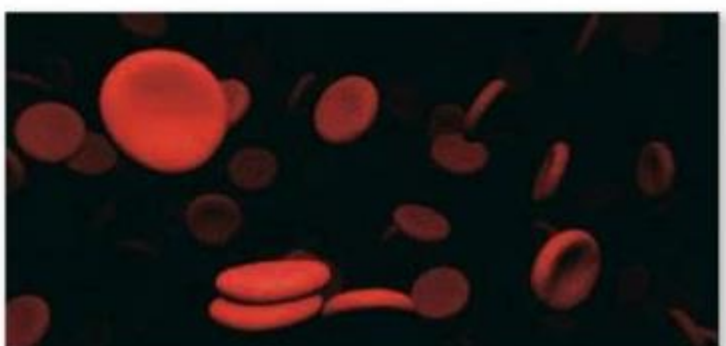
(c) **Chitin is used to make a strong and flexible surgical thread that decomposes after the wound or incision heals.**

Functions of Proteins



Enzyme catalysis: space-filling model of an enzyme

Defense: venom



Transport: hemoglobin

3.3 µm

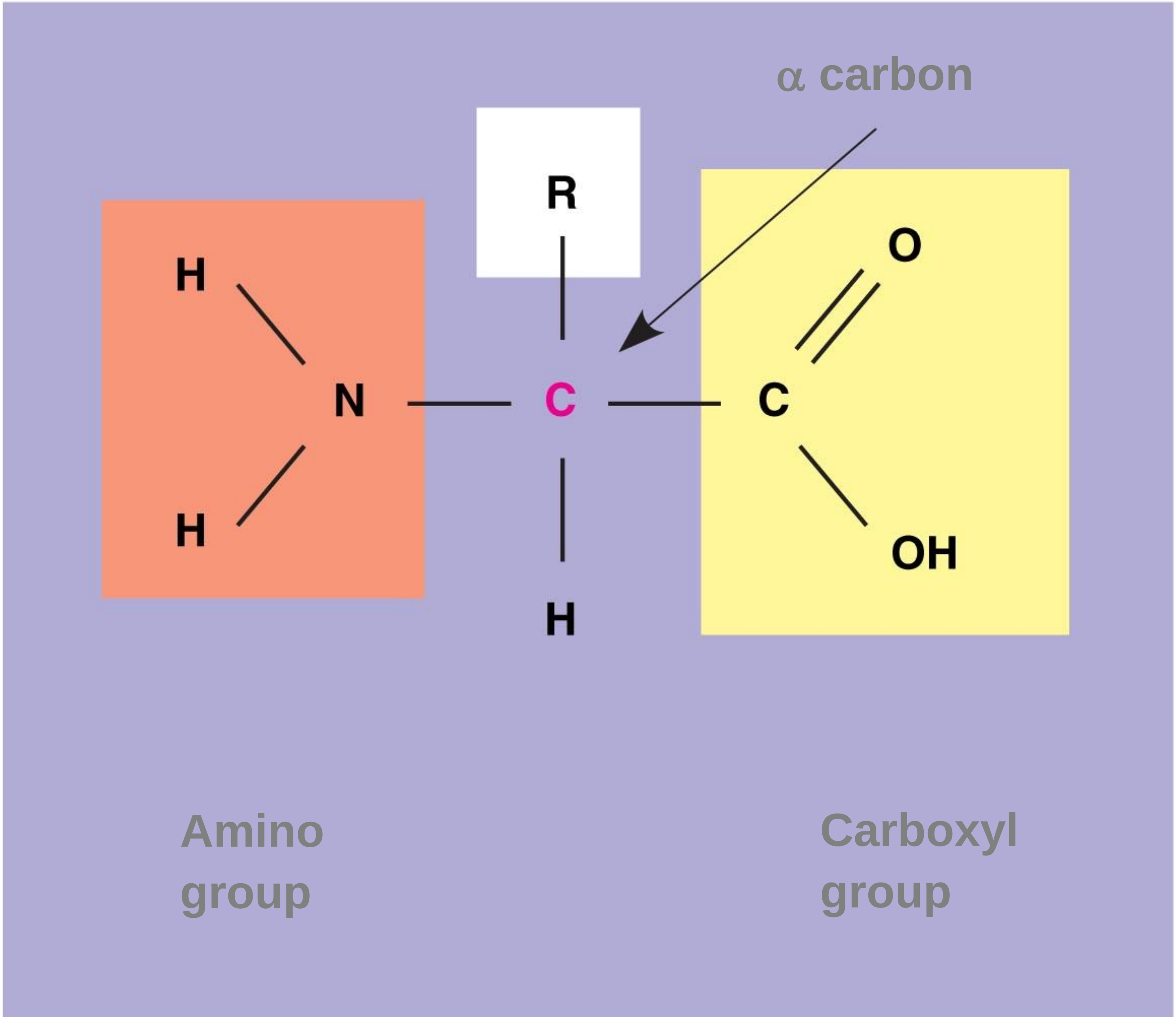
Support: keratin

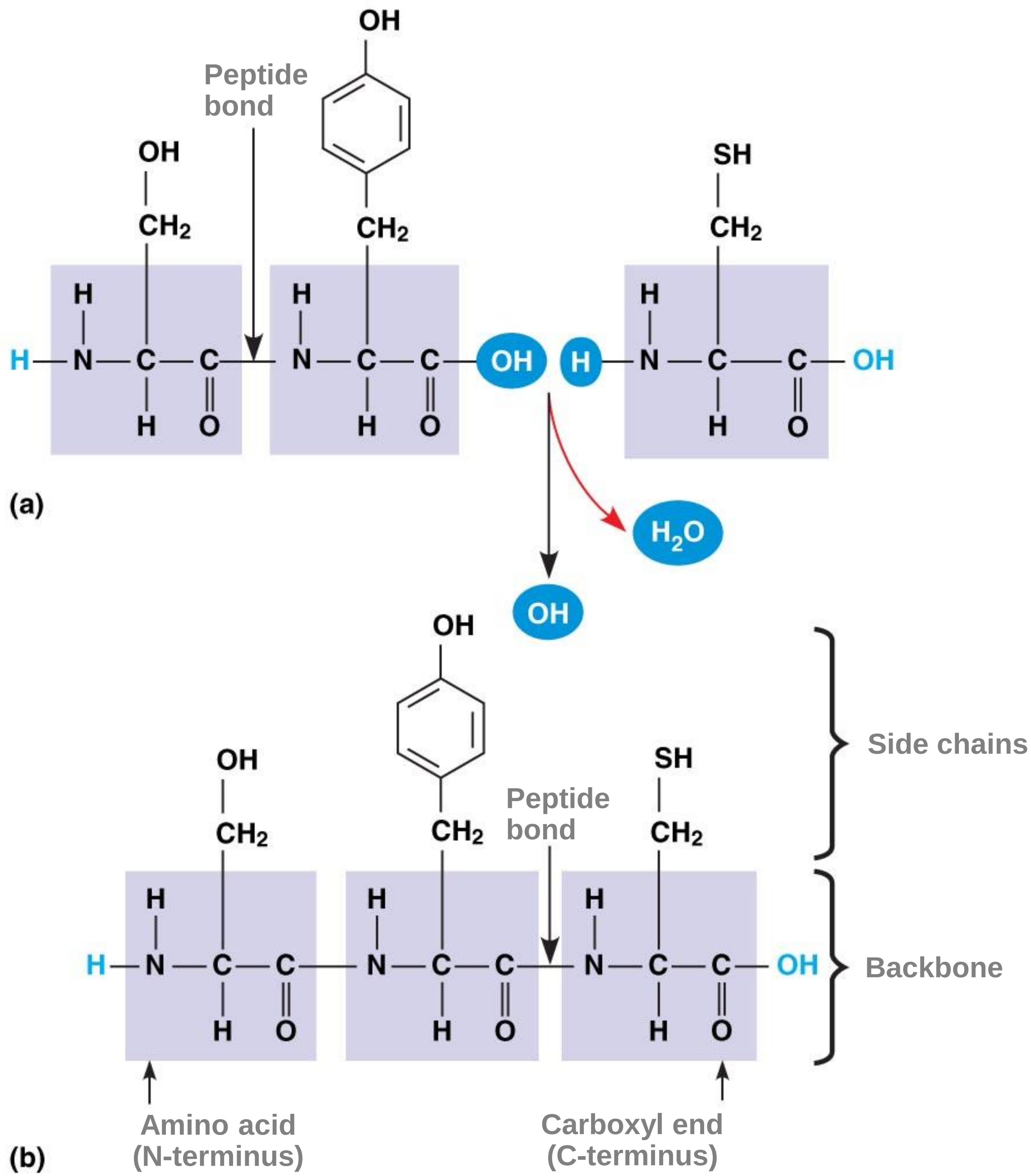
Motion: actin and myosin

Regulation: insulin

Table 5.1 An Overview of Protein Functions

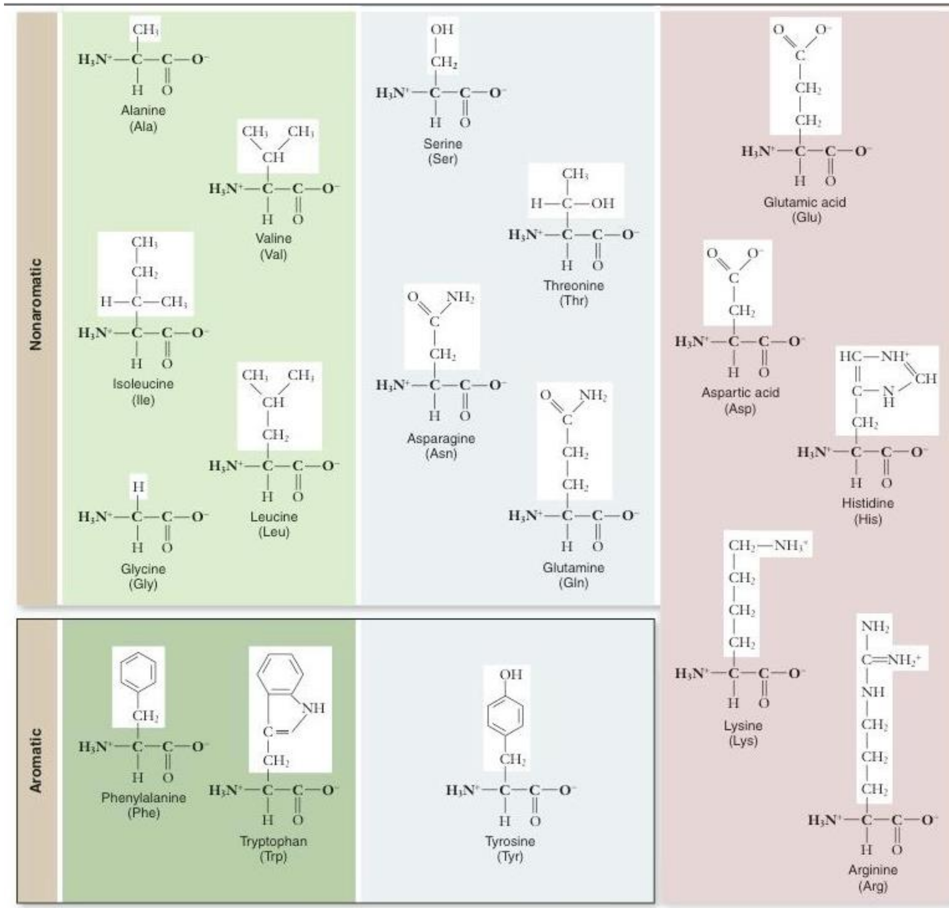
Type of Protein	Function	Examples
Enzymatic proteins	Selective acceleration of chemical reactions	Digestive enzymes (hydrolyze polymers in food)
Structural proteins	Support	Silk fibers (cocoons and spider webs), collagen and elastin (animal connective tissues), keratin (hair, horns, feathers)
Storage proteins	Storage of amino acids	Ovalbumin (egg white), casein (milk), storage proteins in seeds
Transport proteins	Transport of other substances	Hemoglobin (blood), proteins that transport molecules across cell membranes
Hormonal proteins	Coordination of an organism's activities	Insulin (helps regulate concentration of sugar in blood)
Receptor proteins	Response of cell to chemical stimuli	Nerve cell receptors (detect chemical signals released by other nerve cells)
Contractile and motor proteins	Movement	Actin and myosin (muscles), proteins responsible for undulations of cilia and flagella
Defensive proteins	Protection against disease	Antibodies (combat bacteria and viruses)


α carbon
R
H
N
C
H
H
C
O
OH
Amino group
Carboxyl group



Peptide bond
OH
OH
CH2
CH2
SH
CH2
H
N
C
C
H
O
OH
H
(a)
H2O
OH
Side chains
Peptide bond
Backbone
(b)
Amino acid (N-terminus)
Carboxyl end (C-terminus)

Amino Acids



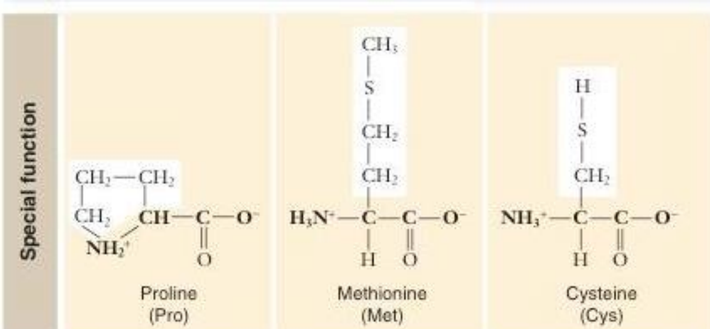
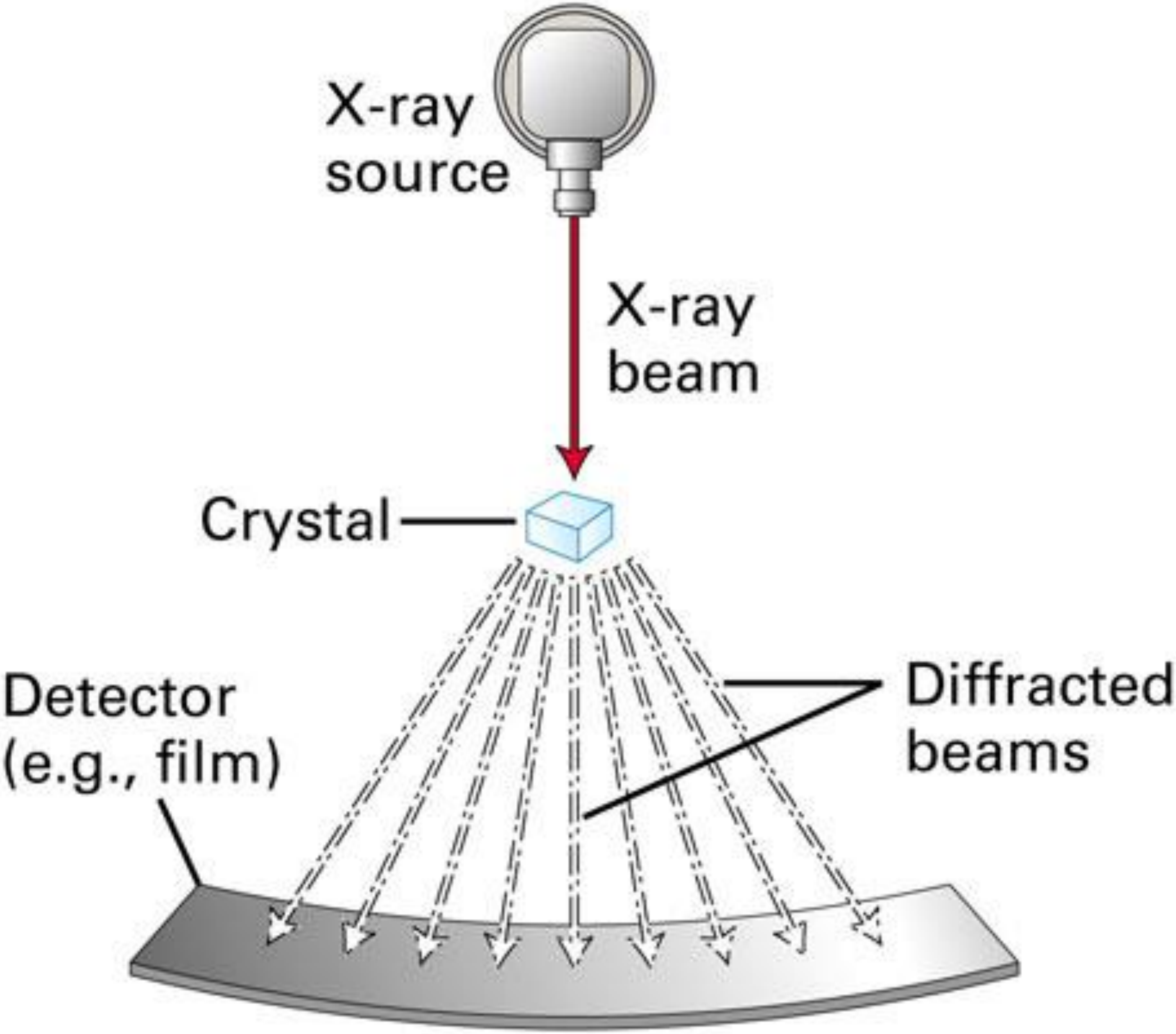


figure 3.20

THE 20 COMMON AMINO ACIDS. Each amino acid has the same chemical backbone, but differs in the side, or R, group. Six of the amino acids are nonpolar because they have $—CH_2$ or $—CH_3$ in their R groups. Two of the six contain ring structures with alternating double and single bonds, which classifies them also as aromatic. Another six are polar because they have oxygen or a hydroxyl group in their R groups. Five others are capable of ionizing to a charged form. The remaining three special function amino acids have chemical properties that allow them to help form links between protein chains or kinks in proteins.


X-ray
source
X-ray
beam
Crystal
Diffracted
beams
Detector
(e.g., film)

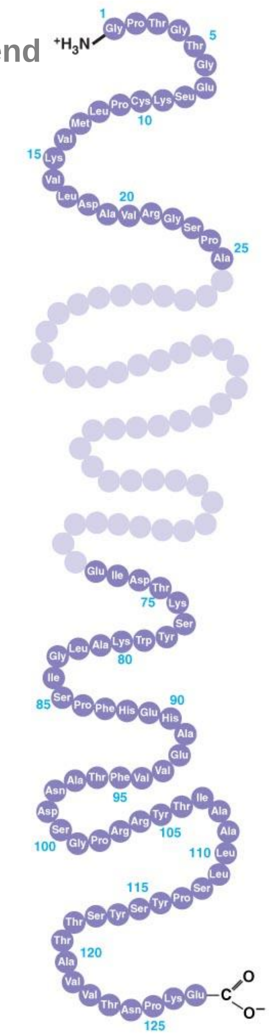
-
- ut
-
- the
  d to

Protein Models

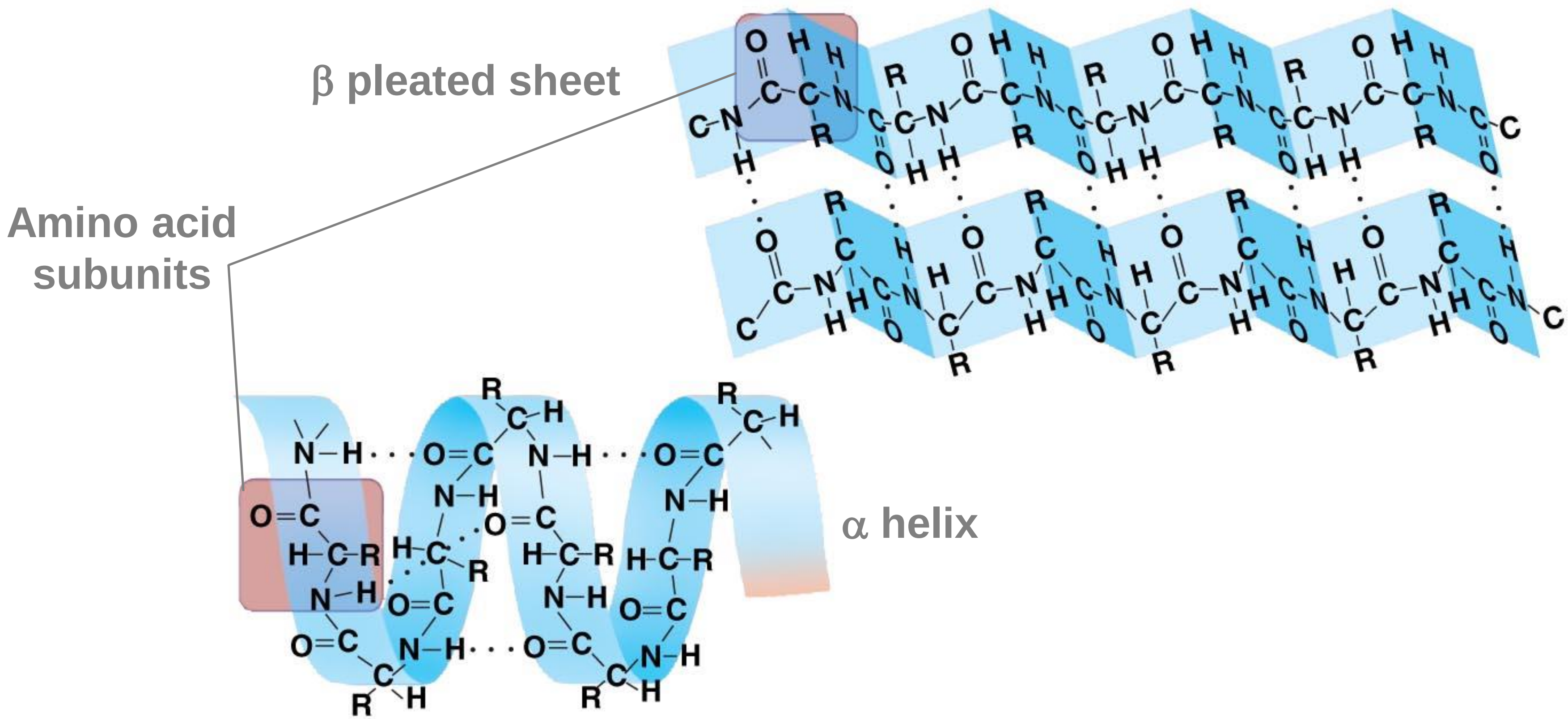
- The next model was taken from the Protein Data Bank: PDB http://www.rcsb.org/pdb/Welcome.do;jsessionid=hX2Nz8hc4jgCyE5ydsM0nA**

- Cholera Toxin

Primary Structures

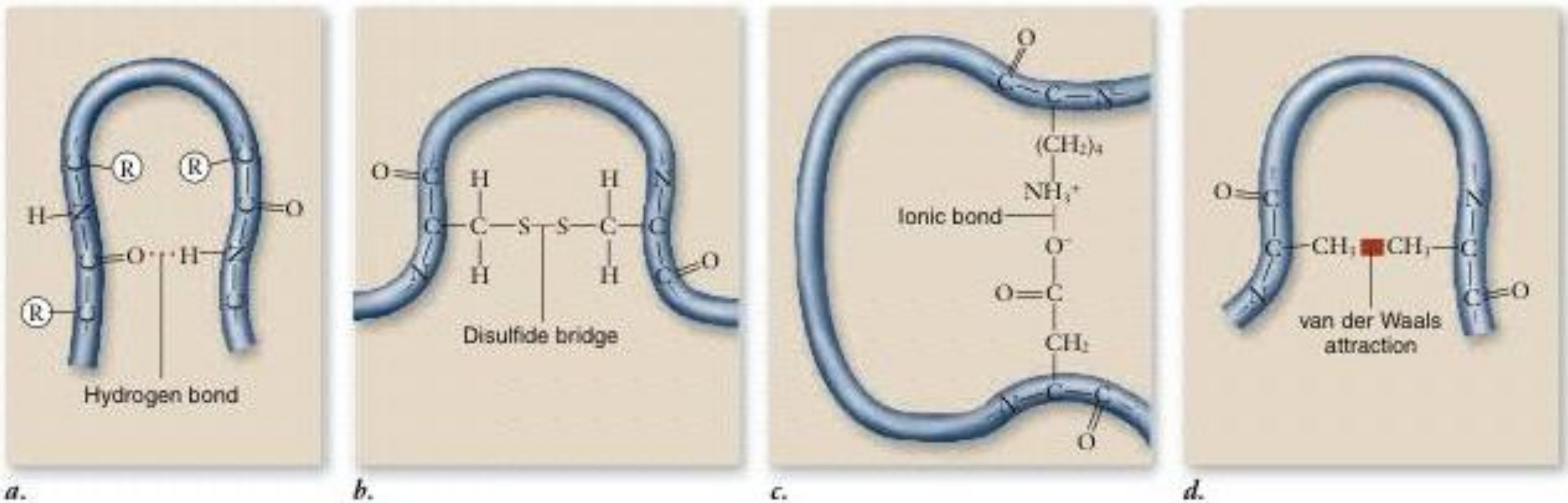


Secondary Structures



Spider silk: a structural protein Containing β pleated sheets

Interactions between A.A contribute to shape



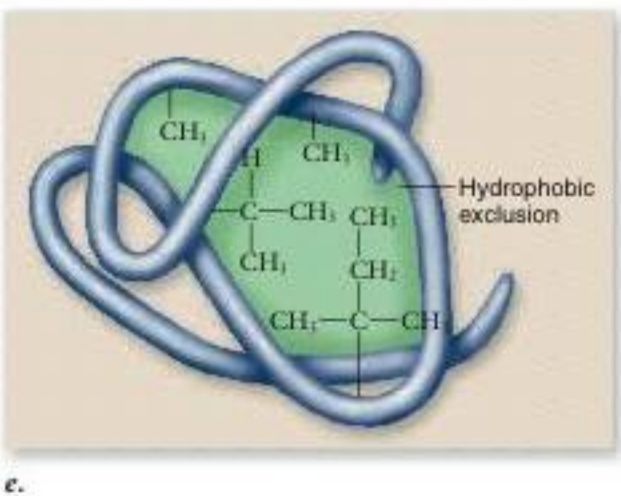
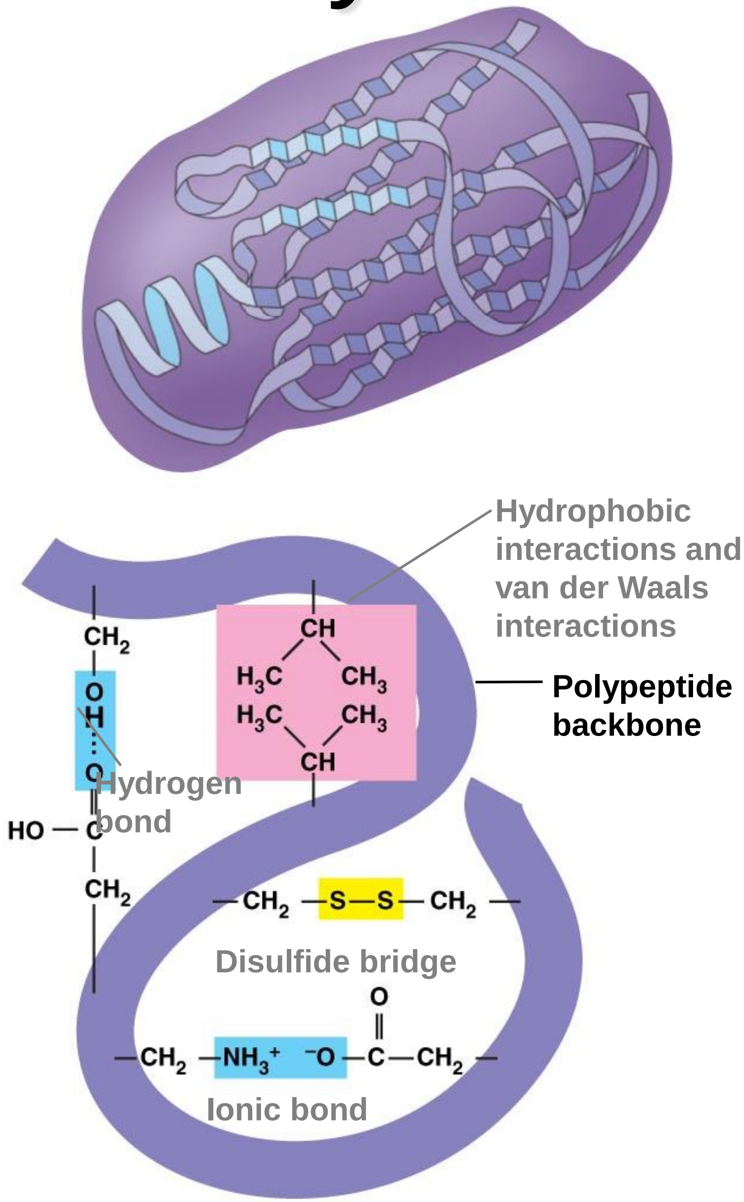
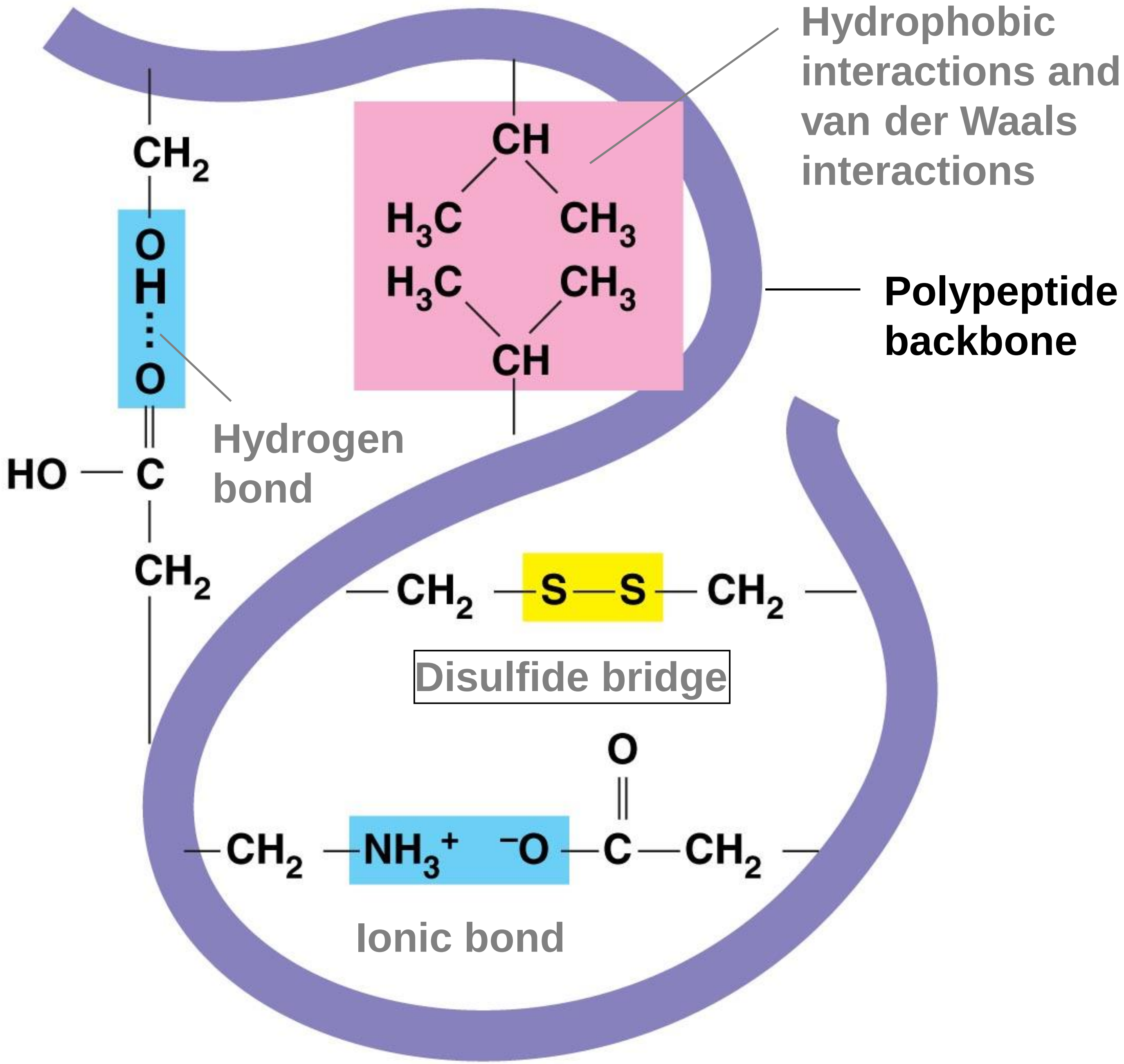


figure 3.21

INTERACTIONS THAT CONTRIBUTE TO A PROTEIN'S SHAPE. Aside from the bonds that link the amino acids in a protein together, several other weaker forces and interactions determine how a protein will fold. ***a.*** Hydrogen bonds can form between the different amino acids. ***b.*** Covalent disulfide bridges can form between two cysteine side chains. ***c.*** Ionic bonds can form between groups with opposite charge. ***d.*** van der Waals attractions occur, which are weak attractions between atoms due to oppositely polarized electron clouds. ***e.*** Polar portions of the protein tend to gather on the outside of the protein and interact with water, whereas the hydrophobic portions of the protein, including nonpolar amino acid chains, are shoved toward the interior of the protein.

Tertiary Structures





Hydrophobic interactions and van der Waals interactions
Polypeptide backbone
Hydrogen bond
Disulfide bridge
Ionic bond
CH2
O
H
O
HO
C
CH
H3C
CH3
H3C
CH3
CH
CH2
S
S
CH2
O
CH2
NH3+
-O
C
CH2

Quaternary Structures

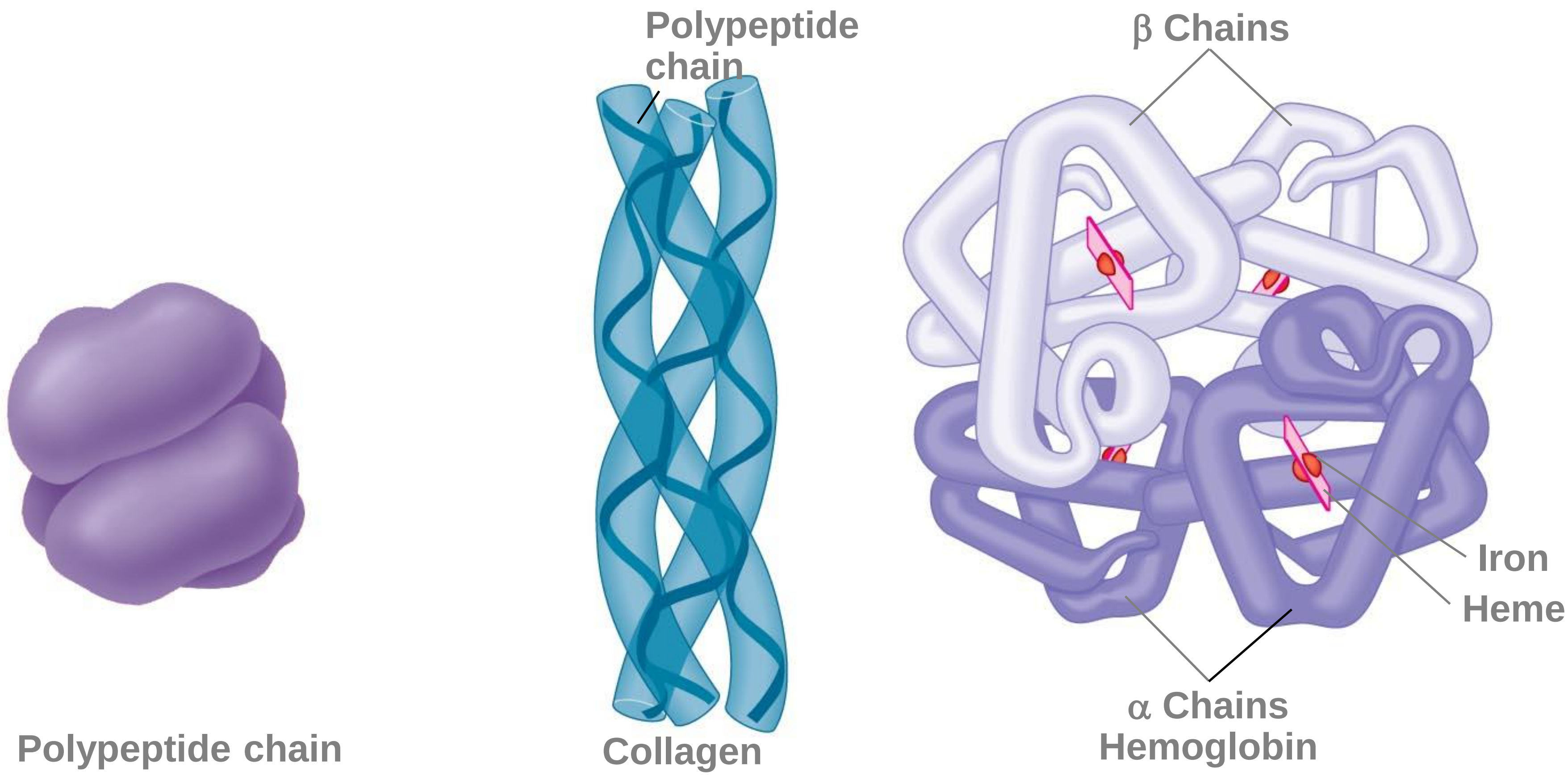
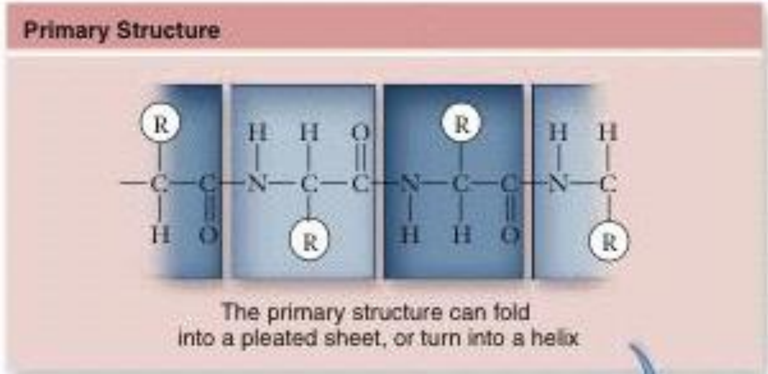
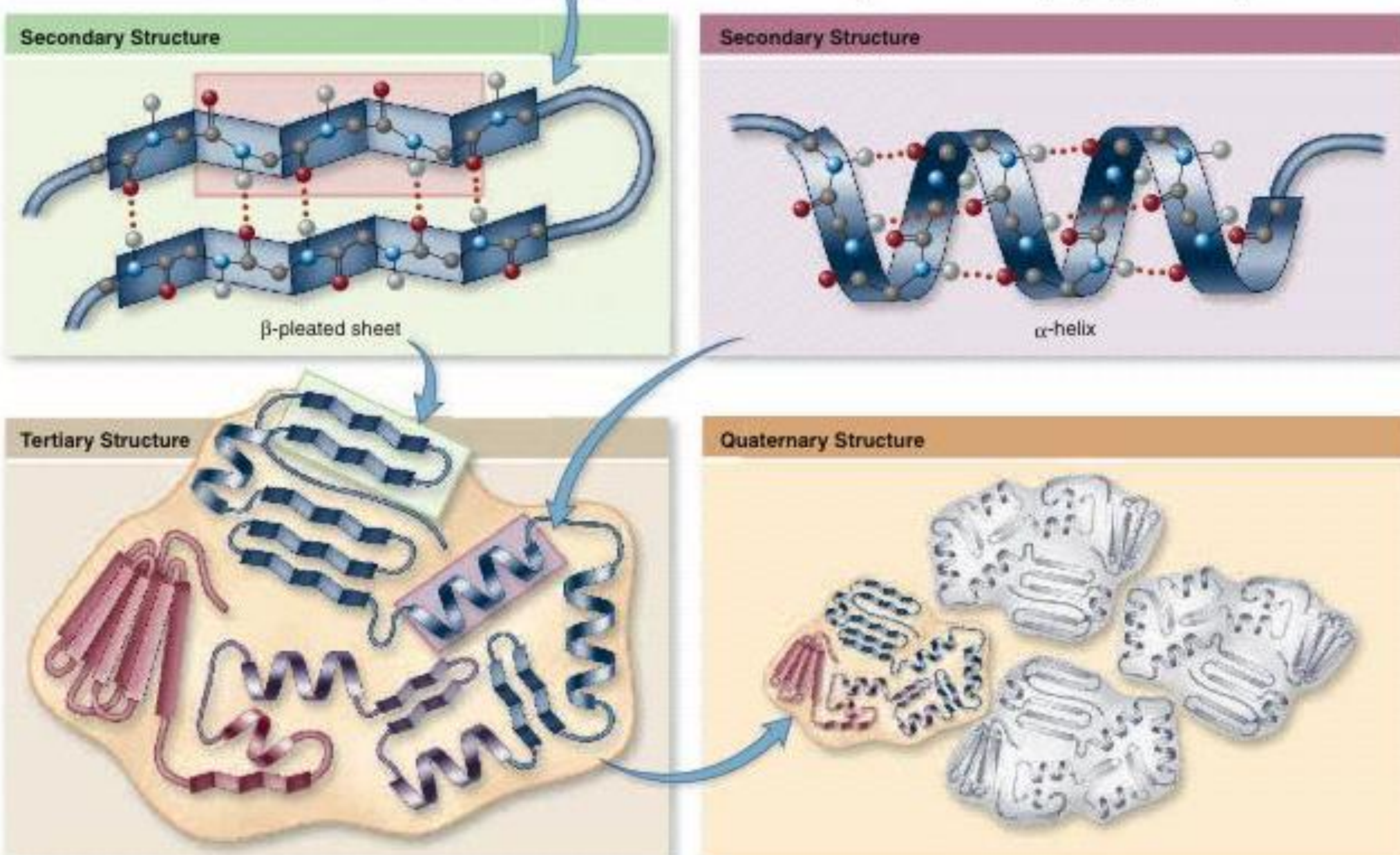


figure 3.22

LEVELS OF PROTEIN STRUCTURE. The primary structure of a protein is its amino acid sequence. Secondary structure results from hydrogen bonds forming between nearby amino acids. This produces two different kinds of structures: beta (β)-pleated sheets and coils called alpha (α)-helices. The tertiary structure is the final 3-D shape of the protein. This determines how regions of secondary structure are then further folded in space to form the final shape of the protein. Quaternary structure is only found in proteins with multiple polypeptides. In this case the final structure of the protein is the arrangement of the multiple polypeptides in space.





Motifs and Domain

A motif in this sense refers to a small specific combination of secondary structural elements (such as helix-turn-helix).

A structural domain is an element of the protein's overall structure that is self-stabilizing and often folds independently of the rest of the protein chain.

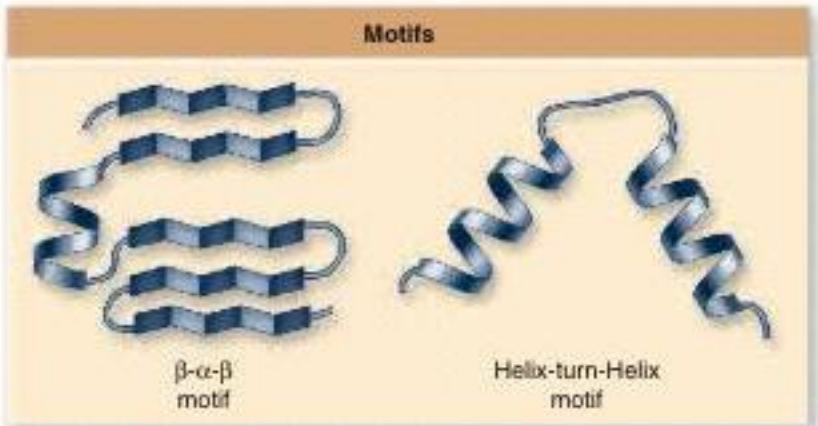
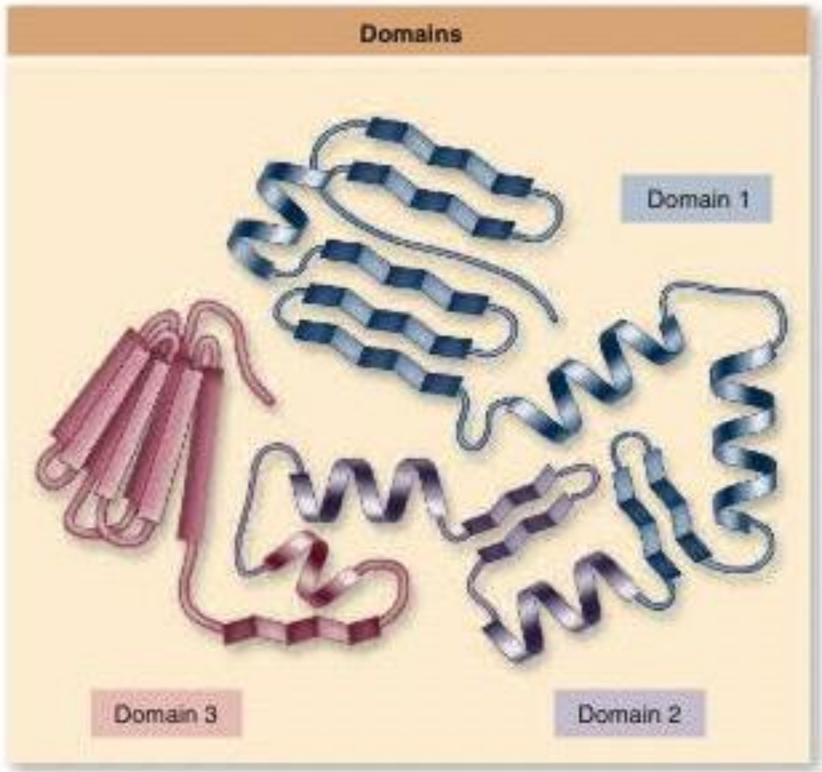


figure 3.23

MOTIFS AND DOMAINS. The elements of secondary structure can combine, fold, or crease to form motifs. These motifs are found in different proteins and can be used to predict function. Proteins also are made of larger domains, which are functionally distinct parts of a protein. The arrangement of these domains in space is the tertiary structure of a protein.

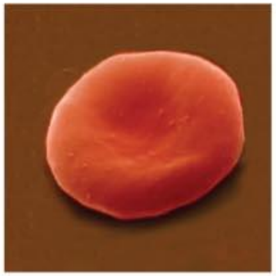


Sickle Cell Anemia

10 µm

Red blood cell shape

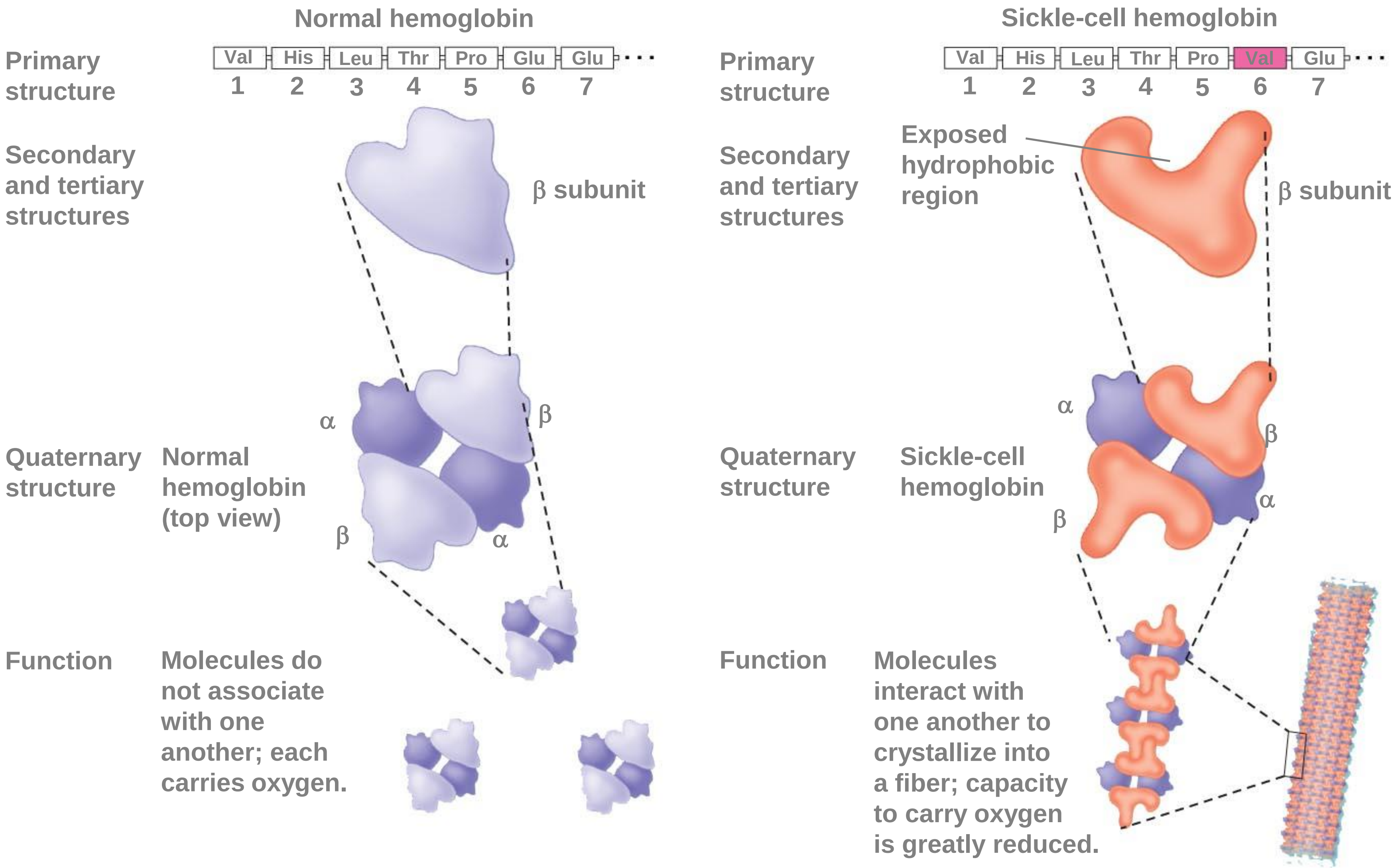
Normal cells are full of individual hemoglobin molecules, each carrying oxygen.



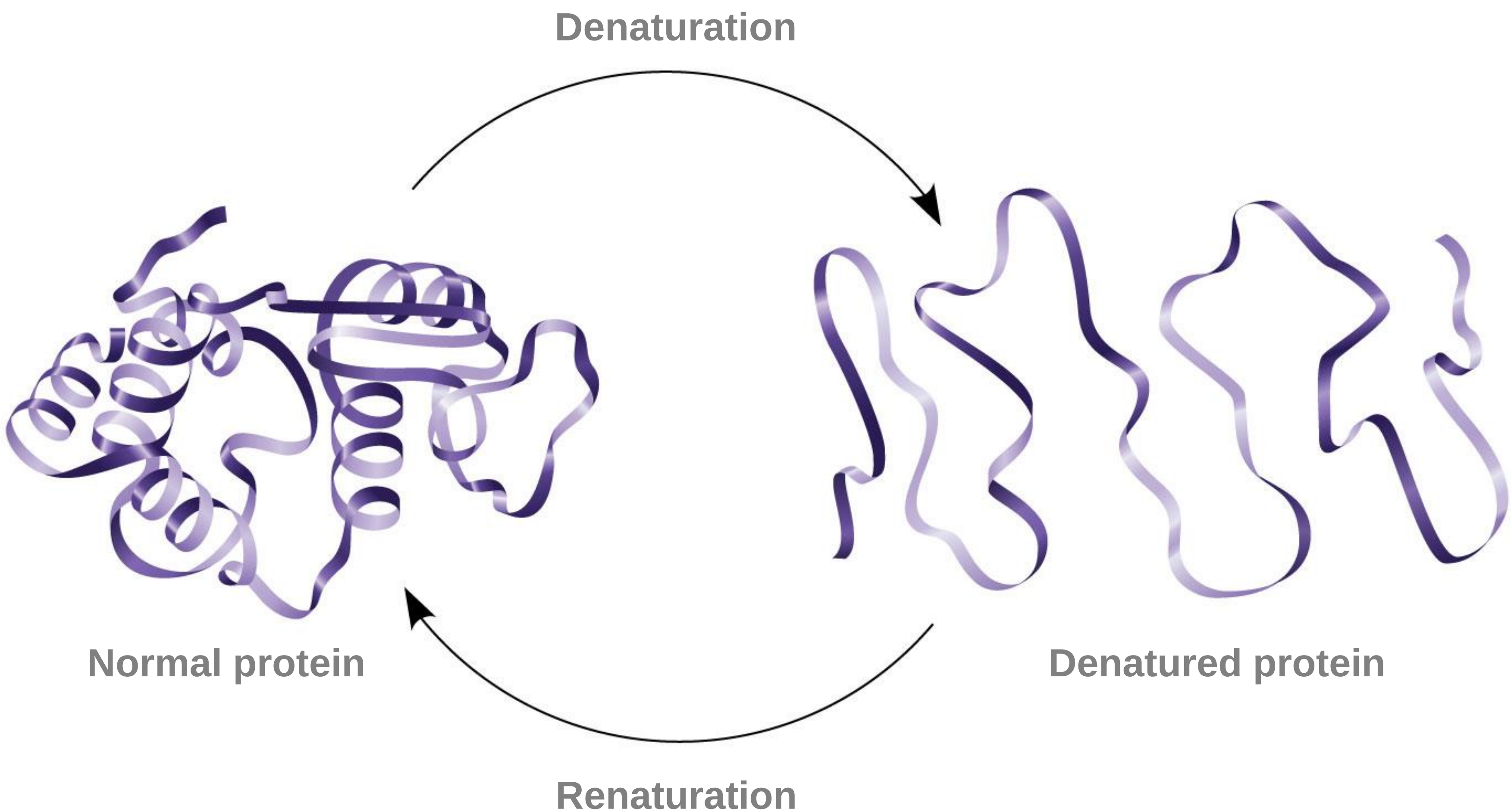
10 µm

Red blood cell shape

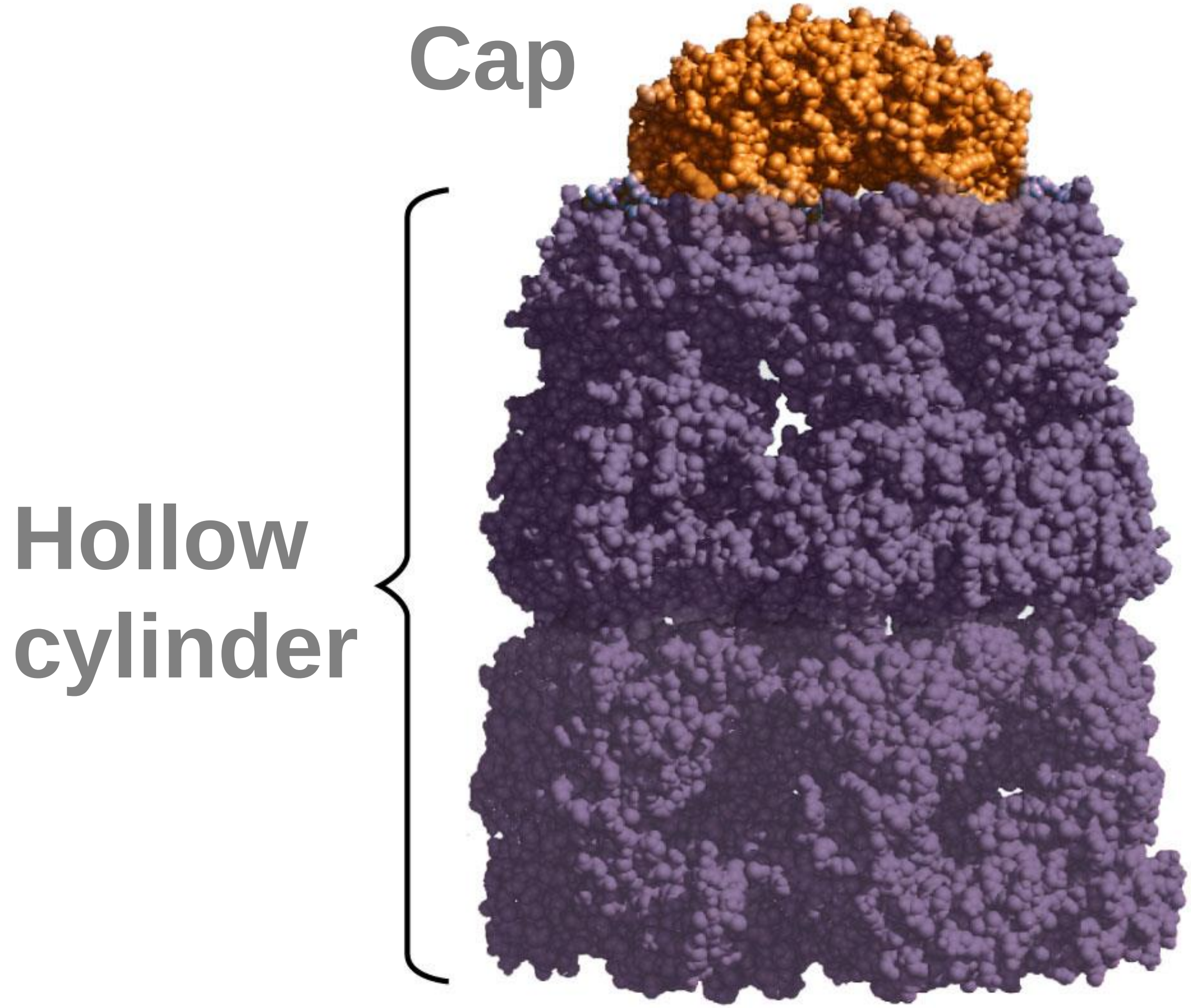
Fibers of abnormal hemoglobin deform cell into sickle shape.


Normal hemoglobin
Primary structure
Val His Leu Thr Pro Glu Glu
1 2 3 4 5 6 7
Secondary and tertiary structures
β subunit
Quaternary structure
Normal hemoglobin (top view)
α
β
β
α
Function
Molecules do not associate with one another; each carries oxygen.
Sickle-cell hemoglobin
Primary structure
Val His Leu Thr Pro Val Glu
1 2 3 4 5 6 7
Secondary and tertiary structures
Exposed hydrophobic region
β subunit
Quaternary structure
Sickle-cell hemoglobin
α
β
β
α
Function
Molecules interact with one another to crystallize into a fiber; capacity to carry oxygen is greatly reduced.

Denature



What conditions can denature proteins?
http://highered.mcgraw-hill.com/sites/0072943696/student_view0/chapter2/animation__protein_denaturation.html



Chaperonin
(fully assembled)

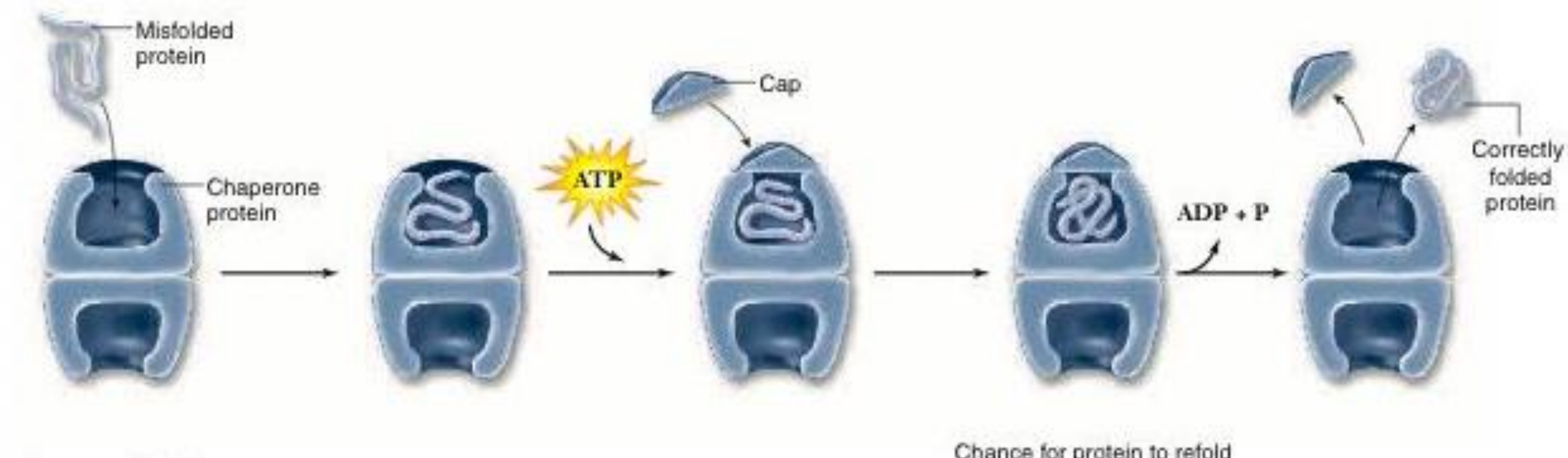


figure 3.24

HOW ONE TYPE OF CHAPERONE PROTEIN WORKS. This barrel-shaped chaperonin is from the GroE family of chaperone proteins. It is composed of two identical rings each with seven identical subunits, each of which has three distinct domains. An incorrectly folded protein enters one chamber of the barrel, and a cap seals the chamber. Energy from the hydrolysis of ATP allows for structural alterations to the chamber, changing it from hydrophobic to hydrophilic. This change allows the protein to refold. After a short time, the protein is ejected, either folded or unfolded, and the cycle can repeat itself.